Building Information Modelling (BIM) Based Energy Analysis
And response to low carbon construction innovations

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Abstract

Building Information Modeling (BIM) is the process of generating and managing building data during its life cycle, it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. The information is stored within a data-rich virtual 3D model, which can continue to be used throughout a building's life cycle.

With the rising cost of energy and growing environmental concerns, the demand for sustainable building facilities with minimal environmental impact is ever increasing.

The most important decisions regarding a building's sustainable features are made during the conceptual design and preconstruction stages.

In this exploratory research proposes a comparative case study analysis of a National Primary School "Sonna National School" based on Building Information Modeling (BIM) and with the integration of Autodesk Green Building Studio to investigate the influence on energy consumption, lifecycle energy cost and carbon emission, to demonstrate the use of BIM for sustainable design at conceptual stage and compare the findings to a preliminary non domestic building energy rating (NBER) using the iSBEM (non domestic energy assessment procedure-NEAP), under the Energy Performance of Buildings Directive (EPBD) to establish the benefits of incorporating BIM into the use of energy analysis.

Phelim Martin
2013

Dissertation Declaration

I hereby certify that this dissertation that I now submit for assessment for the award of MSc in Energy Management is entirely my own work and has not been submitted for any academic purpose other than in partial fulfilment of that stated above.

Phelim Martin.

Signed: Phelim Martin

Dated: 7th May 2013

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2D Two Dimensional

3D Three Dimensional

4D Four Dimensional. Leveraging BIM for project time allocation and construction sequence scheduling presentations

5D Five Dimensional. Leveraging BIM for cost and simulation of construction, focusing on building sequence, cost, and resources

AEC Architecture, Engineering and Construction **BIM** Building Information Modelling was coined in early 2002 by industry analyst Jerry Laiserin to describe virtual design, construction and facilities management. BIM processes revolve around virtual models that make it possible to share information throughout the entire building industry.

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

BPM Building Performance Modelling. Using a BIM model to simulate a buildings performance for, for example acoustic analysis

CAD Computer Aided Design

Clash detection A process of discovering the building system conflicts and issues by collaborating in 3D during the MEP model coordination process

COBie Construction-Operations Building Information Exchange is a standard way to manage information from a BIM model that is essential to support the operations, maintenance and management of the facilities by the owner and/or property manager. The COBie approach is to enter the data as it is created during design, construction and commissioning. Designers provide floor, space and equipment layouts. Contractors provide make, model and serial numbers of installed equipment. Much of the data provided by contractors comes directly from product manufacturers who also participate in COBie

Constructability Model A BIM model used to simulate the actual components of a building in 3D, created as the building would be built, used primarily for MEP model coordination, 4D simulations and 5D estimating or quantity take-offs (compare with design model)

DART Design, Awareness, Research and Technology.

EPDB Energy Performance of Buildings Directive.

IFC Industry Foundation Class is a data exchange method that specifies elements that are used in building construction in an agreed manner that define a common language for construction. IFCs provide a foundation for the exchange and sharing of information directly between software applications of a shared building project model

FM Facility Management

GBS Green Building Studio

GBXML Green Building Extensible Markup Language

IPD Integrated Project Delivery, a new project workflow method and supporting contracts developed by the American Institute of Architects, which leverages early contributions of knowledge and expertise through the utilization of new technologies, allowing all team members to better realize their highest potentials while expanding the value they provide throughout the project life cycle. IPD avoids the realization phase challenges by allowing project data to be analyzed and understood prior to construction

NEAP Non domestic energy assessment procedure

NEEAP National Energy Efficient Action Plan

MEP Mechanical, Electrical and Plumbing Engineers.

WM Without Measures

WAM With additional Measures

It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change.

Charles Darwin

(The Origin of Species – 1930s)

Chapter 1

1.0 Introduction

The current economic climate has tightened the AEC industry, the survival of the industry has become dependent of the AEC industry to adapt to new and challenging to improve their competitiveness by improving their towards sustainable buildings projects. Building Information Modeling (BIM) is a process that begins with the creation of digital rich information modeling which has been collaborated by the various team member disciplines (including architects, structural engineers, mechanical electrical plumbing engineers (MEP), and quantity surveyors) to produce a model that supports the project lifecycle costing's, through design to completion and finally facility management/operators.

The main objective of this research is to explore the suitability of BIM for sustainability analysis at conceptual design process. The sub-objectives includes a brief evaluation of building performance analysis software types. These include Ecotect and Green Building Studio (GBS) other software types have been outlined in the process. In additional to these sub-objectives is the development of a conceptual framework illustrating how construction companies can use BIM for sustainability analysis and evaluate LEED (Leadership in Energy and Environmental Design) rating of a building facility.

Building information modeling is defined as '*a process which involves the production of reliable and co-ordinated construction documentation from a virtual 3D model of a building project'* (Montague 2011).

1.1 Aim

Initially the aim of this dissertation is to analyse how Building Information Modeling (BIM) can be used in energy analysis of construction projects in Ireland/Europe with a result of reducing the carbon footprint at conceptual design stage.

This will be carried out through an exploratory research proposes of a comparative case study analysis of a National Primary School "Sonna National School" based on Building Information Modeling (BIM) and with the integration of Autodesk Green Building Studio to investigate the influence of construction material on energy consumption, lifecycle energy cost and carbon emission, to demonstrate the use of BIM for sustainable design and compare the findings to preliminary non domestic building energy rating using the iSBEM (non domestic energy assessment procedure - NEAP), under the Energy Performance of Buildings Directive (EPBD) to establish the benefits of incorporating BIM in early conceptual design to establish the use of energy analysis.

1.2 Problem Statement

It is clear that design alternatives and more specifically material selection process has a significant influence on energy consumption, lifecycle cost and carbon emission. As a result, identifying and measuring effects of a proper material selection process makes professionals to move towards reduction of energy consumption, carbon emission and lifecycle cost.

As a consequence, despite having much theoretical effort on energy efficiency and carbon neutrality, coming to practice, the problem emerges from having most residential and non-residential buildings not energy efficient (below certified as the minimum requirement of building rating systems), not carbon neutral (due to reluctance of construction industry to move towards up-to-date construction technology rather than following traditional construction systems) and also not cost effective (partly due to not practically distinguishing lifecycle costs of alternative construction materials).

In order to establish this, the following objectives have been set out:

- To identify the potential for using BIM in analysing sustainable design for 'Green Buildings' at conceptual design stage.
- To explore the suitability of BIM for sustainability analysis and reducing overall carbon emissions.
- To understand the key criteria for sustainable buildings design.
- To explore the evaluation of building performance analysis software types. These include Ecotect and Green Building Studio (GBS), iSBEM and other software types have been outlined in the process.
- The development of a conceptual framework illustrating how the AEC industry can use BIM for sustainability analysis and evaluate LEED (Leadership in Energy and Environmental Design) rating of a building facility.
- To investigate the influence of construction material on reducing energy consumption, lifecycle energy cost.

1.3 Research hypothesis

"Successful implementation of BIM on design and build projects will increase efficiency for the AEC industry sector and ultimately lead to greener buildings"

1.4 Rational for research

The dissertation revolves around the central question of the use of the BIM at the conceptual design in the development of sustainable buildings and the evaluation of energy analysis tools in the process. In doing so there is a requirement in understanding the concept principles of green buildings as well as the use of BIM in conjunction with their design and life cycle costing's. The dissertation will comprise of a full evaluation of different types of building performance analysis software types.

The research, therefore, shall be on a relatively small scale and although primary research will be used in an attempt to obtain accurate findings, the study will not claim to be a definitive or comprehensive measurement of efficiency.

1.5 Structure of Dissertation

Chapter 1 Introduction

Chapter one provides the reader with a background to the study, justifies the need for this investigation and defines the scope of the research. Also outlined in this chapter are the aim and objectives which are central to the study.

Chapter 2 Literature Review

Chapter two contains the literature review. This chapter begins by defining terms such as 'Building Information Modeling' and 'Sustainable Design'. The characteristics of BIM and sustainable design on conceptual design process. How they complement each other through the examination of available published information on BIM and Sustainable Design, such as peer reviewed articles, papers and reports. In the process an in-depth analysis of BIM and especially Green Building Studio and Ecotect is evaluated to examine the link/synergy which exists between them. Evaluates BIM Textbooks and BIM Protocols in terms of LEED categories along with best practice guides from Carbon Trust and NEEAP Policy were used as the basis for the literature review. The chapter gives a brief synopsis of the evolution and importance of BIM for facility management. And provides the reader with a background to the study in terms of the architecture, engineering and construction (AEC) legislation and where the need for sustainable/green building emerged.

Chapter 3 Research Methodology

Chapter three provides the reader with the research methodology used by the author in order to fulfill the objectives set out in this dissertation. This chapter also outlines the research design and the techniques that were exercised for the purpose of meeting the aim of this dissertation.

Chapter 4 Case Study

Chapter four provides the reader with details of the relevant case study based on a national school namely 'Sonna National School' project. This BIM assisted pilot project case study will evaluate the use of both Green Building Studio and iSBEM to analyse and benchmark that the early adoption of BIM in building conceptual design can reduce the life cycle cost and carbon emissions.

Chapter 5 Data Analysis

Chapter five presents a discussion/analysis and interpretation of the findings of chapter four. It examines the key issues and themes regarding BIM as identified by the outcome of the case study.

Chapter 6 Conclusion and Recommendations

Chapter six is the concluding chapter which represents the main conclusions that have resulted from the research undertaken by the author. It brings together the information obtained in the literature review and the research findings to reach a conclusion on the research topic. The aims and objectives are evaluated in terms of achievement. It concludes by presenting ideas for further research from issues raised within the research and limitations of the research.

Chapter 2

Literature Review

2.0 What is BIM?

Building Information Modelling (known as BIM here after), is a yet another acronym in an industry full of three- and four-letter words. The term might be new, but with the potential to improve efficiencies throughout the life-cycle of a building and may quickly become an important new tool for facility executives.

According to Krygiel and Nies (2008, p.27) BIM can be defined as the creation and use of coordinated, consistent, computable information about a building project in design – parametric information used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, and construction planning.

Georgia Institute of Technology coined the term. This theory is based on a view that the term Building Information Model is basically the same as Building Product Model, which Professor Eastman has used extensively in his book and papers since the late 1970s (Product model means —data model or —information model in engineering). Architect and Autodesk building industry strategist Phil Bernstein first used the actual term —building information modeling and nicknamed it —BIM. Jerry Laiserin then helped popularise and standardise it as a common name for a digital representation of the building process to facilitate exchange and interoperability of information in digital format. According to him and others, the first implementation of BIM was under the Virtual Building concept by Graphisoft's ArchiCAD, in its debut in 1987 (ABEbytes, Yessios, 2004).

While the rising cost of energy, with no signs of stabilising and growing environmental concerns, the demand for sustainable building facilities with minimal environmental impact is increasing. The most effective decisions regarding sustainability in a building facility should be made in the early design and preconstruction stages.

The study will go on to show how BIM can aid in performing complex building performance analyses to ensure an optimised sustainable building design.

BIM is a huge buzzword in architecture, engineering and construction (AEC), it shows up in every magazine; there are multiple conferences a year about it; software developers headline their products as BIM tools. What is it? How is it different? Why should an architect or contractor or facilities manager care about BIM?

To answer these questions, BIM models manages information as well as graphics for sharing information through construction and the whole building lifecycle, eliminating the need to re- enter data, and avoiding data loss, miscommunication, and translation errors. With rapid developments of building design and analysis software over the last decade, coupled with advances in desktop and laptop computational power, have led to the emergence of new digital models for the design and documentation of buildings (virtual buildings or BIM). The resulting **building information models** can be shared knowledge (collaboration) resources to support decision-making about a facility from the earliest conceptual stages, through design and construction, through its operational life and eventual demolition.

Essentially, BIM combines technology with new working practices to improve the quality of the delivered product and also improve the reliability, timeliness and consistency of the process. Therefore, that there is a workflow process to be followed for example, AEC protocol and PAS 1192-2 (2013). Also it is important to asset and facilities management as it is to construction. To this context, BIM provides a common single and coordinated source of structured information to support all parties involved in the delivery process, whether that be to design, construct, and/or operate.

A BIM project has access to the same data sets (collaboration); therefore the information loss associated with handing a project over from design team to construction team and to building owner/facility operator is kept to a minimum.

> "A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder". (Smith, 2007, p. 14)

Before: After:

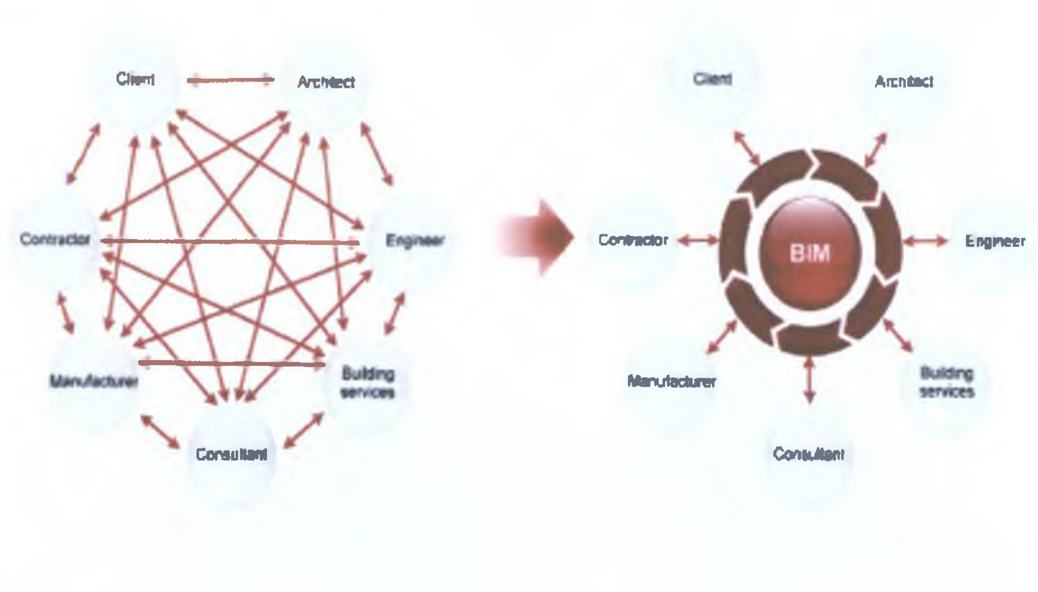


Figure 1: BIM Information Exchange cited in European Commission INNOVA Conference., 2008, p41

Figure 1 above, illustrates smoother flow of common knowledge (i.e. collaboration process), which is key to the success of the successful implementation of BIM.

It would appear that the knowledge base and growth of BIM has accelerated in recent year especially since the noughties and has the potential to bring about transformations in the way clients, architect, construction managers and facility operators/owners operated together through the process of collaboration. This view has been supported in the work of (Race 2012, p16).

Recent research (Succar, et al. 2007) defined BIM as a set of interacting policies, processes and technologies producing a 'methodology to manage the essential building design and project data in a digital format throughout the building's life cycle'.

2.1 Origins of BIM

Phil Berstein, an FAIA (Fellow Architect Institute of America) architect and industry strategist, first used the acronym BIM for "building information modeling." Jerry Laiserin then helped popularize and standardize the term as a common name for the digital representation of the building process as then offered under differing terminology by Graphisoft as "Virtual Building", Bentley Systems as "Integrated Project Models", and Autodesk as "Building Information Modeling" to facilitate exchange and interoperability of information in digital format. According to Laiserin, J and others, the first implementation of BIM was under the **Virtual Building** concept by Graphisoft's ArchiCAD, in its debut in 1987.

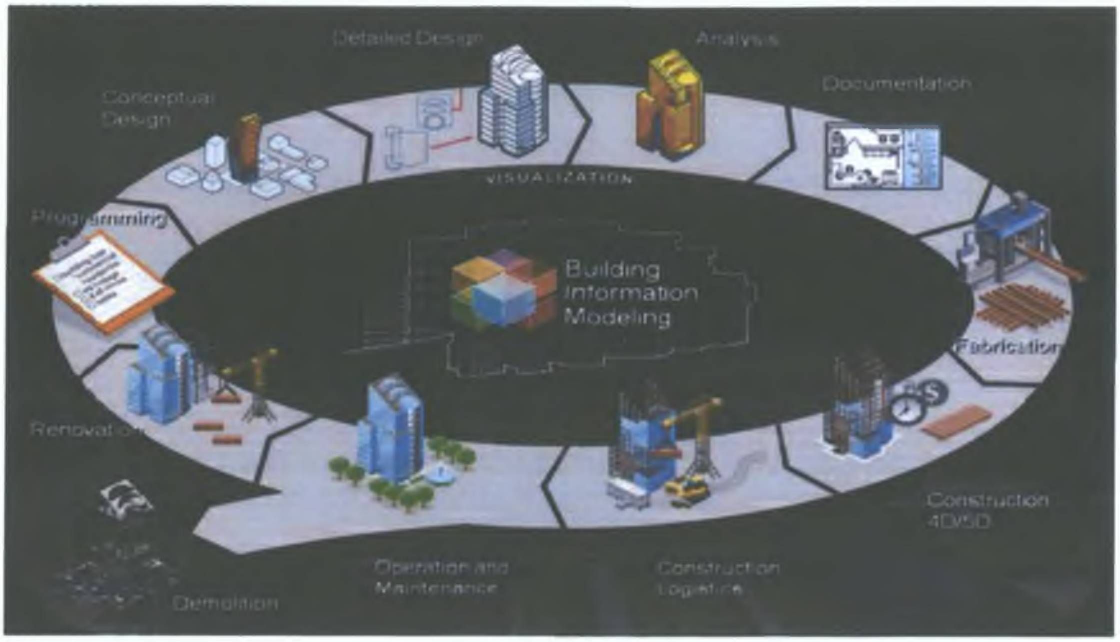


Figure 2: The Daily Life of Building Information Modelling, Phases of a BIM project Lifecycle (Dispenza, 2010)

2.2 Sustainable Design

The definition of the terms *green* and *sustainable* should be clear, what does being *green* mean to you? Undoubtedly it will mean a bit different to you than the person next to you. In fact, in only the past few years has the term become common outside of the industry (Krygiel and Nies, 2008. p.9)

In 2005 if you told someone that you were designing a green building, you would have to follow up with an explanation about how that meant it was environmentally friendly, not the colour green. In a nutshell, that is how the term was and still is widely used - a green building has less of an impact on the natural environment than the traditional buildings the industry has completed over the last three decades. Only recently have we been able to quantify this impact. Industry language has transitioned from using the term *green* to *sustainable*.

A *sustainable* design is better than a *green* one because sustainability takes into account a greater array of impacts than just those that burden the natural environment.

As cited by Brundtland G., H. (1987, p.5) sustainable development was expressed as:

> "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs"
>
> "Those paths of social, economic, and political progress that meet the needs of the present without compromising the ability of future generations to meet their own needs."

The term sustainable design (also called environmental design, environmentally sustainable design, environmentally-conscious design, etc) is the philosophy of designing physical objects, the built environment and services to comply with the principles of economic, social, and ecological sustainability. The intention of sustainable design is to ―eliminate negative environmental impact completely through skill-full, sensitive design.

> "Sustainable design creates solutions that solve the economic, social, and environmental challenges of the project simultaneously, and these solutions are powered by sustainable energies. The combined beauty and function of the design make it something that endures and is cherished; endurance and beauty are central to sustainable thinking. (Williams D. (2007 p.13)

2.2.1 Concept of Green Buildings

Human society has been facing various trade-offs between the uses of natural resources. There have been questions raised about the lifestyles of the modern generation that may affect the sustainability of their descendants. The goal of mankind has been to make the life of subsequent generations easier and more prosperous.

Therefore, the activities of the present generations will certainly affect the livelihood of future generations and it is the job of the present generation to make the life of future generations more efficient. The future generation should have sufficient natural resources, as well as a sustainable environment that can contribute towards its growth. This will require the proper utilisation of natural resources today and the protection of the environment.

This was noted by the various bodies of the world, and the 1992 United Nations Earth Summit was called to discuss implementations of sustainable techniques. The Summit was attended by major countries of the world, with the exception of the United States. The result of the Summit was "Agenda 21", which underlined the various aspects of sustainable design. The fourth point of the agenda was amended by American Institute of Architects (AIA) later (Bunz, Henze and Tiller, 2006).

The main points of the Agenda are as follows:

- Local materials and indigenous techniques are to be used.
- The traditional techniques in various parts of the world are to be promoted.
- The deaths and destruction regarding the natural disasters are to be taken note of by the governments of various countries. This should then be compared with the unregulated practices in the construction industry.
- The design principles should be energy efficient and should be regulated to a certain extent.
- There should be regulations regarding construction in ecologically unstable areas.
- The use of the labour intensive techniques should be preferred in the construction.
- There should be strict guidelines by the credit institutions that prohibit poor buy of building materials by the construction companies.
- International exchange of the knowledge among the architects of the world.
- Recycling of the materials should be encouraged all over the world.
- There should be financial penalties regarding the use of the poor materials and construction techniques.
- Encouraging smaller firms to enter the industry.

- To use clean technologies.

According to the report the principles devised clearly underlined the fact that the traditional techniques are to be encouraged and developed. This means that the traditional techniques incorporate sustainable building designs. The concept of the green buildings is quite old. There are some areas of the world that use traditional and sustainable materials like mud and soil in the construction of buildings. These materials are naturally viable and thus do not demolish the environmental balance (Bunz, Henze and Tiller, 2006).

These techniques devised in the Summit resulted in the development of various bodies all over the world that take care of the development of sustainable buildings.

These bodies have been developed to encourage the development of green buildings in various parts of the world. Some of the most prominent bodies are as follows:

BREEAM (UK), LEED (USA), HK BEAM (Hong Kong), CASBEE (Japan), HQE (France), DGNB (Germany), PromisE (Finland), Green Globes (Canada), Green Stars (Australia), BCA Green Mark (Singapore), China Green Building Labe.ls: GBDL, GBL and GOBAS, Korean Green Building Label (Yu & Kim, 2011 p.122).

With the development of the various bodies around the world, the rating systems for the construction of the buildings became an important aspect. This was based on the environmental, social and economic aspects. The life cycle assessment (LCA) became an important tool for the development of these buildings. The criteria for the development of the green buildings should be based on the holistic approach that underlines the emotional aspect of the people living in the buildings.

2.2.1.1 Green BIM:

Utilising BIM side by side with green design principles, projects and research undergo scientific modeling during the earliest stages of design as the parti is refined. User comfort is evaluated and the design is modeled, helping client, designer, and builder understand the quality of space and experience. Daylight and energy is studied throughout the process. Energy needs are minimised and renewable strategies found to serve the needs of the building. Water use and waste are minimised or eliminated through the modeling and design of the building and site. Fabrication and construction process is anticipated and guided as critical elements of design. Construction waste is identified and redirected as a source for other users and products.

The designer and builders are achieving these results using BIM and other design and construction tools to maximise beauty, efficiency, and functionality while minimising or eliminating impact of the environment.

The concept of where Green Building movement derived from according to (Krygie, K and Nies, B, 2008) began as a reaction to oil shortages and the political and environmental events of the time. This part of the movement was therefore focused primarily on energy conversation. However, after the oil embargo and the Arab-Israeli and Vietnam wars ended in the middle part of 1970s, we went back to our path of ecological ignorance, staying in that pattern until the early 1990s.

There should be a clear distinction between the terms of *green* and *sustainable,* if one said they were designing a green building you would have to follow that up with a explanation of how that meant environmentally friendly and not the colour green. A green building has less of an impact on the natural environment than the traditional buildings the industry has completed over the last three decades, only recently have we been able to quantify this impact (Krygie, K and Nies, B, 2008)

Reducing the Resource Consumption Need

In the green building industry, there is a common saying *"The greenest building is the one that is never built"*. From those championing use of existing building stock you might hear, "The greenest building is the one that is already built." Both of these statements are targeting the same objective. (Lucuik, M. and Huffman, A. Morrisonhersfield, Technical Paper, 2010)

The following is a list of the criteria that should be taken into account for the order of operations in designing for a Green BIM project:

- Space
- Materials
- Energy
- Water
- Wind
- Rainwater
- Sun

Each of these aspects is explained in detailed below.

Space

When a project team is starting programming for a project or beginning designs based on a client-provided program, the first question they should ask is, "Does the client need this space?"

Space has upstream environmental impacts from manufacturing and construction as well as downstream environmental impacts related to maintenance and disposal or recycling.

Materials

Using the building structure as a finished surface can be done with concrete floors and carefully installed metal decks. Both of these materials have the potential to assist in extending the daylight into the building. The concrete can easily be painted to add reflectance, and the metal deck has its own natural reflectance. So, with either of those solutions you have an integrated system.

When it comes to using, we have to talk about the Portland cement. Portland cement has one of the highest embodied energies of all buildings products. While Portland cement is only about 10-12% of a common ready-mix concrete mix, it is accountable for at least 85% of the embodied energy of concrete according to the Portland Cement Associations report "Life Cycle Inventory of Portland Cement Concrete".

Embodied energy refers to all the energy required for the creation of that material or product from harvest to delivery in use. Common stages of material manufacture are raw material extraction, manufacture, assembly, transport, and installation. Concrete has many benefits, including its durability and high mass, the fact that its surface can be an attractive finish and its recyclability.

Energy

From energy prospective you can reduce a building's need in many ways, a few samples have been listed below:

Building orientation, Building massing, Optimised envelope, Optimised glazing, Optimised shading, Daylight dimming, Optimised lighting, Efficient equipment, Passive solar, Thermal mass, Natural ventilation, Optimised mechanical system.

The first seven listed energy load reduction strategies, how they can be combined for a collective better solution. For example, a proper building orientation, facing solar south along with the building mass should be elongated east-west to maximise the benefits of that southern exposure. By selecting a proper glazing percentage, location, and type of glass on this south wall, you can harvest usable daylight, allowing you to include day lighting dimmers around the south perimeter of the building. You could further enhance the daylight penetration and reduce solar conduction load with the use of external shading devices and internal light-shelves. Because the building is receiving most of its lighting needs from the sun, you can reduce the number of overhead electric lights and provide high-efficiency task light.

Water

Water energy conversation and efficiency get a lot of press with the bulk of the world focused on reducing greenhouse gases, reducing the built environment's need for water could be an even more important effort. For too long we've regularly used drinkable water for flushing our waste and watering our expansive residential and commercial monoculture turf grass lawns. These area two primary areas where we can reduce the built environment's need to water.

Wind

Integrating the use of natural ventilation relies on smart decisions for many portions of building design, including:

- Building location on site and proper orientation.
- Building mass and dimensions.
- Windows types, locations and operation.
- Integration of stack inducing elements (open stairs, chimneys).
- Efficient envelope construction (conductance and infiltration).
- External elements (shading devices and vegetation).
- Flexible temperature ranges for comfort.

By optimising the building design by looking at the psychometric chart, one can quickly see when the exterior conditions are in the natural ventilation cooling range. Looking at wind charts we can see the direction and speed of the wind during the same periods. A basic move for facilitating natural ventilation for the design would be to organise the windows of the building to capture those breezes.

Rainwater

Rainwater is a free resource that can be beneficial in every climate zone. Using rainwater reduces the need for municipally provided portable water, especially for non-potable water needs. To use rainwater, you have to collect, filter, store, and convey it to the end use.

Rainwater can be collected from the roof, car parking surfaces, or site runoff. You can store it in barrels or cisterns, located on the roof, hidden in sub-levels of the building or even under the car park. Rainwater can be used for many things, such as irrigation of site landscaping, development of water features, water for industrial processes, flushing toilets, chiller water, geothermal heat sinks, or even for potable uses. Each level of use has an increasing requirement for filtration and cleaning.

Sun

The most powerful of Mother Nature's resources is the sun. The sun provides us three key resources; light, heat, and power. We are interested in maximising the use of the sun's light and heat in lieu of using energy from the municipal grid for those purposes. Use of natural daylight is appropriate for almost every building that has spaces requiring light. When working on daylight strategies, try to keep in mind the following design strategies:

1. Orient the building to face solar south.
2. Determine where to put glazing and how much is required to create a day-lighting solution.

A glazing unit has three important factors to consider:

- U-value: a measure of the rate of heat transfer through a material.
- Visible light transmittance (VLT).
- Solar heat gain coefficient (SHGC).

3. Another method to achieve the same result without expensive glazing is to use external shading.

- Reduce heat gain.
- Control unwanted glare within the building.

(Krygie, K and Nies, B, 2008 p.p 76-107)

2.2.2 Sustainable Design Analysis and Building Information Modelling

Sustainable design is more important than ever as the lifecycle of buildings are increasing and the increase of facility management. BIM solutions make sustainable design practices easier by enabling architects and engineers to more accurately visualize, simulate, and analyze building performance earlier in the design process. The intelligent objects in the building information model enable the advanced functionality of the desktop tools that are included with Autodesk Ecotect Analysis software. Using Autodesk Ecotect Analysis, architects and designers can gain better insight into building performance earlier in the design process, helping to achieve more sustainable designs, faster time to market, and lower project cost.

Designing energy-and resource-efficient buildings, in many locations, is no longer optional, but mandatory. While owners have always sought designs that are cost-effective to operate and that will command premium lease values, research shows that green buildings (for example, LEED-certified) are more likely to deliver on these criteria. A 2008 report from McGraw Hill Construction finds a 13.6 percent decrease in operating costs from green building and a 10.9 percent increase in building values as reported by architects, engineering firms, contractors, and owners over the past three years (McGraw Hill Construction 2008).

More pressing is the growing number of local and national regulations that mandate targets for energy and resource efficiency as well as carbon emission reductions in new and renovated buildings. These government initiatives—such as the 2007 U.S. Energy Independence and Security Act or the European Union's Energy Performance Buildings

Directive (EPBD)—are certainly put in place to help reduce greenhouse gas emissions and slow our impact on climate change, but they are also instituted to reduce dependence on unpredictable markets for oil as an energy source and, most recently, to help stimulate the global economy

2.2.3 Application of BIM and other facets of technology used for sustainable design

The earlier sections of this dissertation specified that BIM can be used to a certain extent for the development of sustainable designs. It has to be noted that for the development of sustainable architecture, most of the work is completed in the design stage of the process. The design stage requires the development of various scenarios that can affect the buildings' sustainability and also develop a model that can take care of the environmental impacts.

BIM takes into account various facets such as the architectural aspects, the lighting, the use of the energy, the use of the renewable resources, etc. All these aspects are used as part of the integrated BIM. In the case of sustainable buildings design, the BIM can offer a breakthrough to architects around the world by providing a framework during the planning and designing stage that can be followed during the construction and operating.

BIM is also involved in assessing the environmental impacts of the buildings, assessing the life cycle cost, energy consumption estimate, maintenance of the buildings, etc. The service life design of the buildings is associated with the estimation of the life of the buildings relating to the use of materials in the buildings as well as the behavior of the components. This can also be discovered with the help of the BIM and thus can play a huge role in determining the sustainability of the buildings.

Therefore, the BIM can be used efficiently in the preparation of buildings that will be sustainable over time.

> "The terms *high performance, green,* and *sustainable construction* are often used interchangeably; however, the term *sustainable construction* most comprehensively addresses the ecological, social, and economic issues of a building in the context of its community." (Kibert, C.J., 2008 p.6)

Thus, sustainable construction will look into the impacts of the environment as well as minimize energy consumption to a certain extent. Therefore, the BIM can be used extensively in the development of sustainable buildings.

The BIM model has been developed over the years with the use of technology. Various software and tools have been developed that are in sync with the BIM process. Some of the software's that have been used extensively are Ecotect™, Green Building Studio™ (GBS) and Virtual Environment™. The use of these tools can be helpful in the accreditation systems like that of LEED (Azhar, Brown and Farooqui, 2009, p 8)

The process and requirements of Leadership in Energy Environmental Design (LEED) is discussed in detail later on in this chapter.

2.2.4 Methodology for Sustainable Solutions

It is necessary to include more input parameters and consider a longer period of time while making decisions during the design process. The order of operations is derived from the following common methodology for reducing energy consumption of buildings; (Krygiel and Nies, 2008, p.76)

1. Understanding climate
2. Reducing loads
3. Using free energy
4. Using efficient systems

Incorporating order of operation to the design of a building's energy use, water use, material use, and site;

1. Understanding climate, culture, and place
2. Understanding the building type
3. Reducing the resources consumption need
4. Using free/local resources and natural systems
5. Using efficient manmade systems
6. Applying renewable energy generation systems
7. Offsetting remaining negative impacts

What designers, builders, and owners generally do?

> "Let's put this building here and use whatever energy is necessary to keep the occupants comfortable with a mechanical system" (Krygiel and Nies, 2008, p 77)

2.3 The Intersection of BIM and Sustainable Design:

During the last few years, we have witnessed the rapid and parallel development of two overarching paradigms in the building design and construction industry: Building Information Modeling and Sustainable Design. BIM has risen to prominence out of a desire to streamline the building design and documentation process, to simplify construction management, and to provide the owner with inherently better capabilities for ongoing facilities management during building occupancy. The initial benefits of BIM were seen through the lens of economics: by making building design, construction, and maintenance more efficient, we can ultimately deliver a better project value at a lower construction cost, which have been outlined in previous chapters. On the other hand, Sustainable Design has emerged out of global concern for the state of our natural environment. As we add more buildings to our collective built landscapes, sustainable thinking is needed to meet the future challenges of land use, energy consumption, and availability of material resources for building construction. Although BIM and Sustainable Design have emerged from somewhat different underlying market factors, they share a significant common thread: the success of both endeavors depends heavily on a front loaded, deeply integrated building design philosophy that aims to include all team players from the very beginning of a project. (Ruben, et al, 2009)

This dissertation has shown that the design process is heavily affected by BIM implementation and major design decisions are crucial at the beginning phases of the project timeline. The closer the project gets to the end of its design schedule, the more difficult and costly it becomes to incorporate design evolutions. The emphasis here is placed on the schematic design phase of the project. Traditional project design delivery allows for the early conceptual phases to be fully tested during design development, and even during final coordination of the construction document deliverables. However, when significant problems and conflicts are identified very late in the documentation process, the time and cost to correct these design deficiencies has typically led to many other problems, including shortened schedules, design revision bottlenecks, and construction document sets with poor or mediocre design coordination. These design issues then cascade into the construction phase of the project, where —Request For Information (RFI's) attempts to reconcile the lack of design team coordination. The implementation of BIM helps eliminate problems associated with the traditional project design delivery concept see figure 3 (below).

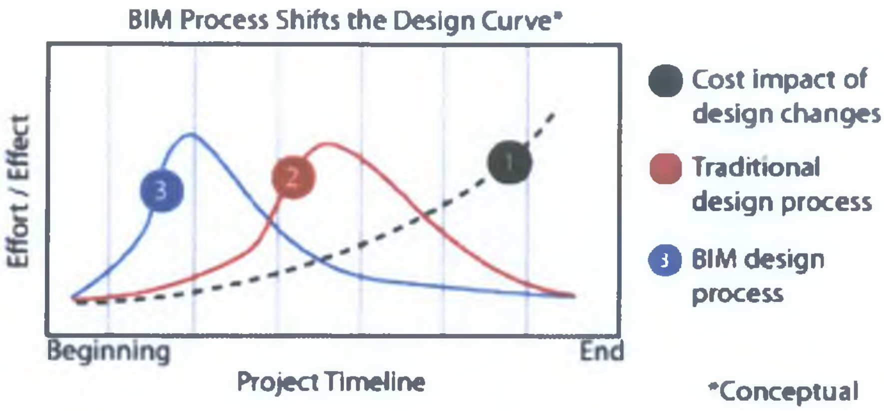


Figure 3: *BIM Shift, Courtesy of Construction Users Roundtable* (Ruben, et al 2009)

Sustainable Design offers very similar benefits to the design process. The most energy-efficient and environmentally conscious designs are typically those that propose passive design concepts from the very beginning. Energy-efficient mechanical, electrical, and plumbing systems can be designed to help heat, cool, ventilate, and power many different types of buildings.

But how do we go about integrating the concepts of BIM and Sustainable Design into any given project? According to (Moakher, E, P., Dr. Pimplika, P,P, 2012 p.13) generally speaking, the building design test period must occur mostly during the project's schematic design phase. This design-testing phase allows for preliminary verification of the broad stroke or big picture sustainable design goals. With architectural computer software design tools and modeling programs, the design team can quickly generate multiple design options during the schematic phase that take into account site specific characteristics such as solar orientation and sky path. (HOK Smartbuilding, 2010)

Project specific sites also see winds that often come from a predominant direction. A wind rose is a useful statistical tool for plotting and evaluating average and peak wind speeds and directions. And the interaction of sun and wind effects, in combination with local topographical conditions, can ultimately affect the site specific microclimate. BIM software applications are now taking this a step further by adding utilities and analysis options that integrate with the physical model to provide solid and reliable environmental analysis results. In turn, these results can be used to help shape building design, identify design deficiencies, and prove initial schematic design concepts. Sustainable design strategies such as using thermal mass, natural ventilation, and day lighting can all be evaluated from the viewpoint of the architectural enclosure and structural system. And all of this work can, and should, be done before the project begins heading down the path of detailed project design and documentation. By the time the project reaches the construction pricing and bidding stages, it becomes far more difficult to apply value engineering strategies when sustainability is successfully deeply integrated into the building design.

Both BIM and Sustainable Design require a different way of thinking about the entire building design process. Both paradigms call for the entire design team to have a much better understanding of how the building is actually constructed, and how it actually behaves, under any given condition of stress. It is in this way that the design team can truly begin proposing deep green designs that minimize both energy and material consumption, serving the interests of both BIM and Sustainable

2.4 History of LEED, its origin

First introduced in 1993, Leadership in Energy and Environment Design (LEED) was developed by the U.S. Green Building Council (USGBC), and spearheaded by Robert K. Watson, Founding Chairman LEED Steering Committee. This industry standard is a voluntary, consensus-based, market-driven program that provides third-party verification of green buildings.

From 1994 to 2006, LEED expanded from one standard for new construction to a comprehensive system of six interrelated standards covering all aspects of the development and construction process. In 2000 USGBS established a benchmark for LEED Green Building Rating System.

In recent times USGBC updated their online reference guides to help promote eco-friendly building practices worldwide. This included an interactive web tool to explain the LEED Green Building Rating System and a web application equating the rating system with a nutrition label. In 2009 LEED was presented an Honorary Award by The National Building Museum for *"Visionaries in Sustainability"* and again in 2005 the National Building Museum awarded LEED with its *"Henry C. Turner Prize"* for its leadership and innovation in construction.

Participation in the voluntary LEED process demonstrates leadership, innovation, environmental stewardship and social responsibility. LEED provides building owners and operators the tools they need to immediately impact their building's performance and bottom line, while providing healthy indoor spaces for a building's occupants.

LEED projects have been successfully established in 135 countries. International projects, those outside the United States, make up more than 50% of the total LEED registered square footage. LEED unites us in a single global community and provides regional solutions, while recognizing local realities.

2.4.1 The Process of LEED

LEED consists of a suite of rating systems for the design, construction and operation of high performance green buildings. From individual buildings and homes, to entire neighbourhoods and communities, LEED is transforming the way built environments are designed, constructed, and operated. Comprehensive and flexible, LEED addresses the entire lifecycle of a building.

LEED evaluation/certification

For my chosen case study and other commercial buildings including neighbourhoods, in order to earn LEED certification, a project has to satisfy all LEED prerequisites and earn a minimum 40 points on a 110-point LEED rating system scale.

How projects can earn points to satisfy green building requirements

For projects to earn points to satisfy green building requirements, within each of the LEED credit categories, projects must satisfy prerequisites and earn points. The allotted number of points that the project earns determines its level of LEED certification, as can been seen below from the list of credit categories:

Main credit categories:

- **Sustainable sites credits** encourage strategies that minimize the impact on ecosystems and water resources.
- **Water efficiency credits** promote smarter use of water, inside and out, to reduce potable water consumption.
- **Energy & atmosphere credits** promote better building energy performance through innovative strategies.
- **Materials & resources credits** encourage using sustainable building materials and reducing waste.
- **Indoor environmental quality credits** promote better indoor air quality and access to daylight and views.

Figure 4: Four Certification Levels (source: LEED (2009) *Four Certification Levels, Core Concepts and Strategies.*

2.4.2 LEED Application

As indicated in figure 4 above, the LEED process assigns ratings of platinum, gold, silver or bronze in recognition of total credits earned by the project. The industry standard for energy efficiency, ASHRAE 90.1 - 2007, is incorporated into LEED through Energy & Atmosphere (EA) Prerequisite 2 – Minimum Energy Performance; EA Credit 1 – Optimize Energy Performance; EA Credit 2 - On-Site Renewable Energy. The U.S. Army policy requires all new buildings to be certifiable at the LEED silver rating. Fort Bragg established the goal of LEED platinum by 2020 for all facilities. For the past 50 years, a wide variety of building energy simulation (BES) analysis tools have been developed, enhanced, and applied throughout the building energy community. Examples of these analyses tools are Ecotect, ENERGYSTAR, EnergyPlus, Green Building Studio, eQUEST, TRACE, DOE2, VE-PRO, and ECOTECT. Input data in these tools are complex, 2D drawing or text-based applications, which require a great deal of time to learn (Crawley et al. 2005)

Building designers consider energy analysis as a time-consuming process and leave it to mechanical or electrical engineers late in the design process. Several research papers describe energy analysis as a holistic evaluation Abaza (2008), Dahl et al. (2005) and Lam et al. (2004) showed that decisions made early in a project on building designs (conceptual and detailed designs) have a strong affect on the life cycle costs of a building.

With the recent innovation in building design and construction, BIM has received tremendous interest for its impact on sustainable development and provides the opportunity to develop energy analysis software programs for the industry. It is also worth noting that several researchers proposed to combine Lean and BIM technologies to improve modeling process in sustainable development (Riley et al, 2005) While the converging approach would enable virtual simulation in collaborative environments, and thus is expected to change the AEC industry in terms of delivery and management of the built environment, it is found that the approach emphasizes the whole process in design and construction processes. (Yezioro et al, 2008) conducted assessing building performance using 3D CAD model for energy analysis in the early design stages.

Having researched the papers of Abaza, Yezioro the relevance of this to my study is that with the early adoption of building designs will impact on the overall life cycle costs. This should be evident with the adoption of BIM at the early building design stage of a project compared with the completed design then been subjected to non-domestic BER rating through iSBEM.

2.4.3 Application of BIM processes for six of the seven possible LEED categories:

As suggested by Krygiel and Nies (2008), in terms of the application of BIM processes there is a list of categories to be satisfied under USGBC LEED requirements namely:

- Sustainable sites
- Water efficiency
- Water reduction
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality
- Innovation in design

I. Sustainable Sites:

With the use of BIM to support the design and demonstration of sustainable outcomes such as development configuration and density, protection and restoration of the natural habitat, and connectivity to alternative transport and other amenities are investigated.

II. Water Efficiency:

Example: Water use reduction (2-4 points)

Employs strategies that use 20-40% less water than the water use baseline calculated for the building.

The calculations for this credit are based on water consumption by building occupants and type of water fixtures. This water usage can be reduced by using water efficient sanitary fixtures (toilets, urinals, kitchen sinks, showers and pre-rinse spray valves); and through the use of non-potable water (e.g. captured condensate water, rainwater or treated wastewater).

It can be achieved by comparing the baseline plumbing systems with design plumbing systems, which will require assessment of the plumbing design models that would contain all required data; such as plumbing fixtures flow rates, water tanks capacity and overall system's water consumption rate. Then by incorporating this data into BIM enables quick assessment by simulating different scenarios (e.g. changing plumbing fixtures' type will show result overall system's water consumption rate).

III. Energy and Atmosphere:

Example: Whole Building Energy Simulation. (3-21 points)

This prerequisite and credit requires calculating all of the buildings energy costs and comparing this with design building energy costs to demonstrate the improvement in the building performance rating. The LEED Reference Guide demands the creation of the baseline and the proposed design energy models using an approved energy simulation program. The baseline model has to be created in accordance to minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-2007. The proposed building model would be designed to optimise the building energy costs.

Krygiel and Nies (2008 p. 98), states that the following factors should be considered in the proposed design model to optimise the building energy performance;

- Building geometry, geographic location and orientation,
- Envelope properties (glazing, thermal conductivity of insulation, walls, roof, floors etc.),
- Building usage including functional use, occupancy,
- Energy usage (such us harvesting and utilising daylight, solar heating power, wind energy etc.)
- Equipment, lighting, and HVAC systems.

Once the baseline and the proposed design models have been established, the energy modelling software can then run calculations to simulate the building energy performance. This ought to include how all the building systems interact and affect each other. For example, if a designer wants to increase fenestration area for one of the facades, it will bring more daylight in the rooms and therefore can reduce electrical lighting load. However, as more heat will be transferred through the glazing the HVAC systems are affected and air conditioning load may increase. All kind of scenarios can be simulated and assessed using the model for the best solution available.

IV. Materials and Resources:

These credits require the calculation of the cost or weight of reused, salvaged, refurbished, recycled, or regional (locally produced)… materials compared with total value of materials on the project.

The BIM can be used to manage procurement of materials. Having costs and weight assigned to materials in BIM, and distinguishing materials' type/content (reused, recycled, or regional…), allows for the extraction of these costs from the calculation; for example:

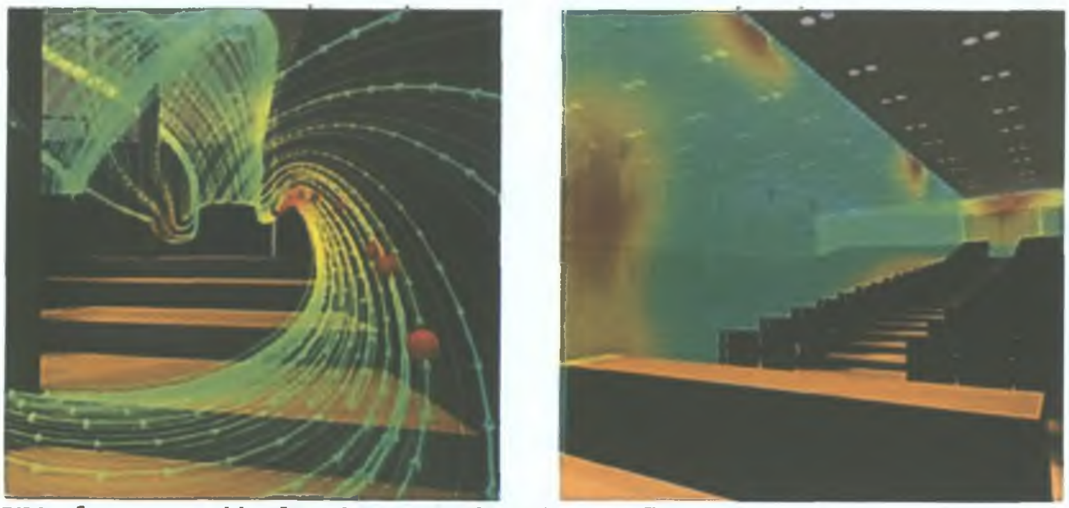
- **Material Reuse. (1-2 points)**
- **Recycled Content. (1-2 points)**
- **Regional Materials. (1-2 points)**
- **Rapidly Renewable Materials. (1point)**
- **Certified Wood. (1 point)**

V. Indoor Environmental Quality:

In this category the use of a combination of BIM function included energy modelling and material verification.

Example: Increased Ventilation.

For Naturally Ventilated Spaces, requirements to use analytic model to predict that room-by-room airflows will effectively naturally ventilate at least 90 % of occupied spaces, as indicated in figure 5 below.



BIM software is capable of simulating natural ventilation air flows.

Figure 5: BIM software simulating natural ventilation air flows (LEED 2009)

In figure 5 above which illustrates the airflow of natural ventilation with a BIM model to establish that at least 90% of the occupied space is supplied by free natural ventilation so that the demand for HVAC system is reduced thus reducing the total energy demand.

Example: Daylight and Views – Daylight. (1-3 points)

Demonstrations through computer simulation that specific 'regularly occupied spaces' achieve certain daylight luminance levels.

BIM software has the ability for performing daylight analysis, that show luminance levels across the rooms depending on such factors as building orientation, fenestration type, etc.,

Example: Low-Emitting Materials (1-6 points)

As for the similarly process to the material and resourcing, BIM can be used to manage and verify procurement of materials. Having material specifications tagged to the model elements allows for verification of critical data such as:

- Adhesives and Sealants
- Paints and Coatings
- Flooring systems
- Composite Wood and Agri-fiber Products
- Furniture and Furnishings
- Ceiling and Wall Systems

To earn credit for Low-Emitting Materials all the above mentioned materials shall comply with certain requirements for content of harmful substances. This can be tracked by integrating specifications or design requirements with the BIM elements.

VI. Innovation in Design:

BIM can support innovation in design through the development and analysis of climate-responsive building elements, such as parametric shading device.

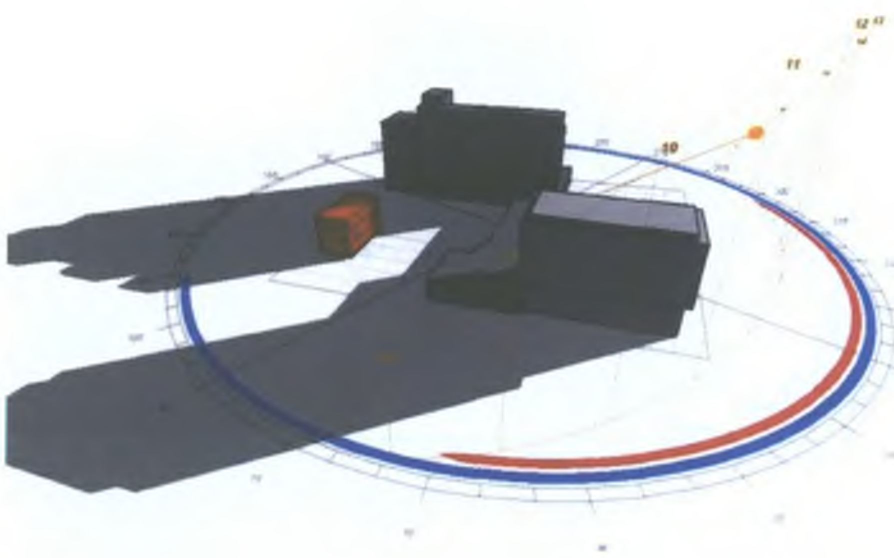


Figure 6: BIM software simulating sun-path diagrams (source: Autodesk 2011)

2.5 Selection of Modeling Tool(s):

At this stage the author will discuss the modeling tool(s) for modeling in terms of energy analysis. The science of energy analysis for buildings has become more and more complicated.

However, considerable work has been done in the effort to transform this available science into design, construction and operation practice. Currently, there are many powerful simulation codes available to help engineers/designers in the energy analysis of energy structures for example: Ecotech, Autodesk Green Building Studio, SBEM, ASHRAE, Bentley, Graphisoft just to name a few. With the rapid development in computing technologies, these codes can make more detailed analysis compared to years ago; therefore it is now becoming one of the most crucial tools in energy analysis.

Generation of heat and power profiles with respect to building energy modeling tend to be rather complex, and depend strongly on assumed usage patterns. The electrical load is based on a usage pattern of installed appliances, lighting, and the heating demand in terms of the building parameters, the desired temperature profile, occupancy pattern, incidental gains, and the heating control system. Estimated heat and power profiles may suffer from inaccuracies due to lack of information about the building parameters or usage without the involvement smart metering, building management systems. However the main advantages of these analytical approaches are the analysis of the effect of energy saving measures and change of usage patterns. The full modeling approach can be complex, and various intermediate methods including both modeling and measurement are possible. The most obvious and useful method involves measurement of the annual energy consumption, and then estimating the energy profiles of target buildings considering meteorological data, or on the measured profiles of similar buildings. The principle outputs from energy simulations software can be grouped under operational data, economic data, and environmental data. Operational data includes hours run, heat utilisation, displaced electricity, heat supplied, fuel used, electrical, heat, and total efficiencies. Economic data includes capital cost, electricity savings, additional fuel cost, maintenance cost, net savings, and payback period. Environmental data includes primary energy savings, carbon emission savings, and emission of other pollutants.

In this chapter of the dissertation, by considering the user friendly interface and suitability of its tools GBS (Green Building Studio) and Ecotect were evaluated in association with the guidelines of LEED (Leadership Energy & Environmental Design) with a rating system of between 1 -10, as illustrated in the table 1 below:

Sustainable Design Features	Rating (1-10)	Ecotect	Green Building Studio (GBS)
Energy:	**6**		
Energy Usage		1	3
Carbon Emissions Calculator		3	3
Resource Management		3	1
Total Score:		**7**	**7**
Thermal:	**7**		
Thermal Analysis		3	1
Heating/Cooling Load Calcs		3	1
Ventilation Airflow		3	3
Total Score:		**9**	**5**
Solar:	**2**		
Solar Analysis		3	1
Right to light		3	1
Total Score:		**6**	**2**
Lighting and Daylighting:	**3**		
Daylighting Assessment		3	1
Shading Design		3	1
Lighting Design		3	1
Total Score:		**9**	**3**
Acoustic	**2**		
Acoustic Analysis		3	0
Total Score:		**3**	**0**
Value & Cost:	**8**		
Lifecycle Assessment		0	3
Lifecycle Cost		0	1
Total Score:		**0**	**4**
LEED:	**8**		
LEED Integration Tools		0	1
Total Score:		**0**	**1**
Total Rating Score:		**150**	**130**

Table 1: Building Performance Analysis Software Evaluation Matrix (Source HCC, Atlanta)

2.6 Construction Industry and Moving towards Sustainable Development:

A starting point for all members of the AEC industry that wish to approach sustainability as a business opportunity - both large developers to small companies and especially with refurbishing existing buildings – it is important to re-think their operations in four key areas:

I. Energy: reducing energy consumption, being more energy efficient and using renewable energy and alternative technology.

II. Materials: choosing, using, re-using and recycling materials during design, manufacture, construction and maintenance to reduce resource requirements.

III. Waste: Producing less waste and recycling more.

IV. Pollution: Producing less toxicity, water, noise and spatial pollution.

This will lead on to a re-assessment of best practice in each area, with cumulative benefits from overlapping improvements between the areas. The implementation of those results could improve profits and investment, and will contribute towards a sustainable future for the construction industry. Of course, it would be as wasteful as some current construction practices for every firm to go-it-alone. Co-operation, through industry bodies, with government, and transparency in what we are doing, can all help reduce the burden of change. But in the end change will come only when individual firms take up the challenge of operating in a sustainable way. We expect that the use of BIM tools in the sustainability and environmental arena will make a significant impact upon being able to achieve more sustainable projects and communities. (CIOB, 2013, p.4).

2.7 Whole Building Energy, Water and Carbon Analysis:

When subscribed to Autodesk Ecotect Analysis one can get access to the Autodesk Green Building Studio web-based service for the duration of their subscription. This web-service enables faster, more accurate whole-building energy, water, and carbon emission analyses and helps architects the majority of which are not specially skilled in any of these analyses to evaluate the carbon footprint of a Revit-based building design with greater ease.

The Green Building Studio web service was first introduced in 2004. Today, its analysis results meet ASHRAE Standard 140 – 2007 and are qualified by the U.S. Department of Energy. It also received the Microsoft Ingenuity Point Award in 2008.

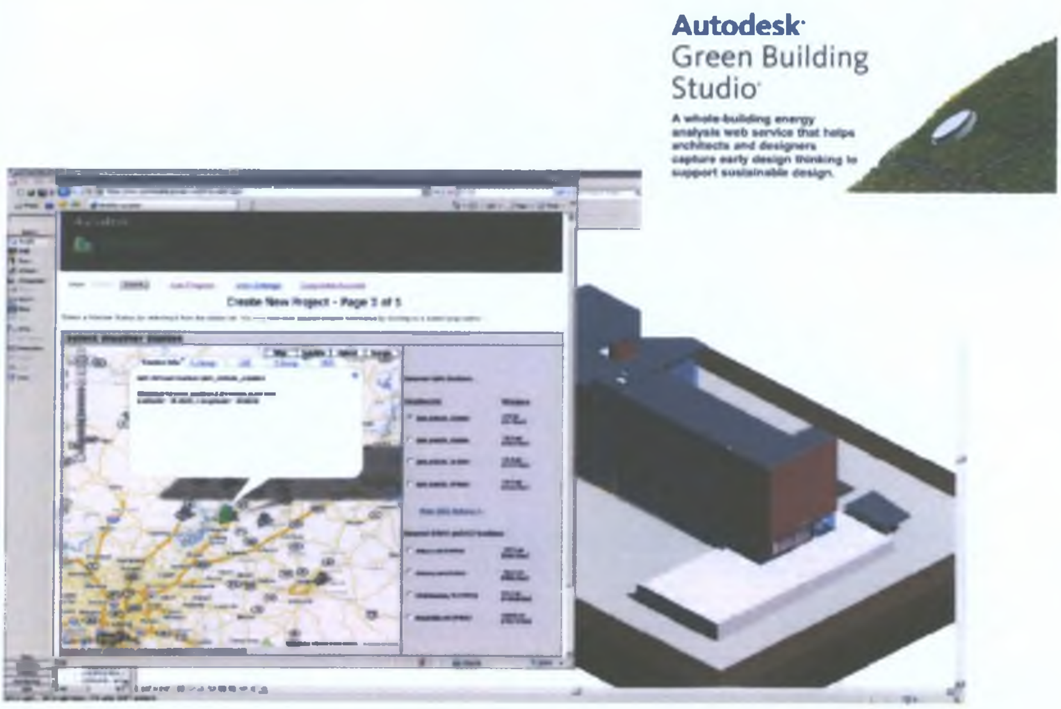


Figure 7: The Autodesk Green Building Studio web-based service enables faster, *"whole-building energy, water, and carbon emission analyses of a Revit-based building design"*. The building location (being defined here) drives the resulting electricity and water usage costs.

The service uses precise hourly weather data, as well as historical rain data, that are accurate to within 9 miles of the given building site as can be seen in figure 7 above. It also uses emission data for electric power plants across the preset countries located within its database and includes the broad range of variables needed to assess carbon neutrality.

This software package was built specifically for architects and using green building extensible markup language (gbXML) for easy data exchange across the Internet, the web-based service was one of the first engineering analysis tools to deliver easy-to-use interoperability between building designs and sophisticated energy analysis software programs such as DOE-2. The link between the Revit platform and the Green Building Studio web service is facilitated through a plug-in that enables registered users to access the service directly from their Revit Architecture design environment see figure 8 and 9 below.

Figure 8: The link between the Revit platform and the Autodesk Green Building Studio web-based service is facilitated through a plug-in that enables registered users to access the service directly from their Autodesk Revit Architecture design environment.

The Autodesk Green Building Studio web-based service helps to streamline the entire analysis process and enables architects to get faster feedback on their design alternatives making green design more efficient and cost-effective.

Based on the building's size, type, and location (which drives electricity and water usage costs), the web-based service determines the appropriate material, construction, system, and equipment defaults by using regional building standards and codes to make intelligent assumptions. Using simple drop-down menus, architects can quickly change any of these settings to define specific aspects of their design; a different building orientation, a lower U-value window glazing, or a 4-pipe fan coil HVAC system.

Usually, within minutes the service calculates a building's carbon emissions and the user is able to view the output in a web browser, including the estimated energy and cost summaries as well as the building's carbon neutral potential. Users can then explore design alternatives by updating the settings used by the service and rerunning the analysis, or by revising the building model itself in the Revit-based application and then rerunning the analysis.

The output also summarizes the water usage and costs, and electricity and fuel costs; calculates an ENERGY STAR score; estimates photovoltaic and wind energy potential; calculates points toward LEED day-lighting credit; and estimates natural ventilation potential. Unlike most analysis output, the Autodesk Green Building Studio report is easier to understand—giving architects and other users actionable information they need to help make greener design decisions (Autodesk, 2009).

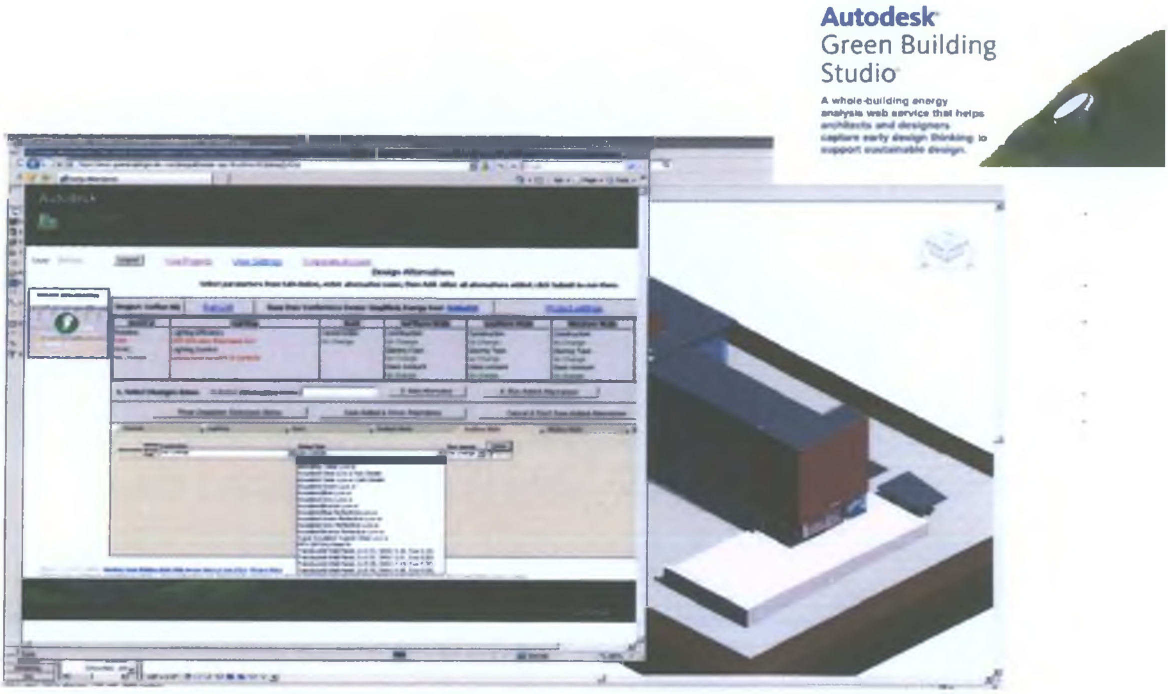


Figure 9: Architects and other users can explore design alternatives by updating the settings used by the Autodesk Green Building Studio web-based service and rerunning the analysis, or revising the building model itself in the Revit-based application and then rerunning the analysis.

The desktop tools in Autodesk Ecotect Analysis provide a wide range of functions and simulations, helping architects and other users to understand how environmental factors will impact building operation and performance in the early design phase. To mitigate a building's impact on the environment, it is important to first understand how the environment will impact the building. Built specifically by architects and focused on the building design process, Autodesk Ecotect Analysis is an environmental analysis tool that enables designers to simulate the performance of their building projects right from the earliest stages of conceptual design.

Autodesk Ecotect Analysis combines a wide array of analysis functions—including shadows, shading, solar, lighting, thermal, ventilation, and acoustics—with a highly visual and interactive display that presents analytical results directly within the context of the building model. This visual feedback enables the software to communicate complex concepts and extensive datasets more effectively and helps designers quickly engage with multifaceted performance issues—at a time when the design is sufficiently —plastic and can be easily changed (Autodesk, 2009).

Figure 10: Early stage Autodesk Revit Architecture models can be analysed. (source: Autodesk Ecotect Analysis, 2009)

In figure 10 above illustrates of how Ecotect helps to determine the optimal location, shape and orientation of a building design-based on basic environment factors such as the overshadowing of a particular building.

2.7.1 Aspects that affects Building Energy Performance:

In this section of the chapter there a number of possible aspects in a building's make up that can affect energy use namely:

- Building materials.
- Heat gains.
- Heat losses.
- Heating system efficiencies.
- Ventilation and air conditioning systems.
- Building energy management systems (BEMS)
- Energy Standards / Policy

In chapter four of this dissertation and in relation to the case study the Department of Education require a minimum A3 Building Energy Rating. And in relation to this reference will be made to Department of the Environment 2008 *Technical Guidance Document Ireland "Part L"* and Department of Education and Science "*Technical Guidance Documents"*

2.7.2 Energy Standards / Policy

There are a number of benchmarks and guidelines available towards achieving energy reduction once the proposed primary school has been constructed notwithstanding the process outlined within this chapter which describes looking at energy analysis at design stage.

One definition of energy management is:

> *"the judicious and effective use of energy to maximise profits (minimise costs) and enhance competitive positions"*
>
> (Chap Hart, Turner and Kennedy, Guide to Energy Management Fairmont Press Inc., 1997)

2.7.2.1 The National Energy Efficiency Action Plan 2009 – 2020:

The *National Energy Efficiency Action Plan* (NEEAP) 2009-2020 (Department of Communications, Energy and Natural Resources), has set out an energy policy framework to combat problems such as Ireland's over-reliance on fossil fuels, which accounted for 96% of all energy usage in 2007 and our problem of security of supply of reliable and affordable energy.

The NEEAP represents the next step in addressing the imperative for energy efficiency. As Ireland move further into the future, price hikes in gas and oil are expected. This is where Ireland needs to react to our current economic situation and build on becoming an efficient, low-carbon-energy system. Energy efficiency offers the most cost effective means of reducing GHG emissions (electricity in buildings use 61%).

Ireland's second National Energy Efficiency Action Plan to 2020 launched on the 28 February 2013, this second action plan provides a progress report on delivery of the national energy savings targets implemented under current EU requirements as well as energy efficiency policy priorities between now and 2020. This reaffirms Ireland's commitment to a 20% energy savings target in 2020. The Public Sector has been challenged to reach verifiable energy-efficiency savings of 33%. This target requires management commitment at the highest level and the involvement of all public sector employees.

According to the report realisation of the public sector's 33% target would lead to annual energy savings to the Exchequer of over €200 million (2011). The net present value of these upgrades is estimated at over €1.4 billion. This is before the value of impacts such as increased productivity, asset value increases and improved building environments are considered.

Schools according to NEEAP are seen as public-sector buildings which primarily consume electricity, natural gas and oil-based fuels as well as smaller amounts of renewable and solid fuels.

According to the national energy efficient action plan The Department of Education and Skills is at the forefront of design with respect to sustainable energy efficiency in school buildings. This performance has been recognised at both national and international level over the past fifteen years with sustainable energy awards for excellence in design and specification.

The Department's Technical Guidance Document (T.G.D.) sets the benchmark for sustainable design in school buildings, with a clear focus on energy efficiency. This approach is supported by a strong research programme, with 39 research projects at various stages.

The Department has announced that the constructing two schools to the passive house standard – the world's leading low energy building standard. Feedback from the two schools will inform future school design and identify the optimum level of passive design opportunities for incorporation in Irish school design standards. All primary schools (first-level) built in accordance with the T.G.D. are capable of achieving an A3 Building Energy Rating (BER) and all post-primary schools (second-level) are capable of achieving at least a B1 BER.

In addition SEAI and the Department are developing a number of strategic projects with the aim of helping schools to reduce energy costs and thus concentrate more resources on their core function – delivering education. These include projects to:

- Stimulate the market for deep energy efficiency retrofit projects in cohorts of schools using innovative procurement models (e.g. energy performance contracting, ESCos) – with a pilot project to commence in 2012/2013.
- Develop a package of supports and an online energy advice portal for schools – www.energyineducation.ie
- Explore on a pilot basis a metering and display programme for school energy and water consumption monitoring.

2.7.2.2 EPBD

The Recast Energy Performance of Buildings Directive (EPBD) adopted in May 2010 [Directive 2010/31/EU of the European Parliament and of the council, Official Journal of the European Union] clearly states that reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions. The directive proposes to calculate the energy performance of buildings on the basis of a methodology, which may be differentiated at national and regional level. Member States may set minimum requirements for the energy performance of buildings.

> Buildings account for 40 % of total energy consumption in the Union. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions. (Directive 2010/31/EU p.1)
>
> Together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) (Directive 2010/31/EU p.1)

Under Article 9 of Directive 2010/31/EU Nearly zero-energy buildings
1. Member States shall ensure that:

(a) By 31 December 2020, all new buildings are nearly zero- energy buildings; (Directive 2010/31/EU p.9)

(b) After 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings. (Directive 2010/31/EU p.9)

2.7.2.3 Beyond 2020

The recent published Energy Technology Perspectives 2010 paper from the International Energy Agency (IEA), ' *Energy Technology Perspectives 2010, Scenarios and Strategies to 2050* provides a useful overview of the long term challenges on the pathway to a low-carbon future. While acknowledging that an energy technology revolution is under way through increasing investments in renewable energy and energy efficiency, the authors nevertheless concede that, whilst encouraging, these efforts will prove largely ineffective when set against the trend of unrelenting growth in energy demand and carbon dioxide emissions particularly from across the major developing countries. The difficultly in agreeing internationally binding targets for tackling climate change through the UN Framework Convention process are a stark reminder of the major obstacles that remain to limiting the increase in global temperature.

Most striking of all however is their assertion that the next decade is critical. In short, they argue that if emissions do not peak by 2020 and decline rapidly in the following years, the attainment of the 50% reduction by 2050 will require greater CO2 reductions, more drastic action and higher costs over a much shorter time scale. (IEA, 2010 p.48) Their conclusion is that while an energy technology revolution is within reach, there are significant financing and skills shortage challenges. They argue that the switch to a low-carbon energy future must be rapid and bold decisive action is required by all.

2.7.2.4 ISO 50001:2011

ISO 50001:2001 replaces EN16001 Energy Management Systems is a 'road map' to help organisations improve energy efficiency, reduce greenhouse gas (GHG) emissions and drive down energy costs. It provides a holistic framework for the systematic management of energy, around a *"plan, do, check, act"* format that fits and works other existing standards on environment and quality. ISO 50001:2011 represents the latest best practice in energy management building upon existing national standards and initiatives. The additional benefits are improvement of business performance, it engages top management, complies with necessary legislation, formalises energy policy and objectives, secures energy supply and it flexible and scalable in terms of an organisation size. Once an ISO 50001 certification has been awarded it clearly sets out the scope of an organisations managements system which is valid for three years and therefore regular management checks means that an organisation remains compliant, the standards also requires the organisation to have a metering plan.

Through monitoring and targeting within energy management involves the collection and analysing of data leading to action using a proven methodology, through the implementation of energy awareness and motivation campaign with establishes continual improvement.

Within a primary school environment it is essential to teach energy awareness through the running of the school by involving the student by means of meter reading which incorporates maths to work off the schools energy loads/usages. SEAI have an excellent campaign through "School Energy Workshops"

- Junior Primary "Guzzler" workshop: 'Guzzler' the puppet will teach children about energy efficiency and environmental awareness through participation in a range of games and activities. Suitable for senior infants, 1st and 2nd class pupils.

- Senior Primary "Energy Challenge" workshop: The workshop is an interactive, curriculum based and covers the principals of energy, the current global problems and what we can do to help. Students learn about the science of energy and climate change through participation in experiments and playing the 'energy game'. Suitable for 3rd to 6th class pupils.

In section 4.5.6 "Design" of ISO5001 particular reference towards design and energy.

- The organization shall consider energy performance improvement opportunities and operational control in the design of new, modified and renovated facilities, equipment, systems and processes that can have a significant impact on its energy performance.

- The results of the energy performance evaluation shall be incorporated where appropriate into the specification, design and procurement activities of the relevant project(s).

- The results of the design activity shall be recorded.

Behavioural changes are often a no-cost way of making significant energy savings, even the most energy efficient buildings can experience high utility bills if the occupants area not energy aware and actively seeking to minimise their energy consumption.

Other ways of looking at reducing energy consumption once the building is operation is the maximum import capacity (MIC) which is the level of electricity capacity agreed between the business and ESB Networks. The MIC represents the maximum load that you are contracted to import from the electricity network for use in your premises. An analysis of the MIC and tariff should be carried out to determine a correct value for the buildings requirements in terms of the MIC to avoid exceeding the MIC as the penalties are high. The system can be supported by training and monitoring of usage using the introduction of energy performance indicators (EPI's) on thermal losses in the network, and electricity on the bases of kWh/sq.ft/pa and the installation of energy data loggers for monitoring and targeting system. An energy management diagnostic questionnaire should also be implemented to establish how energy is utilised. Also have an energy consultant to determine that your power factor is set correctly. (see appendix "E" for an example of a energy management diagnostic questionnaire)

More detailed auditing work would also be useful to provide a more accurate assessment of energy flows and potential for savings. This can provide a sound basis for any medium and higher investments. Lighting, as the main user of electricity, would merit special attention. Again this can be supported by information from the M&T system.

A number of alternative heat sources could be feasible including the installation of condensing oil boilers, a wood pellet or wood chip fuelled boilers and solar panels. In order to make good decisions regarding these investments, it is advisable to first implement other efficiency measures to reduce energy "use" i.e.: no – low cost energy efficient savings.

The alternative energy "supply" options can then be evaluated from a better starting point.

2.7.2.5 DART – Design, Awareness, Research and Technology

Since 1997, the Planning and Building Unit within the Department of Education & Skills have been using a process called the DART approach to develop sustainability and energy efficiency in educational buildings. This acronym focuses on four key areas, namely; **D**esign, **A**wareness, **R**esearch and **T**echnology. The policy is informed by the Building Unit Professional and Technical staff, driven by its technical guidance documents and updated by continued energy research and development.

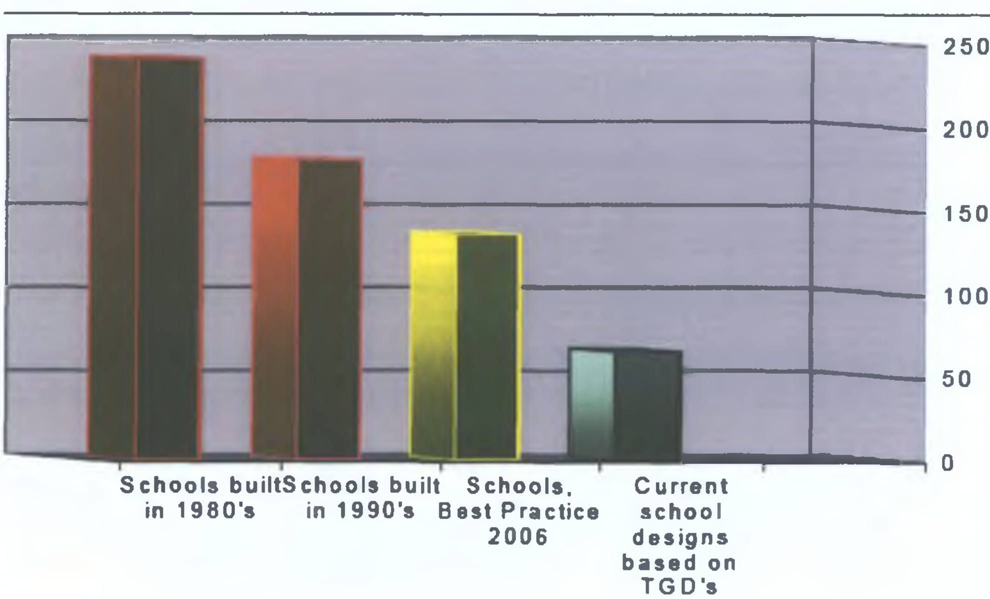


Figure 11: Energy used in Primary Schools kWhr/m2/year.

The current best practice based on schools that are designed and built in accordance with the Departments Schools Technical Guidance Documents must achieve an A3 Building Energy Rating for primary schools and a B1 rating for post primary schools and are capable of being more than twice as energy efficient that schools built to best International Practice. The only way to get above A3 is to have renewable energy on site which is really getting into power generation.

Schools in Ireland by their nature present particular limitations from an energy conservation viewpoint. In energy terms they have relatively short operational hours, do not have building management specialists on site and energy conservation is not a core function of a school. This means that all the heating, lighting, power, water, security and communication systems (known collectively as the building services) used in schools must be robust, reliable and relatively simple and automated.

That is why more emphasises should be focused at the conceptual design stage to maximise the natural resources.

A hybrid approach should be taken with respect to sustainable design in schools based on maximising natural resources and energy efficient technologies. Schools are positioned to maximise gain from the sun during the day for passive solar heating and natural daylight. Passive solar design saves 20 % of early morning heating period and adequate natural daylight when combined with automated lighting systems in the classrooms can eliminate the need for electrical light for up to 80% of the schools teaching hours.

2.7.2.6 BMS

The introduction of a building management system (BMS) interface with a touch-screen technology can allow the pupils, parents, staff and the whole school community to engage with the building and its main eco-friendly technology. Through this process the pupils are being taught about the importance of the environment and the relationship and impact they have in an imaginative but hands on realistic approach. It also promotes and encourages a respect for the natural resources and the volume of water, oil and electricity that can be saved through awareness and familiarity with energy efficient features of the school building. The children being familiar with the features and learning's of energy awareness from the age of 4 years, they will have an understanding of the need for eco-friendly initiatives for the term health of the community and the wider world. Considering the life-long learning children will gain from an energy efficient interactive school building, it raises the question of what kind of homes they will desire to line in or even build in the future.

2.7.2.7 DEC

As of January 1st 2009 all non-domestic buildings being constructed, rented or sold requires a Building Energy Rating Certificate which is based on the building's potential energy performance assuming standard occupancy. Public Buildings are dealt with slightly differently. These buildings require a Display Energy Certificate (DEC) which is based on the operational performance of the building as recorded by meter readings. The DEC displays the school's energy consumption in terms of kWh/m^2. A kWh or kilowatt hour is a measure of energy and m^2 is the size of the building.

The metered performance is then compared to benchmark data for school energy use. This benchmark figure is adjusted for location, hours of use and period of measurement and subsequently converted to primary energy figures. The ratio of the primary energy required by the school to the primary energy required by this benchmark building is the source of the DEC rating. When the school is operational recommendations to employee an SEAI registered energy consultant to prepare a DEC and to have this on display in the reception area of the school.

2.7.2.8 Green schools energy flag

Another incentive to involve the pupils of the school in energy awareness is the green school flag system. Green-Schools, known internationally as Eco-Schools, is an international environmental education programme, environmental management system and award scheme that promotes and acknowledges long-term, whole school action for the environment.

Green-Schools in Ireland is operated and co-ordinate by the Environmental Education Unit of An Taisce (FEE member for Ireland), in partnership with Local Authorities throughout the country, is supported by the Department of Environment, Community and Local Government, the Department of Transport, Tourism and Sport.

Unlike a once-off project, it is a long-term programme that introduces participants (students, teachers, parents and the wider community) to the concept of an environmental management system. However, Green-Schools are far more than just an environmental management system.

According to SEAI over 3,600 primary, secondary and special schools in Ireland (>88% of all Irish schools) are currently participating part in the programme and 2573 schools have been awarded the Green Flag.

2.7.2.9 Energy Management

Energy management is an all-encompassing process that should include every aspect of an organisation from finance, human resources and public relations to maintenance, purchasing and planning.

There is additional information available on energy management from SEAI Energy Map http://www.seai.ie/energymap/

By registering online, you can create your own personalised Energy MAP plan which allows you track your progress through the 20 steps.

When designing primary school buildings attention should be paid to the Department of Education and Science – Mechanical & Electrical Building Services Engineering Guideline for Primary School Buildings, TD002 which outlines the requirements of mechanical & electrical building services with regards to design philosophy, the built environment, heating services, water services and communication services. Within the dissertation there where limitations with regards to the mechanical, electrical and plumbing (MEP) as there were not taken into account in calculation or determining the energy usage of the case study as BIM has a separate aspect with regards to MEP consultants.

2.7.2.9.1 Additional Energy Saving Evaluation on occupied school

The following is a list on potential energy savings available once a school development is operating for a period of time. The design of the school should implement the most energy efficient equipment and products but there are benefits to be had from the following simple list of checks:

- Effective and efficient lighting with appropriate controls (PIR and occupancy sensors, CO_2 sensors) – carry out a lighting survey. In darkness carry out a lighting level survey to ensure that areas are not over lit, avail of the natural lighting
- Brief cleaners to switch off lights when leaving unoccupied areas, behavioral changes are often a no-cost way of making significant energy savings
- Avoid air infiltration through doors and windows, have an IR (Infra Red) thermal imaging survey carried out on the building envelope, i.e.: thermal bridging from poorly constructed joints of the building elements
- Insulate all service pipework, valves, flanges and distribution pipework. Check on an annually bases for blockages, leaks
- Avoid simultaneous heating and cooling i.e.: when the heating is, too hot results in opening windows
- Check on regulate bases the heating zoning (time and temperature) BMS
- Develop, sign and release an energy policy (distribute to all staff members).
- Initiate a energy awareness campaign (involve the pupils – make it fun)
- Form an energy team (staff members and pupils)
- Tender out electricity supplier annually to open market
- Carry out a combustion efficiency test on the boiler annually, compare relationship between degree days (heating days) and fuel consumed. This should highlight any irregular or irrational relationship between heating fuel demand and prevailing weather. Check monthly fuel demand varies in a rational way with changing weather (as recorded in published degree day figures, average day temperatures can be obtained from the local met office)
- Install electricity meter on the main boiler room (Danfoss Infocal 6– Thermal energy calculator)

- Ensure that the boiler water temperature is not too excessive. Regulations on the temperature on hot water taps for primary schools.
- Any vending machines should be fitted with a 7day plug switch timer
- Any hot water boilers (burker boilers) in the staff canteen should be fitted with a 7day plug switch timer

The principal barriers to development, implementing and maintaining a full and effective energy management system at a site is the lack of competent personnel, time management and a lack of energy awareness.

Additional reference material and guidelines are available from:

Carbon Trust – Good Practice Guides:

CTV045-	Introduction to Energy Management
CTG54-	Energy Management
CTV020-	Further and Higher Education
CTV049-	Lighting Technology Overview
CTV032-	Building Control Technology Overview
GIL150-	How to find and repair compressed air leaks
GIL151-	How to Fit Pipework Insulation
CTV008-	Low Temperature Hot Water Boilers Technology
GPG369 -	Energy efficient operating of boilers
GIL126 -	Energy savings fact sheets for lighting
GIL124 -	Energy savings fact sheets for heating

Energy Consumption Guide 54 – energy efficiency in further and higher education; best practice programme.

CIBSE TM:2006 – Energy assessment and report method: which describes a method for assessing the energy performance of an occupied building based on metered energy use and includes a software implementation of the method. Systems assessment against benchmarks for the building systems measured in terms of kWh of annual energy use per m^2 of floor area.

2.8 Building Materials

Materials used in a building's construction have a vital significance on the buildings energy performance. Under section 1.2 Heat Loss and Gain through the Building Fabric Page 16, subsection 1.2.2 Overall Heat Loss Method table 1 illustrates the Maximum average U-value (Um) as a function of building volume (V) and fabric heat-loss area (At) of Department of the Environment 2008 *Technical Guidance Document Ireland "Part L"*.

As illustrated in figure 11 and 12 below (screen shot), BIM has the facility for the designer to build up composite wall types therefore the designer can evaluate the wall makeup for compliance with U-values in accordance with relevant legislation.

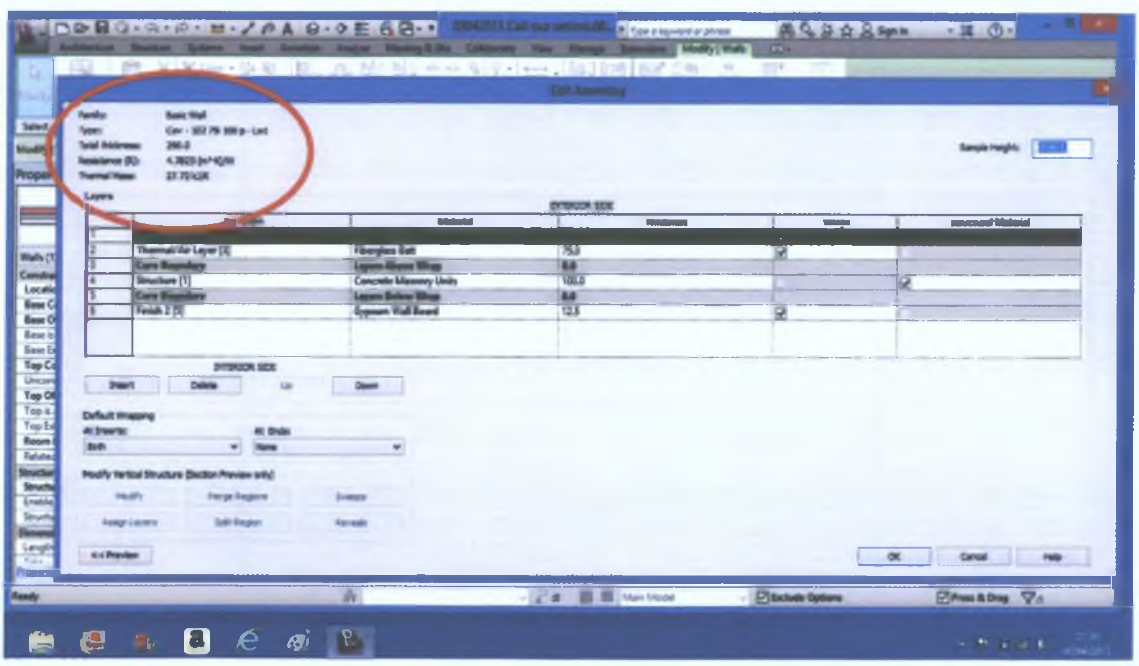


Figure 12: Revit Architecture models can analysis composite wall/floors etc., make-up for compliance (source: authors own desktop screen shot)

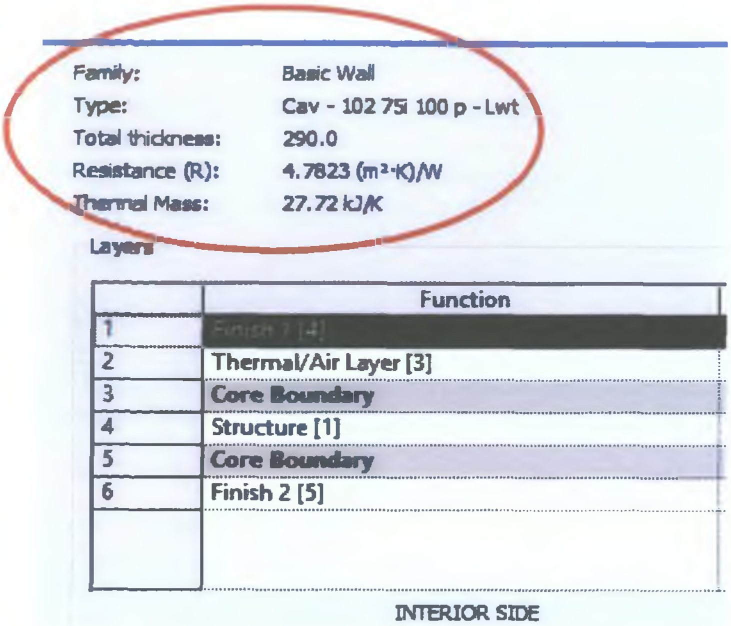


Figure 13: Revit Architecture models can analysis composite wall make-up for compliance – blown up (source: authors own desktop screen shot)

The R-value is known as the thermal resistance of a material is calculated using Equation 1, where C is the conductance, k is the conductivity and x is the thickness of the material.

$$R = \frac{1}{C} = \frac{x}{k}$$ **Equation 1**

$$U = \frac{1}{R} = \frac{\dot{Q}_A}{\Delta T}$$ **Equation 2**

This value is the reciprocal of the heat flow coefficients. The overall heat transfer coefficient (sometimes also known as the U-coefficient), otherwise known as the U-value, represents how well a building material conducts heat. It is calculated using Equation 2 and is an important factor as it depicts how well a building material can retain heat inside the building. The U-value can be defined as the rate of heat transfer through the building material over a given area. The U-value can also be calculated as the inverse of the R-value of the material. If the makeup of a construction takes the form of one or more materials, or air gaps, then the U-value is calculated as the inverse of the summation of the R-values of the construction. In terms of U-values for building constructions, the smaller the U-value, the better the construction is for the thermal performance of the building. Aspects, such as inserting insulation in a wall or roof, will decrease the U-value of the structure.

2.8.1 Heat Gains

Heat gains in the building can affect a buildings performance in terms of energy use and occupancy comfort. Internal heat gain contributions can originate from electrical office equipment, such as photocopiers and computers, or lighting. Occupants can also contribute to internal heat gains.

Solar impact can also produce high heat gains in buildings, especially buildings with lots of glazing within its envelope and in long periods of direct solar radiation. Solar gain refers to the amplification in temperature of a space, structure or object as a result of direct solar radiation. This phenomenon is caused by objects absorbing short wave radiation from the sunlight and emitting long wave radiation back into the building space. When there is a material, such as glass, between an object or space and the sun, high heat gains would be seen. This is because these materials are more transparent to shorter than longer wavelengths resulting in a net gain in temperature. This phenomenon is sometimes more commonly known as 'the greenhouse effect'. Solar gains can result in overheating in a building space and can affect occupancy comfort levels, which can cause reduced productivity levels from the occupants. In addition, it may result in higher energy usage through cooling in a building.

2.8.2 Heat Losses

In every building there are heat losses can occur through a number of areas in a building, there are three methods of heat transfer that can affect energy performance in a building. These are:

- Conduction
- Convection
- Radiation

Conduction is the heat transfer through solid materials from warmer to cooler particles (Egan D., M, 1975, p.p 16-34).

Convection is the heat transfer in air by the motion of heated air from a warmer to cooler surface.

The final type of heat loss that can occur is radiative heat losses. The term radiation describes the heat transfer by electromagnetic waves from a warm to a cool surface.

2.8.3 Heating System Efficiencies

When looking at heat losses a large proportion can occur from inadequate management of the heating system. Heat is transferred to the building space from radiators properly, and the system is not using unnecessary energy pumping and heating water. Therefore, it is important, if possible, to optimise the flow rate in the pipes to make heating more efficient in a building.

2.8.4 Ventilation and Air Conditioning Systems

Ventilation is also an important aspect in a building as it reduces the risk of build up of condensation and pollutants in a building space by controlling the air quality and conditions the air so that it is not too dry or humid. This could also affect thermal performance of the building as well as occupancy comfort which could manifest itself as 'sick building syndrome' (Au Yeung et al. 1991). Without ventilation, a building increases its chances of suffering mould and dampness, mould spores can affect sensitive atopic individuals and can lead to asthma rhinitis, conjunctivitis and eczema (Trotman & Building Research Establishment (BRE), 2004).

A good balance in terms of the ventilation flow rates into a building is essential. A system pulling in large amounts of outside air, especially if it is cold, into the building space results in cooling heated spaces. This would then lead to the building space requiring additional heating loads on the system. Pre-heating the outside air, with a heat recovery system, or reusing an amount of re-circulated air from the building space can reduce this effect.

2.9 Post Occupancy Evaluation

When trying to create a building as energy efficient as possible, it is also important to ensure that the occupants using the space are comfortable. Occupant comfort is significant as the comfort will directly affect the productivity of the occupants. It also gives an insight into understanding a buildings energy performance through the occupant's eyes. It is also used to identify if the changes affect the health of the occupants which could lead to 'Sick Building Syndrome'. If there is poor circulation there may be build up of CO_2 in the space or mould growths in the building space. This could affect the occupants with symptoms such as irritation of the skin, in the eyes, nose and throat which could lead to long term health problems (Au Yeung et al., 1991).

It is therefore important to carry out a Post Occupancy Evaluation (POE) on the occupants to assess the comfort levels in the building. These comfort levels could be associated with thermal, lighting or air quality issues. POE was developed in the United States in the 1960s and has been used in one form or another ever since. Post Occupancy Evaluation is defined as;

> "The process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time" (Preiser 1988, p.p 189-193).

A POE usually consists of a questionnaire which the occupants of the building fill out. The results of the questionnaire will show how comfortable the building occupants are. As well as this, it can also show the occupants behaviour and understanding of the function of a BEMS. In addition to a questionnaire, it is also useful to go around the building and visually inspect it to see if there are obvious signs that can affect thermal comfort.

2.9.1 Analysing a Design in the Context of BIM

Revit-based design models can be exported to gbXML format and imported directly into Autodesk Ecotect Analysis for simulation and analysis throughout the design process. At the onset of the design process, very early stage Autodesk Revit Architecture massing models can be used in combination with site analysis functionality in Autodesk Ecotect Analysis to help determine the optimal location, shape, and orientation of a building design—based on fundamental environmental factors such as daylight, overshadowing, solar access, and visual impact (Autodesk, 2009).

As the conceptual design evolves, whole-building energy, water and carbon analysis can be conducted using the integrated access to Autodesk Green Building Studio in order to benchmark its energy use and recommend areas of potential savings. Once these fundamental design parameters have been established, Autodesk Ecotect Analysis can be used again to rearrange rooms and zones, to size and shape individual apertures, to design custom shading devices, or to choose specific materials—based on environmental factors such as daylight availability, glare protection, outside views, acoustic comfort and visibility analysis ass illustrated in figure 13 below.

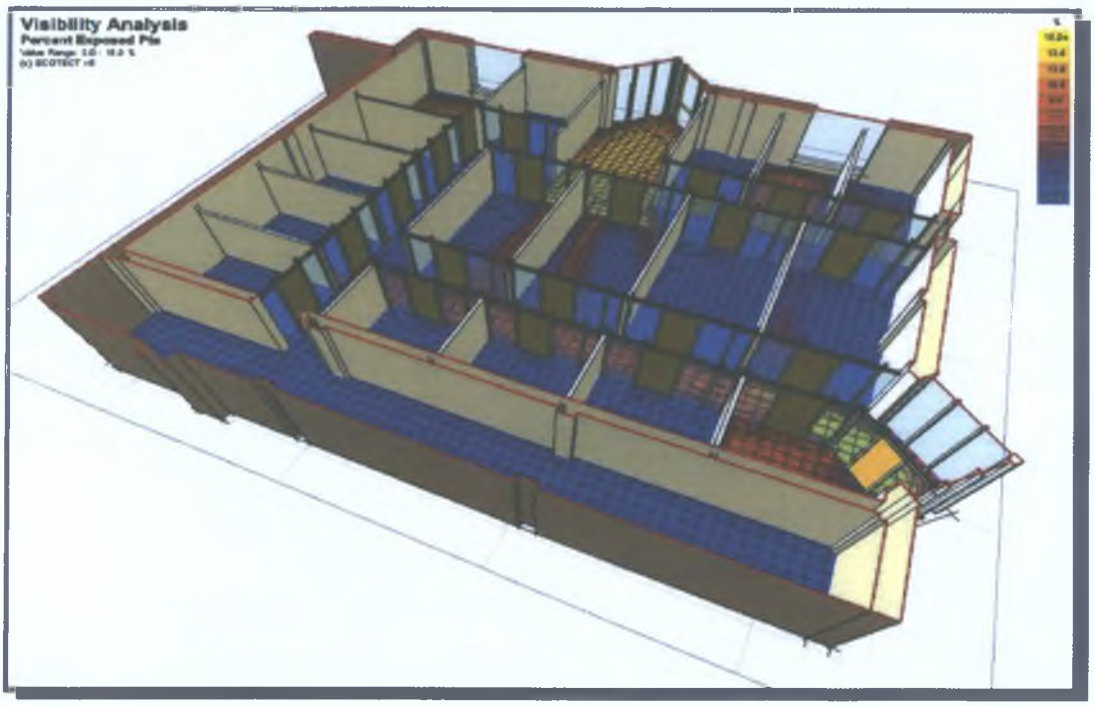


Figure 14: Autodesk Ecotect Analysis can also be used for detailed design analysis. For example, "*the visibility analysis displayed here shows the amount and quality of views to the outside mapped over the floor area of an office*".

Perhaps the most unique aspect of the software is its visual and interactive display of the analysis results. The inability of the designer to easily interpret the results of analyses is often the biggest failing of building performance analysis software. Autodesk Ecotect Analysis provides actionable feedback to the designer in the form of text-based reports as well as visual displays. These visual displays are more than just charts and graphs. The analysis results are presented directly within the context of the model display: shadow animations resulting from shadow casting analysis; surface mapped information such as incident solar radiation; and spatial volumetric rendering such as daylight or thermal comfort distribution in a room. This type of visual feedback lets the designer more easily understand and interact with analysis data, often in real time. For instance, a designer can rotate a view of surface mapped solar radiation looking for variations over each facade or watch an animated sequence of solar rays to see how sunlight interacts with a specially designed light shelf at different times of the year, as illustrated in figures 14 and 15 below.

Figure 15: Using Autodesk Ecotect Analysis, architects can see the results of their analysis displayed in the context of a building model, such as the *surface-mapped results of this solar radiation analysis.*

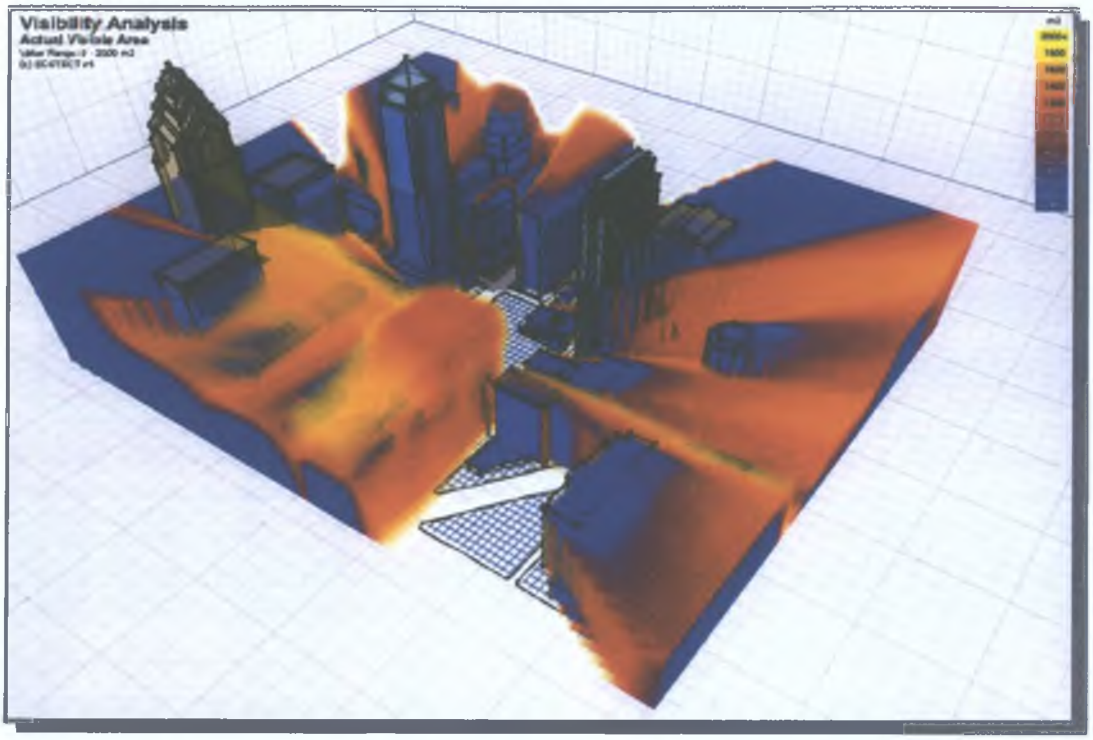


Figure 16: Autodesk Ecotect Analysis software also displays analysis results using spatial volumetric renderings, such as this analysis of the *visual impact of a building within an urban site.*

During conceptual design, Autodesk Ecotect Analysis and the Autodesk Revit Architecture model can be used for a variety of early analysis. For example, the designer can perform overshadowing, solar access, and wind-flow analyses to iterate on a form, and orientation that maximizes building performance without impinging on the rights-to-light of neighbouring structures. As the design progresses and the elements that define a building's thermal zones are established (the layout of the walls, windows, roofs, floors, and interior partitions), the Revit model can be used for room-based calculations such as average daylight factors, reverberation times, and portions of the floor area with direct views outside.

Eventually the Revit model can be used for more detailed analysis—such as shading, lighting, and acoustic analysis. For example, the designer can use Autodesk Ecotect Analysis in conjunction with a shading louver design modelled in Autodesk Revit Architecture to simulate how the design will work under different conditions throughout the year. Or the architect can use Autodesk Ecotect Analysis to help assess the acoustic comfort of a Revit-based design, and then adjust the location of a sound source or adjust the internal wall layout or the geometry of sound reflectors for optimal comfort (Autodesk, 2009) Another major player in the role of BIM software is Bentley

Figure 17: Bentley, screen shot of the modelling environment "ProjectWise" (source: Bentley, 2010)

As illustrated in figure 16 above, Bentley provides software and services uniquely suited for IPD projects—enabled by fully integrated, interoperable, multidisciplinary BIM applications to empower architects, structural, civil, electrical, and mechanical engineers, energy assessors, site designers, and other professionals to design, analyze, construct, and manage facilities of all types and scales.

Each discipline-specific application provides an informed work environment to support the design and documentation process throughout all phases of the project lifecycle—from conceptual design and construction documentation to coordination and construction.

2.9.2 BIM and the Autodesk Green Building Studio

Since buildings account for 70% of electricity consumption and 39% of greenhouse-gas emissions, it's clear that reducing the carbon footprint of the built environment is critical to improving our environment. The 2030 challenge of Carbon-neutral in 2030 (using no fossil fuel GHG emitting energy to operate) and the rise of LEED and other green building certification systems are visible examples of the building industry's commitment to sustainable design. The ability to perform whole building energy, water, and carbon emission analyses early in the design process is essential for sustainable building design. The Autodesk Green Building Studio service allows architects to more easily evaluate the carbon footprint of a building design using the Green Building Studio plug-in for Revit as part of the BIM workflow (Architecture 2030, 2011).

2.9.3 Green Building Studio Energy Analysis and incorporation with Building Modelling

Energy analysis requires spatial information, it is essentially a simulation of energy movement in, out, and through the building. Which walls are exposed to the outside? How many are exposed to sunlight? What are the number, size, and orientation of openings? How much heat is generated by internal lighting and equipment? In the past, this information was manually calculated from 2D drawings. An engineer would use building plans, elevations, and details to collate spaces (type, area, volume), surfaces (including adjacency and thermal properties), and shading. All this information is latent in a Revit model, and in a form that is much easier to interpret than 2D drawings. And, if the project is consistently structured, software such as Green Building Studio can help take the pain out of the process.

The net result is that a time-intensive task that might only be done once, very late in the design process, can realistically be repeated on demand innumerable times. This is a very important contribution to the design process at a stage when change is still possible. There are some crucial things to note and chief among them is how to go about modelling a building in the BIM tool.

2.10 Building Information Modelling (BIM) Network

UK Government mandate:

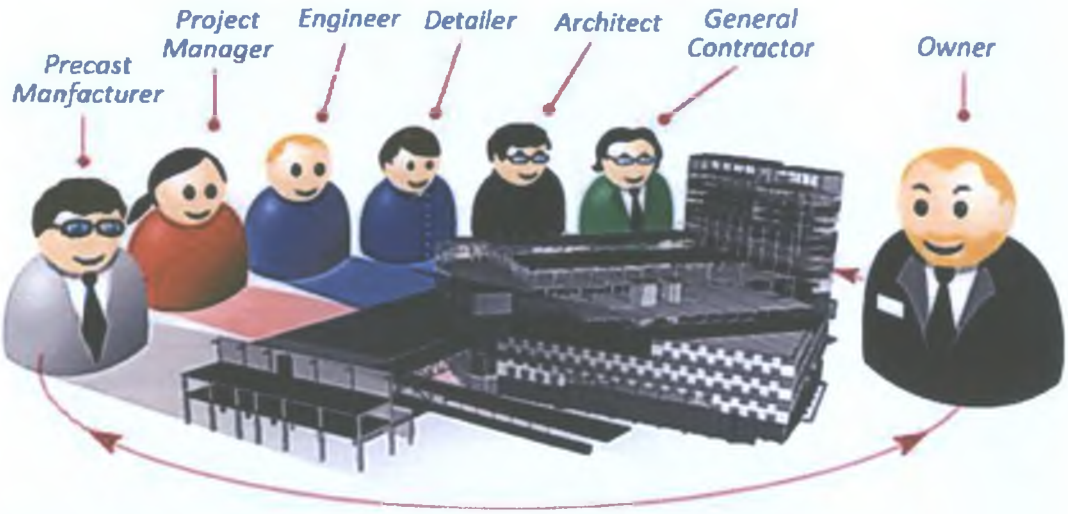


Diagram 1: Typical collaboration process; (source: Construsoft – Telka)

It appears that BIM is receiving a great deal of attention in the technical press, and in the development of public sector procurement strategy. Various other client groups are becoming more aware of the potential that BIM has to offer, and are requiring it to be used on their projects, therefore it appears that client/stakeholders are one of the main driving forces behind the adoption of BIM. This all means that BIM is being more widely specified. The technology issues with developing and integrating different models for a project, successful implementation of BIM also requires a greater willingness to work collaboratively.

Buildings account for significant carbon dioxide emissions, both in construction and operation and as a result governments around the world are setting targets and legislating to reduce the carbon emissions related to the built environment. Challenges presented by increasingly rigorous standards for construction projects will mean a paradigm shift in how new buildings are designed and managed.

This will lead to the need for computational modelling and visualization of buildings and their energy performance throughout the life-cycle of the building. Many governments are planning to reduce carbon emissions for new buildings, alongside many challenges faced by the architectural, construction and building management professions in adjusting to the proposed requirements for low or zero carbon buildings.

2.11 BIM Maturity Levels

To help with the implementation/protocol of BIM a maturity model has been devised to ensure clear articulation of the levels of competence expected and the supporting standards and guidance notes (not shown in this diagram), their relationship to each other and how they can be applied to projects and contracts in industry.

The purpose of defining the Levels from 0 – 3 is to categorise types of technical and collaborative working to enable a concise description and understanding of the processes, tools and techniques to be used. In essence, it is an attempt to take the ambiguity out of the term 'BIM' make specifying for it clear and transparent to the supply-chain and enable the client to understand precisely what is offered by the supply-chain.

The production of this maturity index recognises that differing construction client and their supply organisations are currently at different level of experience with their approaches to BIM and serves as a structured 'learning' progression over a period of time.

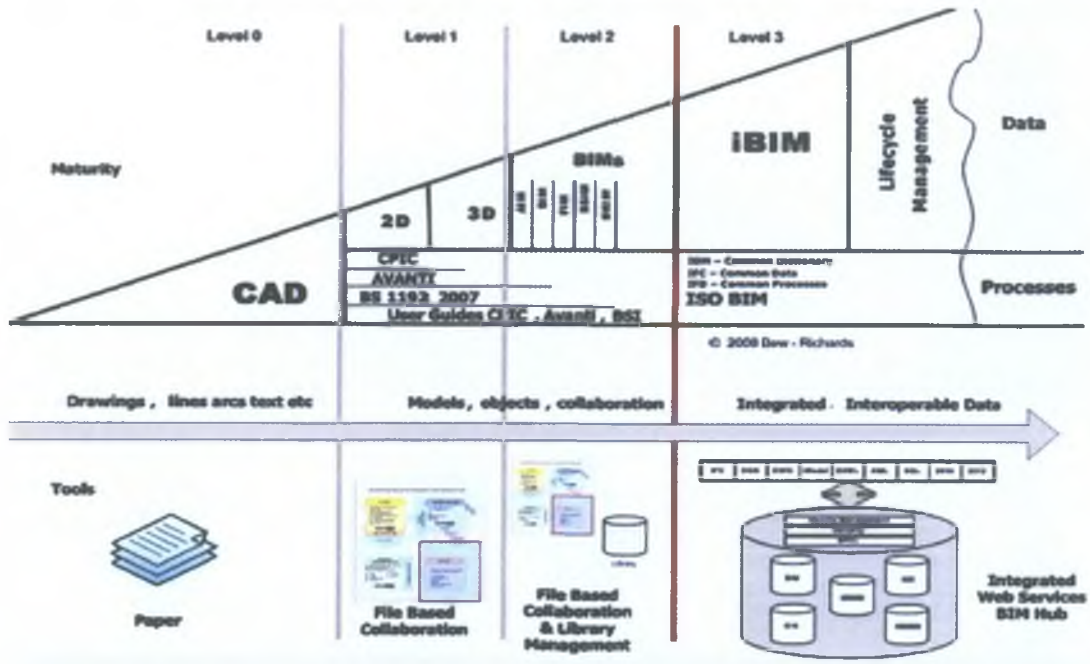


Figure 18: New-Richards UK Government BIM Working Party Strategy Paper, BIM Maturity levels, 2011, p.16.

2.11.1 Level Definitions

0. Unmanaged CAD probably 2D, white paper (or electronic paper) as the most likely data exchange mechanism.

1. Managed CAD in 2 or 3D format using BS11992:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration.

2. Managed 3D environment held in separate discipline "BIM" tools with attached data. Commercial data managed by an event related potential (ERP). Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as "pBIM" (proprietary). The approach may utilise 4D programme data and 5D cost elements as well as feed operational systems.

3. Fully open process and data integration enabled by 'web services' compliant with the emerging Industry Foundation Classes (IFC / IFD standards, managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes. (UK Cabinet Office (2011) Government Construction Strategy).

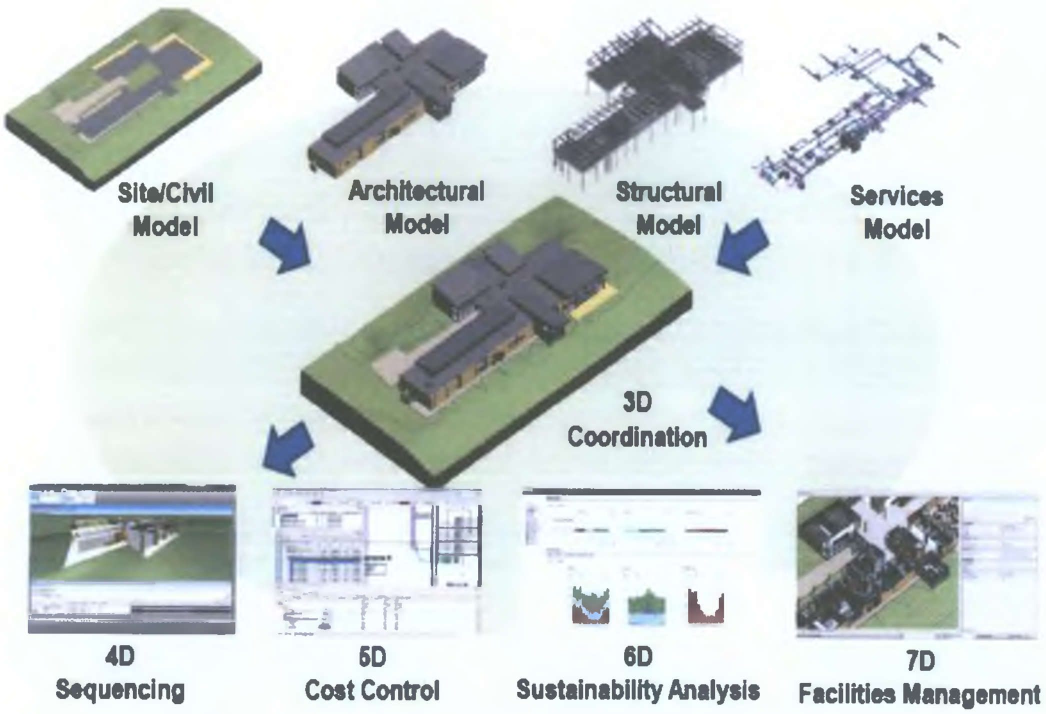


Figure 19: BIM Model Example; (Source: CITA BIM Group (2012) - BIM Presentation to GCCC p.12)

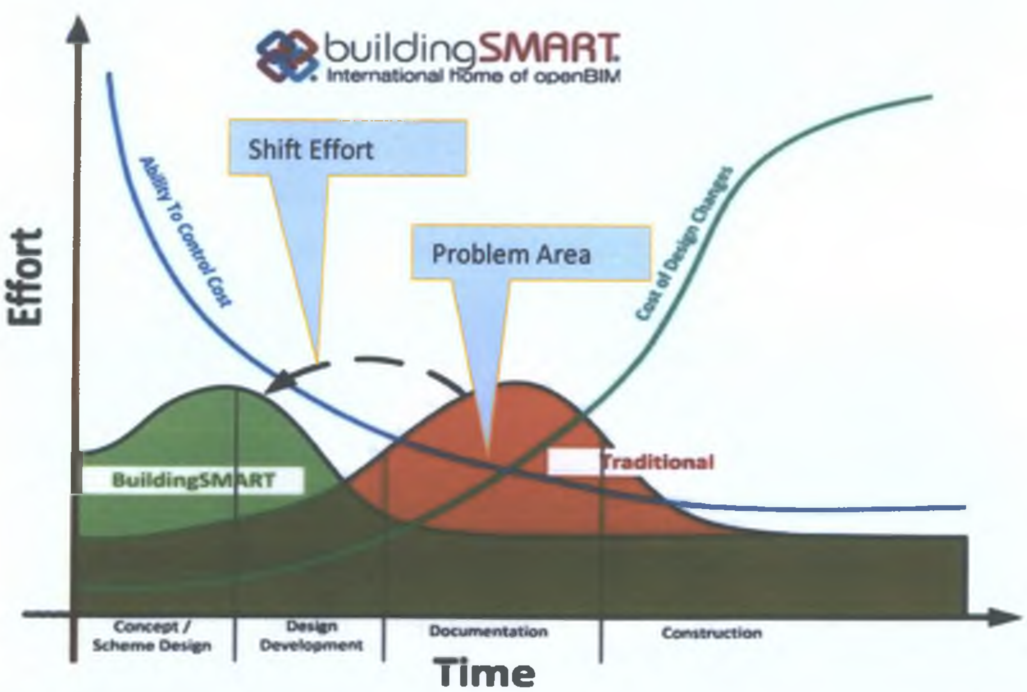


Figure 20: Benefits of BIM "*MacLeamy Curve*" (2012) MacLeamy, P.,*CEO, Hellmuth-Obata-Kassebaum).*

Figure 19 above; illustrates the cost of decisions mapped along the timeline of a typical construction project. It clearly shows that decisions made early in a project (during design) can be made at lower cost and with greater effectiveness. A reasonable inference to draw from this graph is in fact the idea that projects will benefit by having more diverse expertise (i.e., more interested parties) in the room during design, so that value engineering decisions, especially ones that affect the life cycle costs of the project, can be moved forward in time, when decisions are relatively inexpensive.

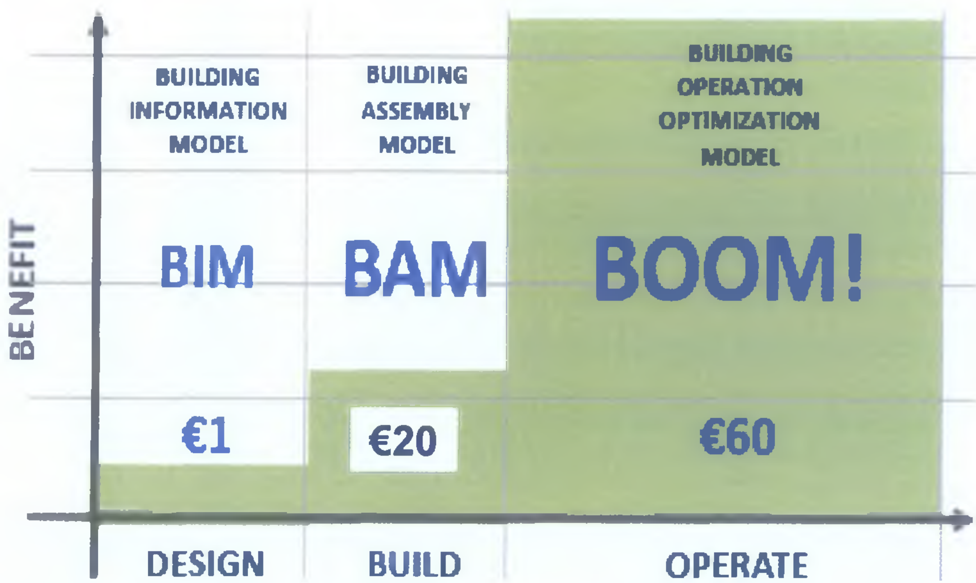


Figure 21: BIM, BAM, BOOM (2010) MacLeamy, P., *CEO, HOK)*

According to MacLeamy (2010) figure 20 above illustrates that it's more beneficial financially to design right and spend more time on the concept and in the collaboration process, Cost over time of a building designed, built and operated using BIM tools. For every €1 spent in design, €20 is spent in construction and €60 dollar is spent in operating the building over its useful life over 50 years or more. BIM promotes BAM (building assembly management) used by contractors (he believes and architect and building team working together on a BIM and BAM to design the building can save 30% of the construction costs). During the buildings life time the building owner can bridge BIM and BAM to optimise building operation i.e.: BOOM (the building operation optimisation model). BOOM helps the owner to manage energy consumption and scheduled maintenance, since BOOM is managing 60 times the percentage of design the cost savings potential is enormous.

2.12 BIM UK Government Construction Client Group

Building Information Modelling (BIM) Working Party Strategy Paper and HM Government "Low Carbon Construction"

Figure 22: BIM Government Construction Client Group (2011), Low Carbon Construction (2010) and Government Construction Strategy (2011).

Paul Morrell (Chief construction adviser UK Government) "Working Party Strategy Paper" which is promoting major stimulus in encouraging the public sector client down the BIM route with the use of COBie, which is 'a vehicle for sharing predominantly nongraphic data about a facility'. COBie is a non-proprietary format based on a multiple page spreadsheet. According to (Morrell, 2011) the UK Government is implementing BIM on a Level 2 basis by 2016 on all government/public contracts.

2.12.1 What is COBie?

According to William, E, E., (2012) Construction Operations Building information exchange (COBie) is a means of sharing, predominantly non-graphical, data about a facility. It was developed in America and will need to be adapted for use in the UK / Ireland and in infrastructure. COBie is a non-proprietary format based on a spreadsheet so it can be managed by organisations of any size at any level of IT capability but can be linked to other systems and software.

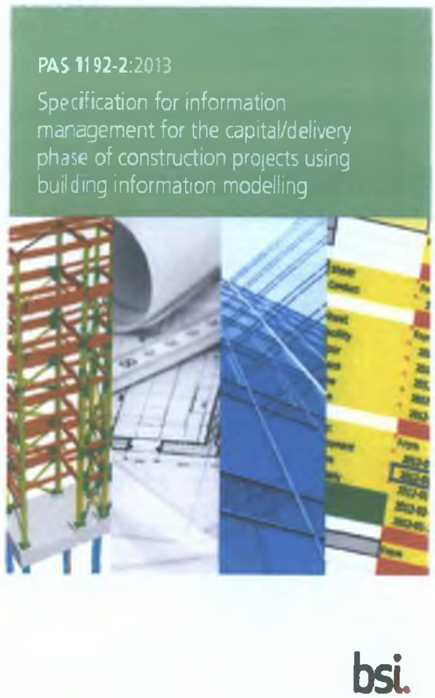
COBie transfers information to owner/occupier to manage their assets efficiently. It documents the asset in 16 linked spreadsheets.

COBie will be adopted as the standard means of reporting data from a BIM model. Reporting at specific stages is referred to as a 'COBie data drop'.

2.13 BIM Legislation/Protocol

The BIM Execution Plan is managed by the BIM Coordinator one per project, BIM Manager one per BIM Stakeholder who interfaces with the BIM Coordinator, a Level of Development (LOD) has to be agreed and both have to follow data exchange protocols PAS 1192-2-2013 (2013)was published February 2013, see figure 22 below.

BIM overlay RIAI Work Stages in progress – adopting elements of CIC Scope of Services and BIM Overlay to the RIBA Plan of Work.



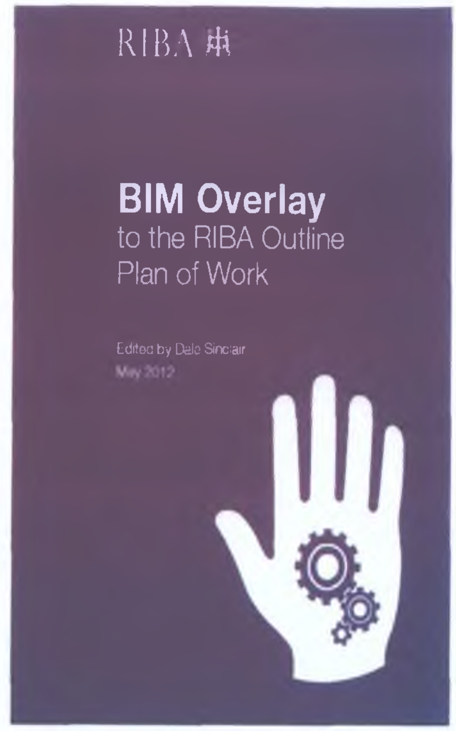


Figure 23: PAS 1192-2-2013 "Specification for information management for capital/delivery phase of construction projects using building information, BSi. (2013) and RIBA BIM Overlay to the RIBA Outline Plan of Work, Sinclair, D. (2012)

When will the new BIM policy kick in?

As reported by BIM Task Group, there will be a phased rollout over five-years beginning next summer, with a view to getting all appropriate projects into a 3D collaborative environment by 2016. The Summary Action Plan attached to the Government Construction Strategy contains a detailed implementation plan for Building Information Modeling (BIM), which will be announced within the next few weeks.

"Government as a client can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information"

The UK Government Strategy is setting requirements for COBie, fully collaborative 3D BIM by 2016 and Government will action take that will reduce costs by up to 20% by the end of this parliament. In doing so the UK Government has set up a BIM Task Group – opening statement:

> "The report announced the Governments intention to require: collaborative 3D BIM (with all project and asset information, documentation and data being electronic) on its projects by 2016.
>
> Essentially the UK Government has embarked with industry on a four year programme for sector modernisation with the key objective of: reducing capital cost and the carbon burden from the construction and operation of the built environment by 20%".

Given the tendency of the Irish Government to base much of construction legislation on that which is in the United Kingdom, it may only be a matter of time before similar provisions are made here.

Firstly the Irish Government needs to establish a BIM implementation plan or a set of protocols similar to AEC UK and PAS 1192-2 (2013) as adopted by the UK Government.

2.14 BIM benefits for facility management

While BIM has proven its value in design and construction for five years or more, the necessary technologies for using BIM in facility management only now are emerging (FMLink, n.d). A large number of new building projects have been designed and built with BIM software, however there is a tremendous opportunity to leverage this wealth of information and greatly improve the practice of facility management.

2.14.1 BIM for owners and facility managers

Owners can realise significant benefits on projects by using BIM processes and tools to streamline the delivery of higher quality and better performing buildings. BIM facilities collaboration between project participants, reducing errors and field changes and leading to a more efficient and reliable delivery process that reduces the project time and cost. Owners can use a building information model to:

- Increase building value
- Shorten project schedule
- Obtain reliable and accurate cost estimates
- Assure program compliance
- Produce market-ready facilities
- Optimise facility management and maintenance (Eastman et al, 2011)

2.14.2 Preventive Maintenance

Information in relation to building mechanical equipment that can be stored in BIM models is valuable in creating the database needed for ongoing preventive maintenance. Equipment that requires regular inspection and upkeep, particularly heating, ventilation and air conditioning equipment and life safety systems, are of particular significance. Additionally, information about air and electrical distribution systems that undergo periodic modification is valuable to facility managers.

2.14.3 Benefits of BIM for Facility Management

The following are some of the benefit available to facility managers with incorporating the use of BIM:

- **Improved space management**
  By understanding the details of how space is used, facility professionals can reduce vacancy and ultimately achieve major reductions in real estate expenses. The room and area information in BIM models are the foundation for good space management.

- **Streamlined maintenance**
  The key challenge in developing a maintenance program is entering the product and asset information required for preventive maintenance. The Information about building equipment stored in BIM models can eliminate months of effort to accurately populate maintenance systems.

- **Efficient use of energy**
  BIM can help facilitate the analysis and comparisons of various energy alternatives to help facility managers dramatically reduce environmental impacts and operating costs.

- **Economical retrofits and renovations**
  A "living" BIM model provides an easier means of representing three-dimensional aspects of the building. Better information about existing conditions reduces the cost and complexity of building renovation and retrofit projects.

- **Enhanced lifecycle management**
  Some building design professionals are embedding data on life expectancy and replacement costs in BIM models, thereby helping an owner understand benefits of investing in materials and systems that may cost more initially but have a better payback over the life of the building.

2.15 The Situation Today within the Irish AEC industry

BIM adoption and implementation are no longer the main challenge for most firms who are currently grappling with, as they were a few years back. Although there is a lack of usage of BIM in the Irish AEC industry, a survey carried out by the RIAI indicated that only 16% of architects are currently incorporating BIM. In today's AEC industry, the challenge is the social implications of the technology and associated work processes on firm culture and workflow brought about by implementing BIM, "the fear of change".

2.15.1 The Irish Construction Industry in 2012

As cited by (McAuley, 2012) conference paper, at the current point in time, the Irish construction industry is facing one of its most uncertain and challenging periods and will possibly see more major cuts in all areas of the economy in 2013. Despite this, Ireland pushes forward with sustainability initiatives with the Government ruling that environmentally-friendly policies are to get priority in competing for State contracts worth up to €16 billion a year (Gromley, 2010). These and further initiatives are in place, so as to reduce greenhouse gas emissions by up to 20% by the year 2020. It has been established that by the end of 2018 the public sector must own or rent only buildings with high energy-saving standards and promote the conversion of existing buildings to "nearly zero" standards. (McAuley, 2012).

Furthermore, the "retro-fitting" of Ireland's existing building stock will challenge Ireland to meet carbon targets and if there are any skilled workmanship in this area. The draft Building Control Regulation 2013 (S.I. No. 80 of 2013) due to be enforced on 1st March 2014 will require a more stringent process of construction with the isle of Ireland. And to this effect BIM has the potential to be utilised on future and present public works projects in Ireland to significantly assist the Irish Government in managing a low carbon energy future. Focus is on the application of a sophisticated BIM model in helping to predict the performance of buildings or assess retrofit/upgrade options in managing low carbon construction. Construction IT Alliance (CITA) carried out a four day workshop in late 2011, the author's data collation methodology involved the testing and analysis of a BIM model for a public works project. The workshop proved a success and provided the platform for the Irish Government to see at first-hand, how a collaborative BIM model can be used on public works projects to provide a low carbon future for both future and existing building stock. (McAuley, 2012)

A report compiled by DKM Economic Consultants (2012) for the Society of Chartered Surveyors Ireland, entitled "The Irish Construction Industry in 2012" provided a detailed analysis on the current state of the construction industry in Ireland and provided a preliminary assessment for 2013. It has estimated that construction output will amount to just €7.5 billion in 2012, having peaked at close to €39 billion or almost 25% of GNP in 2006. The total number of persons employed by the sector is around 150,000, which includes indirect employment i.e. those companies supplying the construction sector. The last time total employment was around 150,000 was in 1997

Despite this, Ireland pushes forward in sustainability initiatives with the Government ruling that environmentally friendly policies are to get priority in competing for State contracts worth up to €16 billion a year (Climate Change Response Bill 2010, Bill no. 60 of 2010)

Furthermore, the Government also announced details in 2012 of a €1.5 billion programme to provide new schools and extend existing schools across the country. These initiatives are to be complemented by the Capital Works Management Framework (CWMF) which was introduced by the Department of Finance (2007). The CWMF is a series of documents which collectively describe the operating environment, procedures and processes to be followed for the delivery of capital works projects. The aim of the CWMF is to ensure that there is an integrated methodology and a consistent approach to the planning, management and delivery of public capital works projects, with the objectives of greater cost certainty, better value for money and more efficient project delivery. Within the CWMF the Irish government has published a new suite of public sector contracts, where there is a plan to bring Ireland in line with the Energy Performance of Buildings Directive (EPBD).

The EPBD ensures that Ireland meets strict EU regulations set by the European Parliament since 19th May 2010 and to avoid crippling fines which could prove detrimental to an already faltering economy.

This directive requires that:

- All buildings built after 31 December 2020 must have high energy-saving standards and powered to a large extent by renewable energy.
- By the end of 2018 the public sector must own or rent only buildings with high energy- standards and promote the conversion of existing buildings to "nearly zero" standards.

As reported by The Economist (2000, cited in Arcdox, 2010) stated that the total cost of construction includes waste of 30%, representing a forecasted cost of €3 billion in Ireland in 2011. The use of BIM and (Integrated Project Delivery) IPD can lower this level of waste and reduce the economic strain which is currently being placed on the construction industry.

2.16 The External Environment

Introduction

Climate policy in Ireland has developed in the context of national and EU commitment to the 1992 United Nations Framework Convention on Climate Change (UNFCCC). Article 2 (p.3) of the Convention sets out the fundamental objective of stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system. It further states that such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. The main drivers towards a sustainable future have been the Kyoto protocol 1997 (where Ireland was committed to reducing greenhouse gas emissions to 13% of 1990 levels) and Copenhagen in 2009 and the Kyoto Protocol extension (2013-2020) in Doha, Qatar (not effective yet). Other main drivers for Ireland include the carbon tax, tax incentives for using energy efficient equipment and the National Energy Efficiency Action Plan (NEEAP) 2009-2020. As reported in this Government policy document, are the Government's plans and actions to achieve its target of 20% energy efficiency savings across the economy in 2020.

The second Action Plan NEEAP-2 (2013) provides a progress report on delivery of the national energy savings targets implemented under current EU requirements as well as energy efficiency policy priorities between now and 2020. The second Action Plan reaffirms Ireland's commitment to a 20% energy savings target in 2020. Recognising that Government must lead by example, the Government is committed to achieving a 33% reduction in public sector energy use.

2.16.1 Kyoto and Ireland

Ireland is a party to the UN Framework Convention on Climate Change and has ratified the 1997 Kyoto Protocol. Ireland joined the European Union in 1973 and accepts the supremacy of EU law in the case of a conflict between community and national law. Irish climate change policy is primarily driven by European law and policy.

Figure 23 on the following page displays a breakdown of GHG emissions for 2009. According to the *EPA* (2009), the Industrial and Commercial sector (17.9%) is the fourth biggest producer of GHG emissions in Ireland. According to the Environmental Protection Agency *(EPA) Irelands Green House Gas Emissions Projection 2011-2020* document published on the April 16th 2012, the projections indicate a total 'distance to target' for the Kyoto Protocol period of 4.1 – 5.1 Mtonnes of CO2eq. This compares to a total 'distance to target' of 6.3 – 8.1 Mtonnes of CO2eq in the April 2011 projections.

The projections indicate that total non-ETS emissions will be 4.1 – 7.8 Mtonnes of CO2eq above the 2020 target. This compares to a projection of 4.1 – 8.8 Mtonnes of CO2eq above the 2020 target in the April 2011 projections. In addition, the projections indicate that Ireland will exceed its binding annual limit in 2015-2017 and will exceed our obligations over the 2013-2020 periods by 1.9-20.6 Mtonnes of CO2eq.

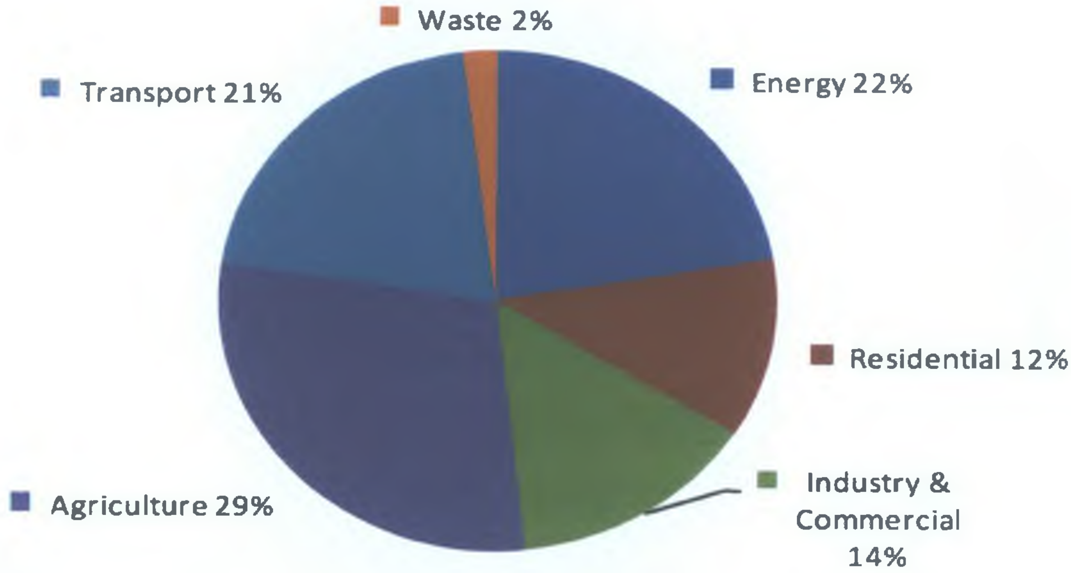


Figure 24: Projected sectoral share of total greenhouse gas emissions over the period 2008 – 2012 for the With Measures and With Additional Measures scenarios (Source: EPA 2011 p.17)

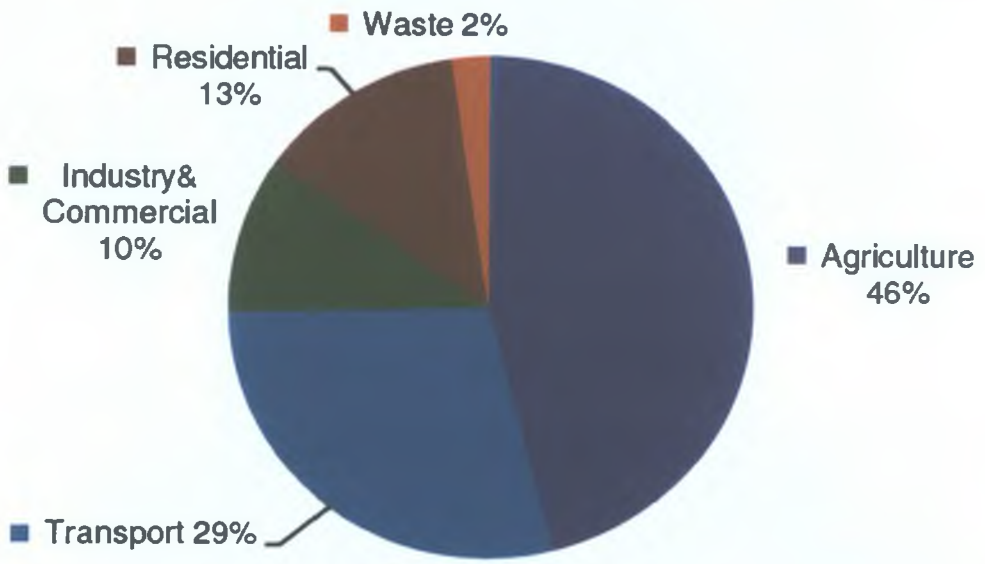


Figure 25: Projected sectoral share of non-ETS greenhouse gas emissions in 2020 for the With Additional Measures scenario (Source: EPA 2012 p.17)

2.16.2 Irish Government Commitment

Ireland will reach its Kyoto commitment but this is largely due to the economic downturn and buying credits from other countries who have reached their targets. The Kyoto protocol provides several flexible mechanisms which enable Annex I countries (Industrialised countries) to meet their GHG emission targets. This can be done by acquiring GHG emission reductions credits. Credits are acquired by an Annex I country financing projects that reduce emissions in non-Annex I countries or other Annex I countries who have excess credits. The flexible mechanisms are emissions trading, the clean development mechanism and joint implementation.

According to Legge and Scott (2009) report "*Policy Options to Reduce Irelands Greenhouse Gas Emissions*" mentioning that a side effect of our economic recession since 2008, is that Ireland may meet its required Kyoto commitment for 2008-2012 to reduce its GHG emissions, but that the long term targets for 2020 and beyond remain stringent. This is good news in one sense that not everything regarding the recession is bad news. This can help Ireland in a big way by;

- Saving the economy money by not having to buy credits from other countries to meet our targets.
- A reduction in GHG emissions throughout this recession will help meet our targets.

Chapter 3

Research Methodology

3.0 Introduction

This chapter will discuss the research methodology used by the author in order to fulfill the fundamental objectives set out in this dissertation. This chapter also outlines the research design and the techniques that were utilised for the purpose of meeting the aim of this dissertation. The rationale for the research method is as follows:

A definition of research according to The Concise Oxford Dictionary is

> *"the systematic investigation into and study of materials, sources, etc.., in order to establish facts and reach new conclusions"* (Oxford Dictionary, 1991, p. 1022)

> *"Research Methodology will not only aid the writer in identifying and describing the various activities, but should also help the proposal reader to understand the continuity of the various activities"*. (Wiersma, 2009, p.22)

This chapter focuses on the research strategy, methods of data collection, the limitations of the research methods and ethical considerations.

According to Creswell (2009) there are three types of research strategies used overall in the research (e.g. quantitative experiments, qualitative case studies and mixed method research methods).

The type of research to satisfy the dissertation objectives that has been adopted is the quantitative research method.

According to Creswell (2009), quantitative research is a means for testing objective theories by examining the relationship between variables. These variables in turn can be measured, typically on instruments, so that numbered data can be analysed using statistical procedures.

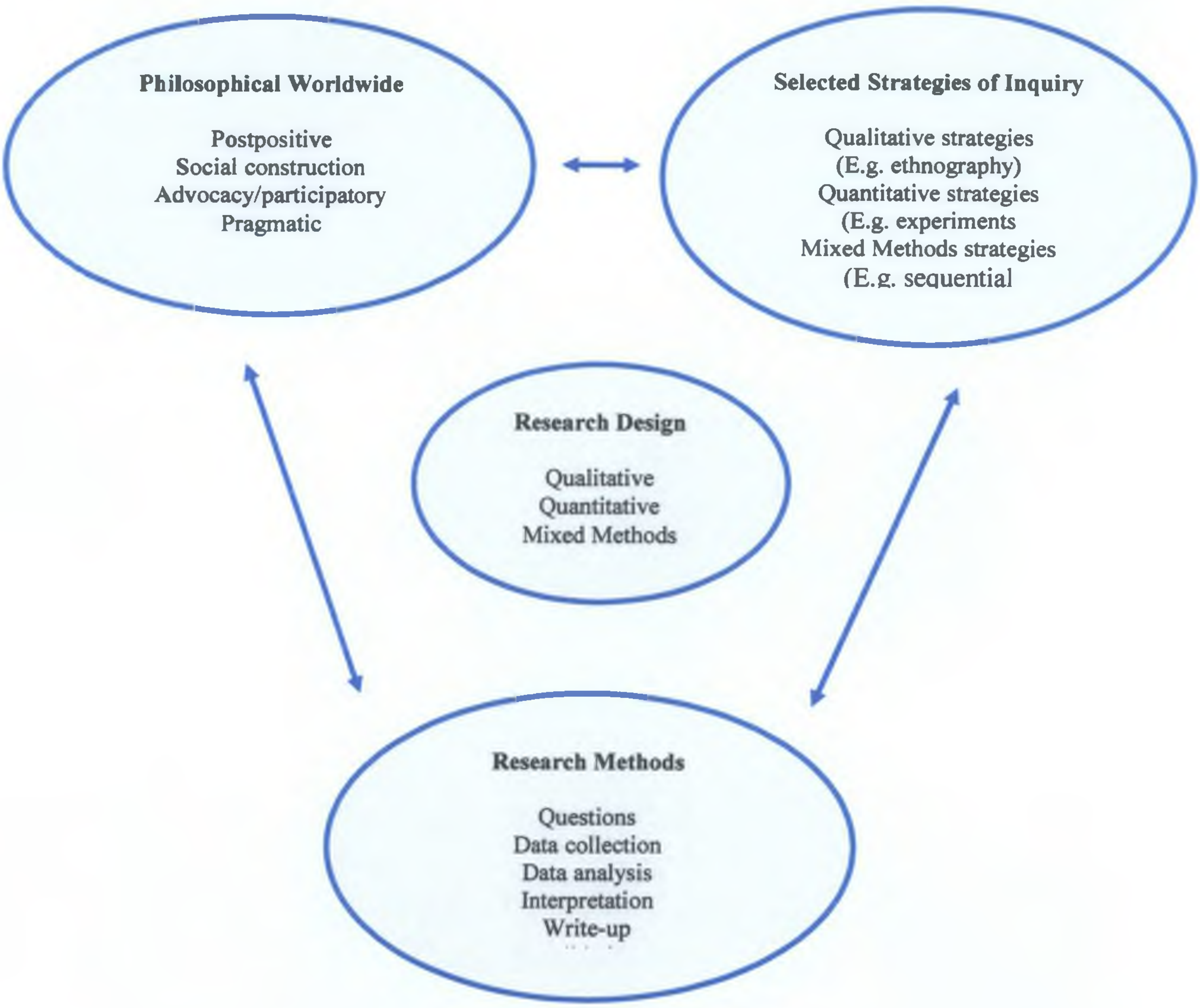


Figure 26: A Framework for Design – The interconnection of Worldviews, Strategies of Inquiry, and Research Methods illustration based on Creswell, (2009) p.5.

3.1 Fundamental Objectives of the Research

Below is a list of the fundamental objectives that were established at the start of the dissertation:

- To explore the evaluation of building performance analysis software types. This includes a brief comparison of Ecotect and Green Building Studio (GBS), iSBEM and other software types have been outlined in the process.
- To explore the result of a provisional non-domestic Building Energy Rating (BER) against those established against BIM and GBS.
- To explore the suitability of BIM for sustainability analysis.
- To understand the key criteria for sustainable buildings design.
- To outline the benefits of incorporating BIM in sustainable buildings design.
- To explore the evaluation of BIM in reducing to overall carbon emission.
- The development of a conceptual framework illustrating how the AEC industry can use BIM for sustainability analysis and evaluate LEED (Leadership in Energy and Environmental Design) rating of a building facility.
- To investigate the influence of construction material on reducing energy consumption, lifecycle energy cost.
- Identifying the future recommendations of using BIM in green buildings based upon the present study.

The objectives of this research requires initial discussions and extensive preliminary literature review regarding sustainability analysis concepts including sustainable design, building rating systems such as LEED and also Building Information Modeling from both primary and secondary sources including books, white papers, technical papers, lecture information, web pages, professional industry journals and policy documentation. Modeling skills are also required for the case study to be modeled in the BIM and exported to Green Building Studio Analysis software as a gbXML file format for sustainability analyses such as energy consumption and carbon emission and a similar process through iSBEM non-domestic Building Energy Rating (provisional) for comparison of the overall results and outcomes.

3.2 Proposed Methodology and Data Collection

The decision was made, that the most beneficial way to establish and satisfy the dissertation objectives was to carry out a desk top case study.

The building chosen for the case study was a single storey national primary school located in the Midlands which was subjected to a BIM conceptual mass model which was subjected to an analysis for building energy usage and carbon emissions. Results are also based on this mass model been uploaded and exported in a gbXML format to Green Building Studio.

Similarly the case study was also evaluated to an analysis of its building energy usage and carbon emissions through the process of carrying out a preliminary non-domestic Building Energy Rating through iSBEM software analysis in accordance with Energy Performance Building Directive EPBD Directive.

The data collected/results for both energy usage and carbon emission (CO_2) of the case study were collected and subjected to a comparison to establish that the incorporation of

BIM in the initial conceptual design process can potentially have major benefits in terms of the reducing energy consumption, lifecycle costs and reduction in carbon emissions.

In chapter 5 the author will carry out a data analysis on the results based on the case study modeling, he will go on to analyse the building's energy usages and make adjustments by way of various material alternatives enabling findings to emerge that will indicate best cases regarding minimum energy consumption, lifecycle cost and carbon emission.

3.3 Green Building Studio Assessment

Revit Building is linked directly to Green Building Studio (GBS), service from GeoPraxis (www.geopraxis.com), an industry leader in the development and implementation of building energy analysis tools and web-based solutions. The GBS service creates a geometrically correct thermal model of the building, applies local building code assumptions, creates a DOE-2 input, runs the analysis, and return summary results to the designer's browser.

In this fashion, energy analysis can be performed throughout the design process. In early design phases, massing studies can be used with resulting energy analyses to make decisions about how the building is placed on the site. As the design progresses, various daylighting options can be evaluated for energy savings.

The following lists of items were assessed in the calculation process. (Autodesk Green Building Studio White Paper, 2008)

- Annual energy cost
- Lifecycle energy costs (30 year)
- Annual energy consumption (electric and gas)
- Peak electric energy demand (kW)
- Lifecycle energy consumption (electric and gas)
- Onsite energy generation from photovoltaic and wind systems
- Water use analysis
- Assistance with daylighting using glaze factor calculations
- Natural ventilation potential calculations
- Carbon emission calculations

In addition, the web-based service collects data from three sources as follows:

1. The Revit software model: All the building geometry comes from the model, including the number of rooms, the connections between rooms, and their relationship to the exterior, exposure, and aspect to the sun; and the shape and total area of built surfaces or openings.

2. Responses to a few basic questions: In order to explain the building's use or context, it is required to select a building type from a drop-down menu and enter the postal code for the site. Selecting a weather station for the project is also required, although the closest one is selected to be the default.
3. Regionalised databases: Based on the above information, Green Building Studio will extract additional information about local weather conditions, construction, and materials. The service will automatically add any information which is not provided, so it can adapt to the requirements as design evolves.

3.3.1 Energy Analysis using Conceptual Masses – Details Workflow

In order to establish an energy analysis using conceptual masses the following steps were implemented.

1. Firstly sign into Autodesk 360 "set up an account" Enter your Autodesk ID and password.
2. Create a mass model of the case study (three different models forms were created all with the same footprint)
3. Load the mass family into a BIM model project for simulation or create an in-place mass directly in a BIM project.
4. Add mass floors, set conceptual masses as the basis for the energy simulation.
5. Decide how you will perform "thermal zoning" in the mass model.

- Automatic Zones: include basic perimeter zones and a core zone based on an offset of the mass perimeter. In the following step, there is the facility to use the Core Offset and Divide Perimeter Zones options to create automatic zones.
- Custom Zones: allows the user to refine the energy simulation to more closely reflect the design intent. To create a custom zone, modify the mass model, create a form to describe the desired zone, and use the Cut Geometry tool to incorporate the form into the mass model.

6. Create the energy model.
   - Building Type: review the occupancy type assigned to the building, which can be modified at a later stage.
   - Ground Plane: verify that the value shows the ground level for the model. During simulation, floors below the ground plane level are treated as underground floors.
   - Location: review the geographic location and weather station specified for the project and can be modified as needed.
   - Automatic Zones: for the core offset, specify a linear dimension to create a building core, or specify 0 (zero) if no core is desired.
   - Conceptual Constructions: review the default of the conceptual constructions assigned to the mass subcategories, and modify as needed.
   - Target Percentage Glazing: specify a value that reflects the preferred percentage of windows per mass zone face. Glazing is applied to each mass exterior wall as a strip window. Glazing is calculated using both the Target Glazing Percentage and the Target Sill Height values. Glazing percentage is a target value because the rectangular shape must fin within the form face, and the specified percentage cannot always be accommodated.
   - Target Sill Height: specify a height for the bottom edge of the glazing, changing the still height that exceeds what can be accommodated by the specified glazing percentages, the sill height value is disregarded in favour of the target glazing percentage.
7. Modify selected glazing.
8. Display a 3D view of the model and analyse through running the energy simulation.
9. In the run energy simulation dialog, Green Building Studio uses the concept of a Project as a starting point for the simulation and analysis of the model. The project defines the building type (such as school, single family residence, office), project operation schedule (such as, default, 24-hour, 7-day) and the project location.

   There are different settings in the Energy Settings within Green Building Studio which can be overridden such as: Project Name, Time Zone, Currency, Electricity unit cost, Natural gas unit cost and if using an existing project the utility bill history with historical weather data.

   The software checks to ensure that the model contains at least one mass floor, has a geographic location, and that Enable Energy Model is selected. If these conditions are not met, a dialog notifies the user of the conditions and automatically fixes them to allow the simulation to proceed.

If there are no error conditions, a gbXML file is created and sent for energy simulation. The server returns the simulation results to Revit (BIM), where they are displayed in the Results and Compare dialog.

10. When the simulation is complete, the Results and Compare analysis is created from the project tree.
11. Optional – modify the mass model and energy settings if required.

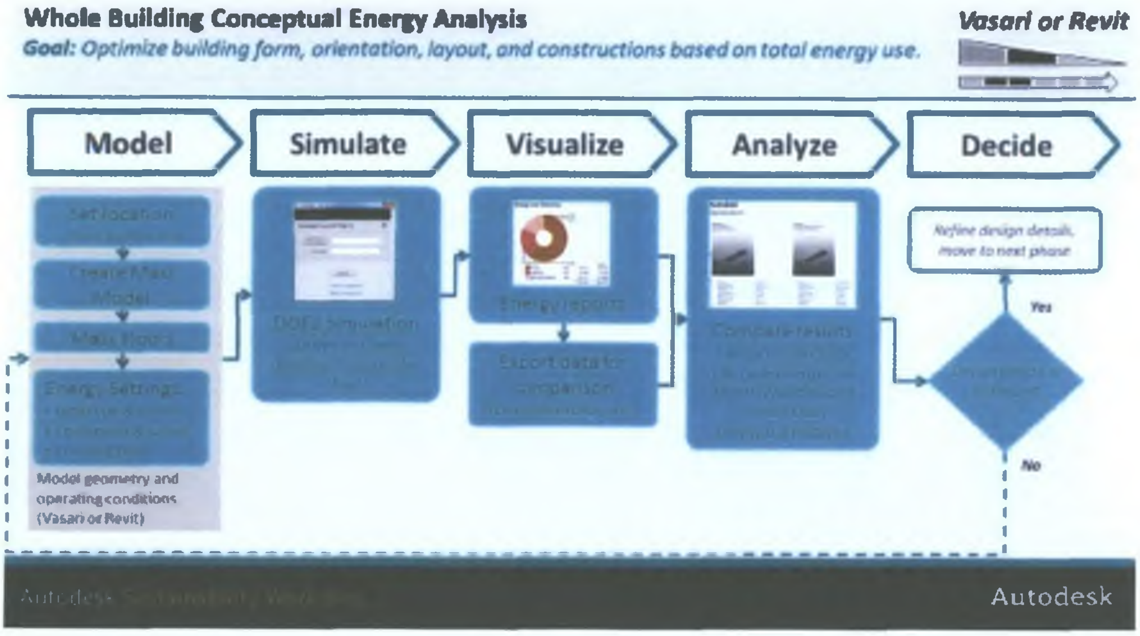


Figure 27: Whole Building Conceptual Energy Analysis Workflow.

History of Autodesk Green Building Studio

The original Green Building Studio web-based service was first introduced in 2004 and by 2007 its analysis results had met ASHRAE Standard 140 and were certified by the U.S. Department of Energy. The service was even awarded the Microsoft Ingenuity Point Award in 2008. Built specifically for architects and using gbXML for easy data exchange across the Internet, the web-based service was one of the first engineering analysis tools to deliver easy-to-use interoperability between building designs and sophisticated energy analysis software programs such as DOE-2. The link between the Revit platform and the Green Building Studio web service, now an Autodesk product, has been streamlined through a plug-in that enables registered users to access the service directly from their Revit design environment.

3.3.3 Carbon Neutral Building according to GBS

This section summarises the estimated CO_2 emissions for building design. To calculate CO_2 emissions, Green Building Studio uses data from the U.S. Environmental Protection Agency; which has historical records for all the fuel and emissions of all power plants in the world.

A carbon neutral building, as defined by the Green Building Studio web service accounts for regional differences in the carbon footprint of the regional electric grid, and mandates that any fossil based electricity and fuel use be eliminated through efficiency gains or offset by onsite non-fossil based energy sources such as PV or wind energy.

3.4 iSBEM
Non-domestic Energy Assessment Procedure (NEAP)

According to SBEM Technical Manual Version 3.5a (SEAI, 2010) the following list of items are assessed within the process of calculating a non-domestic BER

- Thermal characteristics of the building (shell and internal partitions, etc..,); this may include air tightness.
- Heating installation and hot water supply, including their thermal characteristics.
- Air-conditioning installation.
- Natural and mechanical ventilation.
- Built-in lighting solution (mainly in the non-residential sector)
- Position and orientation of buildings, including outdoor climate.
- Passive solar systems and solar protection.
- Indoor climatic conditions, including the designed indoor climate.
- Active solar systems and other heating and electricity systems based on renewable energy sources.
- Electricity produced by combined heat and power.
- District or block by combined heat and power.
- Natural lighting.

Chapter 4

Case Study

4.0 Introduction

The objective of this chapter is to demonstrate how the use of BIM technology on a construction project/design can reduce the energy consumption, carbon emission, lifecycle costing performance of such projects, and overall enhance sustainable design. As mentioned in the chapter 3 the building chosen for the case study is a single storey national primary school located in the Midlands see site location map and associated drawings in Appendix "A", which has not yet been constructed but has acquired full planning permission and is in the tendering process with the Department of Education (DOE). The project designers are JM Associates, also located in the Midlands.

The floor area of the national school consists of 509sq.m and the HVAC consists of a time and temperature controlled oil fired system. There are plans to carry out an alternative renewable fuel source in the near future.

The following is a list of the rooms associated within the case study:

- Four number classrooms each with a boys and girls toilet and a wet area for cleaning art equipment
- Multipurpose room
- Staff canteen
- Disabled toilet
- Staff toilet
- Reception/office
- Boiler room

4.1 Site Description

Figure 28: Photograph of the site location of where the school shall be constructed. (source: author)

The site topography, figure 28, indicates the location of the new national school.

The duration of construction of the project is expected to be in the region of 10 to 12 months and will commence in latter quarter of 2013.

Figure 29: Photograph of the existing outdated and overcrowded school onsite (source: author)

Depicted in figure 29 above, the existing school will be upgraded in terms of u-values and elemental construction thermal performance and the purpose changed to gymnasium, but is not part of this case study.

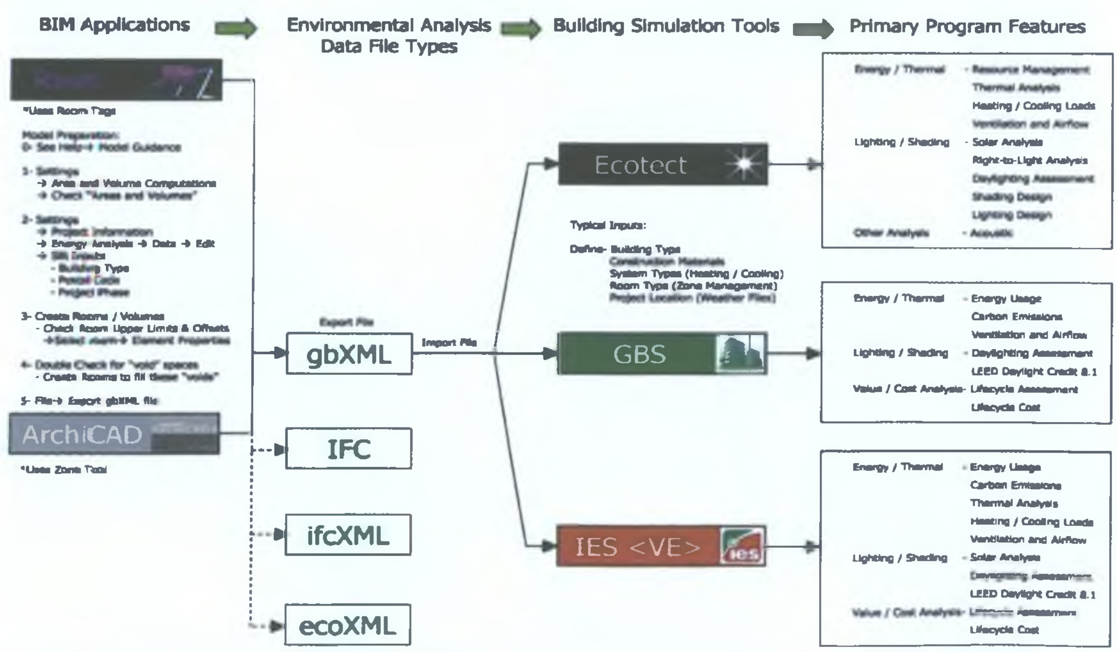


Figure 30: Integration of BIM and Building Performance Analysis Software, (source: Holder Construction Company, Atlanta, GA

Figure 28 depicts the process of BIM and Building Performance Analysis Software integration by outlining various data transfer steps. The boxes on the right hand side indicate software features evaluated in this analysis.

4.2 Test case – iSBEM analysis.

Firstly the original planning drawings and specification where tabulated and inputted into the latest version of iSBEM v.3.5.b (SBEM v3.5.b.1) courtesy and down loadable from SEAI, where the research carried out has revealed that this type of a survey has not be carried out before.

The process involves filling in the following criteria in the software to produce the necessary non-domestic building energy rating.

Details of the various calculation procedures adopted within SBEM, comprising for each:

- The input data required
- The source of each data item
- The assumptions made
- The calculation algorithm(s) used
- The source of those algorithms
- The output data generated
- A commentary on the strengths and weaknesses of the approach adopted

1. General
   1.1. Project complexity
   1.2. Building type

2. Project Database: (Building Fabric, thermal capacity)
   2.1. Constructions of walls
   2.2. Constructions of roofs
   2.3. Constructions of floors
   2.4. Construction of doors
   2.5. Glazing

For each of the above sub-sections materials make-up of the project has been to be assigned which includes the u-values (W/m2K) and km values (kj/m2K)

3. Geometry

There are a number of stages to defining the geometry of the building in the interface:

- Zone the building on the drawings according to the zoning rules.
- After "zoning" the building, create the zones in the interface (i.e., select their building and activity types), and enter their basic dimensions, i.e., area, height, air permeability, etc.
- Define the envelopes of each zone, in terms of their type, i.e., walls, floor, ceiling/roof, areas, orientations, the conditions of the adjacent spaces, the constructions, and any thermal bridges.
- Within each envelope element, there may be windows/roof lights or doors. The areas, types, shading systems, and constructions of windows and doors within each envelope element need to be entered.
- Similarly, within the envelope elements or within the window/door, there may be additional thermal bridges, which need to be defined.

4. Building Services

Building services - setting up the systems used in the building:

- HVAC systems
- Hot water generators including solar hot water
- Photovoltaic systems
- Wind generators
- Combined heat and power
- Lighting and its control
- General issues relating to ventilation, power factor correction, etc
- Allocation of systems to each zone

5. Ratings - deals with the results in terms of ratings for the building.

6. Building Navigation – used to review entered data.

Information is entered into the first four of these forms by the user and once the building description is complete, the calculation can be run. Results are then displayed in the Ratings form.

SBEM calculates the energy demands of each space in the building according to the activity within it. Different activities may have different temperatures, operating periods, lighting levels, etc.

SBEM calculates the heating and cooling energy demands by carrying out an energy balance based on monthly average weather conditions. This is combined with information about system efficiencies in order to determine the energy consumption. The energy used for lighting and hot water is also calculated.

Once the data has been input using iSBEM, the SBEM calculation engine analysis's the data to:

1. Calculates lighting energy requirements on a standardised basis, which takes into account the glazing area, shading, light source, and lighting control systems.
2. Establishes the standardised heat and moisture gains in each activity area, from the database.
3. Calculates the heat energy flows between each activity area and the outside environment, where they are adjacent to each other, using CEN standard algorithms.
4. Applies appropriate HVAC system efficiencies to determine the delivered energy requirements to maintain thermal conditions.
5. Aggregates the delivered energy by source, and converts it into the equivalent primary energy consumption and CO2 emissions.

6. Determines, on the same basis, the primary energy consumption and CO2 emissions of a reference building with the same geometry, usage, heat gains, temperature, illuminance requirements, ventilation conditions, and weather but with set specifications for building component construction, HVAC, and lighting systems.
7. Determines, on the same basis, the primary energy consumption and CO2 emissions of a notional building which is similar to the reference building but with fixed ventilation and cooling conditions and space and water heating fuel.

The results from the case study analysis through iSBEM software are detailed and outlined in appendix "B" of this dissertation.

4.3 Test case - Green Building Studio analysis.

Firstly the original 2D CAD planning drawings were redrawn in Revit 2013 to produce a 3D conceptual mass model which was then exported to a gbXML file format and inputted into the latest version of Green Building Studio (version 2014.1.28.2302) courtesy and down loadable from Autodesk.

The process involves following criteria in the software to produce the necessary energy and carbon usage.

1. Whole building energy analysis software—Determine virtual building's total energy use and carbon footprint.
2. Design alternatives analysis—Consider alternatives to improve energy efficiency.
3. Detailed weather analysis—Extensive weather data available for project site.
4. Carbon emission reporting—Emissions reporting for nearly all aspects of the building.
5. Daylighting analysis
6. Water usage and costs—Estimated water use, in and outside building.
7. ENERGY STAR scoring—Scores provided for each design.
8. Natural ventilation potential—Summarizes mechanical cooling required and estimates hours design could use outdoor air to cool the building naturally.

The utility units, electric cost (/k/Wh) within Green Building Studio where changed to reflect the latest available from ESB. The location of the school was inputted into the model which established the weather conditions for the area, along with the number of occupants within the structure and the number of water consuming units.

The results from the case study analysis through Green Building Studio software are detailed and outlined in appendix "C" of this dissertation.

Alternative design options of the conceptual mass were developed to establish alternative analysed energy simulations that enable architects to establish what initial design changes would impact on the carbon output of the model (see appendix "C").
These changes would highlight the benefits to the overall lifecycle of the model by producing alternative mass forms which have the same floor area.
The models that have been generated and analysed with the data results indicating the energy consumption for the year and a lifecycle energy usage and cost has be calculated.
The software also generates the potential renewable energy available in terms of PV potential and wind turbine potential for the mass.

4.4 Limitations

There were limitations associated with running the Green Building Studio process as the whole process of BIM revolves around collaboration from all stakeholders i.e. architects, MEP's, quantity surveyors and facility managers produce a full BIM model.

Chapter 5

Data Analysis and Discussion

5.0 Introduction

The first step in the early energy modelling process requires the use of energy modelling software to generate annual energy consumption and cost data for a set of building design alternatives. Annual energy use will vary depending on building configuration and design details. The energy modelling process is grouped into two sub-processes: the macro-level energy analysis focuses on comparing building size, shape, and orientation; and, the micro-level energy analysis considers building details such as wall penetrations and building system details.

This dissertation had started out with the main aim related to building information model, specifically in relation to energy analysis tools, whether the building information model is beneficial in terms of establishing a buildings energy consumption at conceptual design stage and therefore reduction in carbon emissions.

In order to investigate the carbon footprint of each of the design options that were designed with the same footprint (see section 5.2) then the embodied energy of all the building materials must be examined to give a true reflection of the whole energy usage. There were limitations within this research in terms of energy usage evaluation which could not be calculated as the case study in on a proposed primary school therefore there is no energy usage data is available and mechanical, electrical and plumbing (MEP) could be calculated for incorporation within BIM to give a true energy usage.

5.1 iSBEM – NEAP Data Analysis

The first step was to carry out a provisional non-domestic energy assessment procedure based on the planning drawings of the case study; the process involved has been outlined in detail in chapter 4 of this dissertation.

The results of the analysis resulted in the following:

As illustrated in figure 29 below, the provisional BER rating was established at an "A3" which is the equivalent to121 kWh/m²/yr (0.49) and a carbon dioxide (CO_2) emission of 30 $kgCO_2/m^2/yr$ (0.57). This is in compliance with the Department of Education and Science requirements of a minimum A3 rating, and therefore in line with the second edition of the National Energy Efficiency Action Plan (NEEAP).

Figure 31: Cut out of the provisional BER rating (see Appendix "B" for more detail)

The heating allocated to the case study accounts for 70.2% of the CO_2 emissions, lighting accounts for 24.8% of the CO_2 emissions, some of the spaces within the building are at a high risk of overheating and auxiliary accounts for 5% of the CO_2 emissions as illustrated below in figure 30.

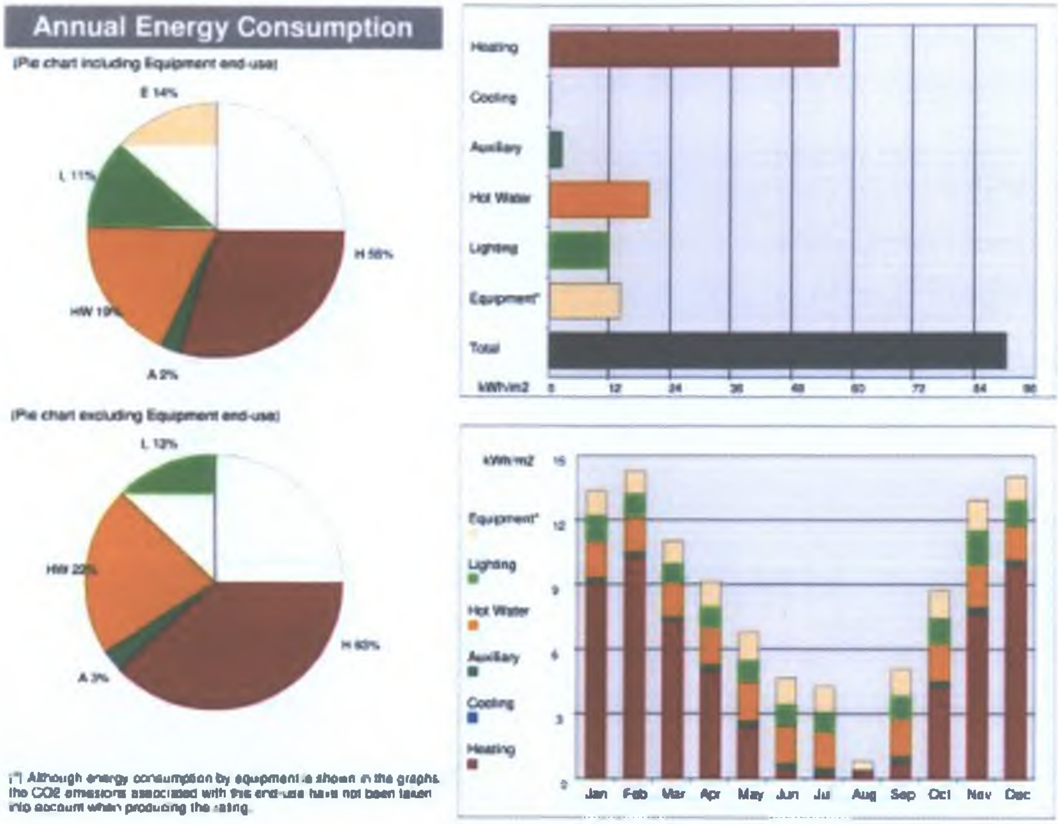


Figure 32: Cut out of the provisional BER rating, Main Calculation Output (see Appendix "B" for more detail)

The results from the investigations of the modelling highlight some of the limitations in the iSBEM tool that was used to carry out the EPC (Energy Performance Certificate) calculations also correlated by Raslan, R., Davies, M., and Oreszczyn, T., (2007).

The proposed primary school has no alternative energy sources allocated at the time of preparing the non-domestic provisional BER.

5.2 Green Building Studio Data Analysis

For the purpose of establishing the best way to illustrate the energy simulations that enables architects to establish the best design in terms of carbon emission, alternative designs of conceptual mass where produced all of the same footprint, the results have been illustrated below, which outline the effect of the design on the overall energy efficiency with the parameters of orientation and glazing aspects.

5.2.1 Green Building Studio – Original Design

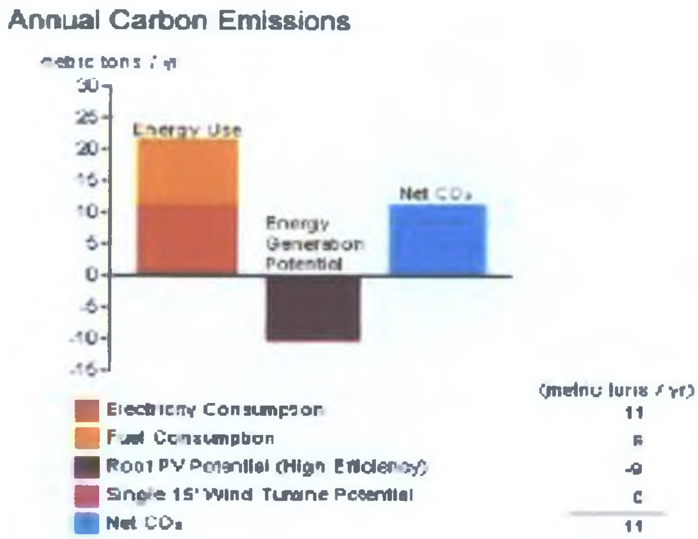


Figure 33: Cut out of the original school conceptual mass (see Appendix "C" for more detail)

The energy use is 11 and 8 metric tons per year and the net CO_2 is 11 metric tons per year.

Annual CO_2 Emissions	- Electric	16.5 Mg
	- Onsite Fuel	9.3 Mg
	- Large SUV equivalent	2.6 SUV's / year
Annual Energy	- Energy Use Intensity	941 MJ/m²/ year
	- Electric	81,410 kWh
	- Fuel	186,176 MJ
Lifecycle Energy	- Electric	2,442,291 kW
	- Fuel	5,585,280 MJ

Annual Energy Cost € 26,820.00

Lifecycle Cost € 365,294.00

5.2.2 Green Building Studio – Design Option 2

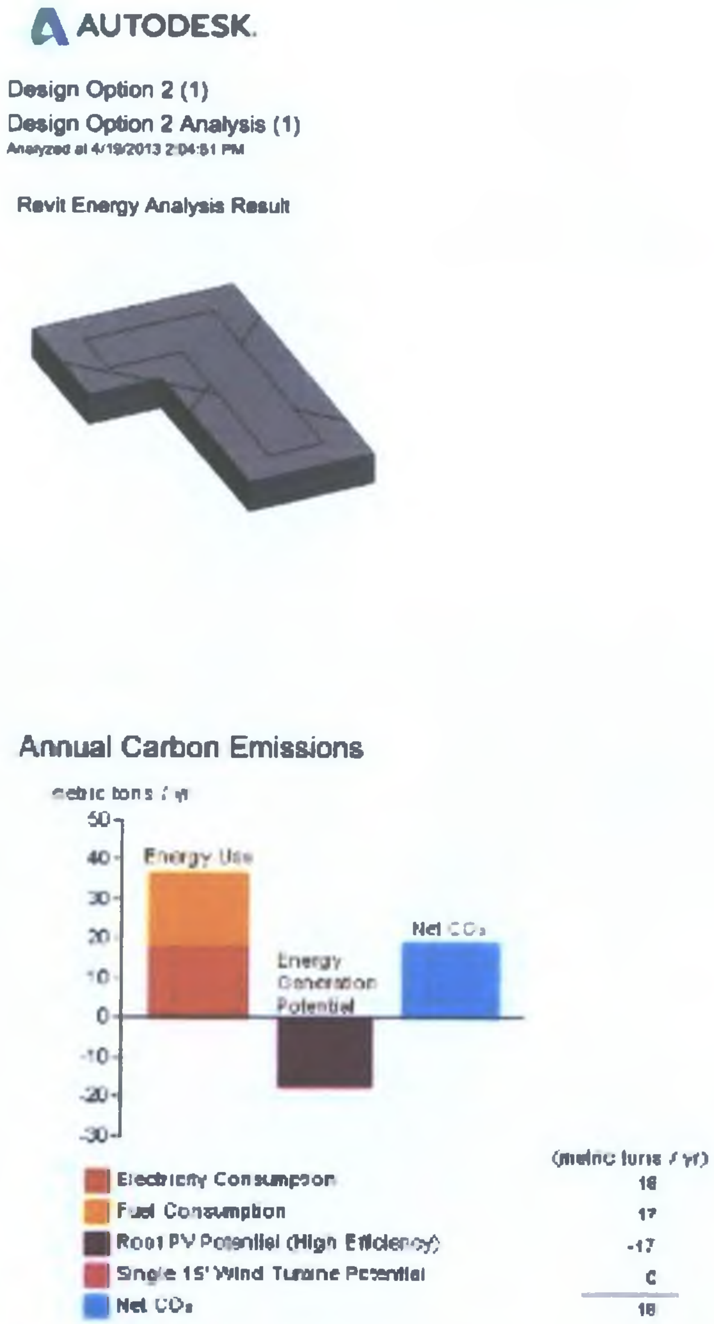


Figure 34: Cut out of the design option 2 conceptual mass (see Appendix "C" for more detail)

The energy use is 18 and 17 metric tons per year and the net CO_2 is 18 metric tons per year.

Annual CO_2 Emissions	- Electric	8.7 Mg
	- Onsite Fuel	4.9 Mg
	- Large SUV equivalent	1.4 SUV's / year
Annual Energy	- Energy Use Intensity	497 MJ/m²/ year
	- Electric	43,019 kWh
	- Fuel	97,919 MJ
Lifecycle Energy	- Electric	1,290,557 kW
	- Fuel	2,937,567 MJ
Annual Energy Cost	€ 14,167.00	
Lifecycle Cost	€ 192,956.00	

5.2.3 Green Building Studio – Design Option 3

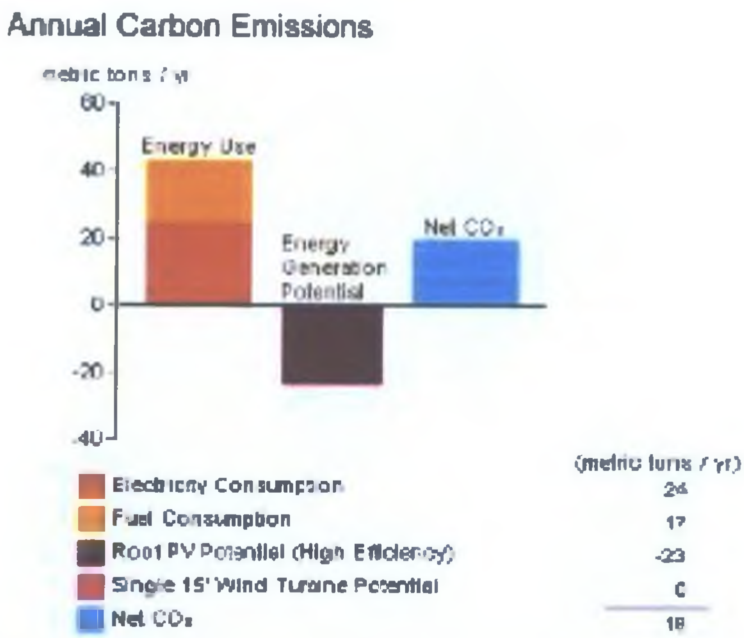


Figure 35: Cut out of the design option 3 conceptual mass (see Appendix "C" for more detail)

The energy use is 24 and 17 metric tons per year and the net CO_2 is 18 metric tons per year.

Annual CO_2 Emissions	- Electric	16.5 Mg
	- Onsite Fuel	9.4 Mg
	- Large SUV equivalent	2.6 SUV's / year
Annual Energy	- Energy Use Intensity	949 MJ/m²/ year
	- Electric	81,773 kWh
	- Fuel	188,785 MJ
Lifecycle Energy	- Electric	2,453,201 kW
	- Fuel	5,663,535 MJ
Annual Energy Cost	€ 26,961.00	
Lifecycle Cost	€ 367,205.00	

5.3 Green Building Studio – Analytical Comparison:

Design	Annual CO_2 Emissions			Annual Energy			Lifecycle Energy	
	Electric (Mg)	Onsite Fuel (Mg)	Large SUV Equivalent	Energy Use Intensity (MJ/m2y)	Electric (kWh)	Fuel (MJ)	Electric (kW)	Fuel (MJ)
Original Design	16.5	9.3	2.6	941	81,410	186,176	2,442,291	5,585,280
Design Option 2	8.7	4.9	1.4	497	43,019	97,919	1,290,557	2,937,567
Design Option 3	16.5	9.4	2.6	949	81,773	188,785	2,453,201	5,663,535

Table 2: Green Building Studio Design Options analytical comparisons.

Design	Annual Energy Cost	Lifecycle Cost
Original Design	€ 26,820.00	€ 365,294.00
Design Option 2	€ 14,167.00	€192,956.00
Design Option 3	€ 26,961.00	€ 367,205.00

Table 3: Green Building Studio Design Options comparisons – costings.

5.4 Discussion

With both the non-domestic provisional BER and the different design options of Green Building Studio established and once all of the analyses have been tabulated, the data output from Green Building Studio with the aid of BIM indicated clearly that the use of conceptual mass design has its benefits to the designer in terms of energy analysis at the conceptual design stage of a project and in doing so has the potential in producing a greener sustainable design building with lower CO_2 emissions and a lower life cycle cost for the end user.

The energy analysis enabled a relatively easy calculation to be performed with regard to whole-life energy use for all three design options.

As illustrated in table 2 and 3 above with the preparation of design options all of the same floor area, design option 2 has the lowest annual energy cost and lifecycle cost than the other two conceptual mass designs.

Autodesk Revit is **not** the only BIM program available-it was chosen because of its direct link to Green Building Studio (GBS).

Chapter 6

Conclusions and Recommendations

6.0 Introduction

The main aim of this dissertation was to analyse a case study building with regards to the implementation of BIM through Green Building Studio at conceptual design and compare these results against a benchmark figure of the same case study analysed through SEAI non-domestic energy assessment procedure (NEAP). In doing so, research was carried out through BIM to introduce the benefits of sustainable and lifecycle costing of buildings.

By the research carried out it has highlighted the importance to incorporate energy modelling analysis early in the conceptual design of construction projects, as this allows for key decisions to be made by architects, engineers and facility managers very easily which can have a profound impact on the buildings energy performance and life cycle.

The analytical analysis of the different thermal mass and conceptual form options through Green Building Studio chosen for the school, established the minimal energy performance gains to be achieved by adopting a form that was more energy intensive but didn't give a true reflection as a space for the occupants for their required usage was not established this is one of the limiting factors of BIM as it requires full collaboration. By analysing conceptual mass forms, BIM allows for the opportunity to establish an energy analysis for designers which can be produced quickly and should be implemented at each stage of design process throughout all disciplines involved in the BIM model.

Within the BIM model and the energy analysis process there is the facility to carry out a daylight analysis which allows the designer to design the school in this case in accordance with the guidelines set by the Department of Education & Science with regard to natural lighting daylight factor requirements.

Also established within the study was the potential of using BIM in analysing sustainable design for "Green Buildings" and the exploration in the evaluation of BIM in reducing to overall carbon emission.

There are numerous energy reduction programmes and guidelines available to the school in order to reduce their energy consumptions even further once the school is operational with at 3 months energy bills. Recommendations that the board of management should employee an energy consultant to evaluate their actual energy usage through an energy diagnostic questionnaire, carry out a display energy certificate DEC and for the school to sign up and establish a Green Energy Flag.

The school should encourage their pupils in the knowledge of energy awareness through the SEAI excellent campaign through "School Energy Workshops" and an energy management plan should be established to train staff in energy conservation. The implementations of these energy reduction programmes and guidelines have been outlined in detail in chapter 2 earlier.

6.1 Key Findings

As illustrated previously early design energy analysis provides an opportunity to make cost-effective decisions early in the building life cycle, and to meet energy conservation which can be established with the use of BIM and Green Building Studio.

Healthy buildings can pay for themselves since building construction, operation and energy costs typically amount to small portion (about 10%) of a business's costs while 90% goes towards salaries (USGBS, 2008).

As indicated in table 2 of chapter five, the case study has proven that with a simple conceptual mass and a relatively simple energy analysis at the early conceptual design option, it provides the designer with valuable information and an insight into the life-cycle cost of that structure with the benefits of reduction in overall carbon emissions. Throughout the research process the author briefly evaluated the different building performance analysis software types (as illustrated in table 1; chapter 2) to establish which software programmes was most suitable to carry out the energy analysis. The installation of time and temperature control BMS provides benefits in terms of energy reduction.

The research identified the key criteria for sustainable building design in the aspect of "Green BIM" in chapter 2.

Since the building is not yet under construction some key information for running a few sustainability analyses were not available within the timeline of this study.

Therefore in my opinion BIM can aid considerably in performing complex building performance analyses to ensure an optimised sustainable building design and reducing in lifecycle costing for the end user.

6.2 The Emerging Challenges

The AEC industry face substantial challenge in the areas of sustainability, moving to a low carbon economy and designing more resilient infrastructure. The multi-faceted and frequently conflicting requirements, with significant uncertainties and generally spanning the whole lifecycle, will require a very substantial paradigm shift to engage them fully.

The main emerging challenge will be improving the existing best practice standard of an A3 rated school to achieving an A1 rating, as outlined below one of the best methods with the greatest end results would be designing to a passive standard at the conceptual stage through the use of BIM. The barriers to the implementation of this methodology are not just to the construction end product but more importantly could be the lack of available funding from the Department of Education and Science to fund such a product.

A more comprehensive capability will necessitate many such tools, a high level of BIM integration and a design approach that is able to locate optimal solutions in a very complex design space. This will require considerable investment and innovation and is likely to see knowledge based techniques fully integrated into BIM concept.

By carrying out this dissertation it has highlighted the benefits of introducing BIM at the early design stage of a project and how this can be compared to the results of a provisional NEAP of the same project in terms of energy reduction and whole lifecycle costing. At present architects design and then analysis later where as the implementation of BIM allows for the model to be analysed throughout or at any stage of the design process to be evaluated.

The traditional method of calculation a buildings energy usage is through a provisional BER which involves the full design of the structure and its services, which means that by the time the modelling is done, the design is fully developed and only minor changes can be entertained, with BIM and Green Building Studio minimal time and effort is required to give the architects a quick energy analysis of the proposed design.

> *"The future of architectural practice may depend on architects' ability to test the performance of their designs before final design decisions are made and before the construction starts or the building is occupied and used".*
> (Mathews, M. 2009)

Within the research of this study there were no similar papers that analysed and compared the results of an NEAP Building Energy Rating with those of a conceptual mass analyse through the energy model of Green Building Studio. Therefore the research has highlighted that the traditional way of calculation a buildings energy use required rethinking, as considerable time and effort is wasted design projects that do not maximise their energy saving potentials.

6.3 Recommendations

It was established by this study, that an energy analysis software package such as Green Building Studio has the major benefits to a design project if incorporated at an early conceptual design stage, in order to optmise the building layout, orientation in terms of maximising the available natural resources, fenestration and reduce the amount of time and energy spent by architects designing project to only find out at the end through carrying out a provisional BER that the proposed design is inefficient in energy consumption.

With the limitations previously outlined within the dissertation the actual energy usage should be established through an MEP consultant and this data incorporated into the BIM model to establish the accurate energy reduction savings available to the primary school.

Alternative energy sources should also be evaluated from the school, especially those relating to the high energy demand of the heating for example cogeneration or combined heat and power controlled by an ESCo company. Other alternative energy sources could be waste water treatment – i.e. anaerobic digester which might be a more feasible option with the location of the school. Natural gas supply is not a viable option as the primary school is located in the rural countryside there is no natural gas line within the vicinity.

A more detailed costing study is required to assess the economic viability of adopting the facility to facilitate power and heating demands of any other high energy users in the vicinity of proposed primary school where the costs involved in installing a CHP plant could be shared. The school should also carry out a lighting evaluation in terms of lighting controls, time control, time delay, occupancy control, photo-electric cells in order to comply with the Departments of Education and Science requirements of a daylight factor of 4.5, which in simple terms means 70% to 80% of teaching hours should have no need for electrical lighting in a school environment.

An energy audit/feasibility should be carried out on the operation school which focuses on the following:

- Assessment of annual energy usage.
- Calculating the energy consumption of various items of equipment (Building fabric, controls, Heating, Lighting etc..).
- Survey of the building to assess the condition of the existing building fabric and building services. (Infrared Thermal Image Report)
- Control strategy for the heating system.
- Feasibility of renewable technologies, wind generation, geothermal heat pumps, biomass heating systems, photovoltaic, solar hot water heating, rain water recovery, district heating systems etc.., just to name a few.
- Install oil meters of the oil tanks to accurately monitor the oil consumption.
- Carry out a feasibility study into a scada type management system to remotely control and monitor the schools energy consumption through an ESCo consultant.

The school should implement the no-cost, low-cost and medium-cost energy saving as outlined in chapter 2 and implementing housekeeping guidelines as outlined in appendix “F”. As outlined in the BER supplementary report in appendix “B” this provides a starting point for the proposed school to improve on energy consumption.

An area that would substantially improve the schools energy rating from the best practice standard of an A3 rating to an A1 rating would be to design the as a passive design, but unfortunately the construction costs of such a design that might not be sanctioned by the department.

If the next generation of schools with photovoltaic array cover their electricity costs, have battery storage to cover meetings at night and some school activities in the morning, and at the height of summer power could go into the grid, than the school could have the potential of becoming carbon neutral.

Energy efficient boilers and individual digital room temperature controls combined with a strong emphasis on air tight testing (currently twice as good as Irish Building Standards) and insulation levels minimise heat requirements should be incorporated into the design and construction process. Water usage should be minimised through automatic shut off taps and dual flush toilets, while local water blending valves are provided to prevent scalding and rain water recovery should be provided in accordance with the best practice guidelines of the Department of Education and Science.

Alternative fuel for transport

Electric school buses are a possibility. An expert in the field on school transport or transport in particular would have to carry out a feasibility study in this regard. There are several projects nationally that are looking at how to make transport energy more renewable through the use of bio-fuel, electric options and so on. Touching on the sustainable neighbourhood approach again which is about getting a balance between the distance to schools, the number of schools in an area and how wide a circle the bus must travel would all have to be assessed as a further investigation.

Planning for sustainable neighbourhoods and not just the physical environment is also very important, the Joint Code of Practice on Provision of Schools and the Planning

Process August 2008 should be looked at as this will assist greatly with sustainable school provision and sustainable travel patterns.

The really positive aspect of sustainable school buildings is that the school will also be used as a life learning tool. There is no better way for children to learn about sustainable development than by living and working in a place that upholds a sustainable ethos.

6.3.1 The main objectives of the sustainable energy programme are summarised as follows:

- provide quality educational facility appropriate to its users requirements
- demonstrate exemplar role
- provide a quality internal environment for the occupants of classrooms allowing the occupants to control their own internal environment through the use of natural daylight controls and heating and natural ventilation controls. All rooms are designed to have adequate natural light for 80% of the occupied period which is important as studies have shown that the use of natural light improves the ability of students to learn
- research and encompass reliable low energy design solutions through the use and evaluation of BIM and Green Building Studio
- identify and maximise new technology potential
- reduce energy consumption in schools
- reduce reduced carbon dioxide emissions in schools
- provide feedback to the Planning & Building Unit Technical Staff on the operation of the school and its systems
- explore the potential of school buildings to act as a life-learning tool that enables the building to be an active learning resource for energy conservation and sustainability for the pupils and teachers
- accumulate monitored data to feed into the design process for the next generation of even more sustainable schools continuously under development by the Department Planning and Building section
- enable school staff and children to learn about the benefits of sustainable design techniques
- to educate schools, designers, and the public in the use of sustainable techniques through public presentations and technical publications
- to allow the contractors involved in the projects to learn about sustainable construction, particularly in the use of air tightness construction and testing requirements. Pre construction, the design teams provide recommendations to the contractors about sustainable building techniques along with a number of walk and talk meetings on the building envelope as it was under construction

According to Carbon Trust CTV020 – Further and Higher Education (FHE); two thirds of the energy consumed by the FHE sector is made up of fossil fuels, electricity accounts for around 60% of energy costs, therefore major benefits can be obtained from the following no-cost and low-cost saving opportunities available:

6.3.2 Cost Saving Opportunities

Once the school is constructed the following saving opportunities should be carried out.

No-Cost Saving opportunities where applicable:

- Implement energy awareness plan
- Install motion detectors in rooms not used regularly
- Change any inefficient lights to compact fluorescent lamps (CFL's) or LED when they require replacing
- Have all external light on a timer
- Change external lights to LED
- Regular cleaning of the light fittings every two years, light levels decreases >50% due to aging lamps and dirt on fixtures, lamps and room surfaces (ultrasonically)
- Turn off lights when leaving rooms and buildings
- Turn off lights in buildings at night time, weekends and school holidays in room not occupied during these times
- Turn off lights in over lit areas

Low-Cost Saving opportunities

- Install energy saving CFL light bulbs instead of old-style incandescent lights
- Install T5 fluorescent lights to replace old types. The new lights are smaller diameter tubes.
- Fit occupancy sensors in storerooms, electrical rooms and toilets
- Use a door operated switch to turn on lights in rooms where the doors are kept locked
- Install 2no. outdoor lighting circuits, one for operation during the evening hours (fully lit) and one for night-time operation when less activity is occurring (lower level of lighting for security)
- Replace oversized lights with suitable sized alternatives

Medium-Cost Saving opportunities

- Replace all light fixtures with the school premises with energy fixtures and lamps
- Replace old-generation tungsten halogen outdoor lights with more efficient metal halide lamps

For additional information in relation to daylight and lighting technology see appendix "D"

6.4 Possible further research in the area

BIM for School Projects

There is a necessity in establishing the overall benefits of BIM through a full collaboration of each discipline, as previously mention the dissertation had limitations with regards to the mechanical, electrical and plumbing (MEP) aspect of input.

A full evaluation from the project team should be implemented on BIM-based design models for energy and structural analysis, design and construction visualisation, specification, material and cost estimating, fabrication/pre-construction, and ultimately as a platform for ongoing facility operation and maintenance. The collaboration on this project should extend beyond building delivery into lifecycle management.

Streamline Construction Process

Prior to the proposed school commences construction, the project team should carried out and evaluation into continuing to rely on BIM solutions for visualisation, coordination, planning and clash detection. From the site office computers to handheld tablet PC's.

Extend BIM to Lifecycle Management of the School

When the design and construction is complete, the board of management should look into extending BIM to lifecycle management by linking the data-rich design models of the new building into its existing operations and maintenance (O&M) platform, and with the incorporation of the building management energy system (BEMS) to finally use BIM for "smart" building operations and live maintenance monitoring for the facility managers.

The new Building Control (Amendment) Regulations 2013 are coming into operation in March 2014, which aim to strengthen building control and compliance, and this includes the lodgement of drawings at commencement stage, with the Local Authority. It would be invaluable if project information could be submitted in digital format (i.e. BIM), a format of computable data that can be automatically analysed, to flag potential issues of non-compliance. The Irish government is seriously lacking in terms of implementation of BIM, they are spending a lot of time, effort and money developing a submission system based on outdated practices and technologies (paper drawings), without looking at what is happening around the world, particularly with our closest neighbours in the UK.

As the potential for Building Information Modelling to influence the practice of architectural design especially at conceptual design becomes reality, it is essential that architects develop a strategy to successfully implement BIM within their organisation.

6.5 The future of BIM in Ireland

BIM remains a high importance to the AEC industry, as previously mentioned, it should be noted that the UK Government are implementing Level 2 BIM on all government contracts by 2016. The benefits of BIM are fast becoming common knowledge throughout the AEC industry. Ireland needs to embrace BIM and develop and alter the way the construction industry operates within the next five years. The main drivers of BIM are the contractors and project owners, a few of the larger construction contractors within Ireland have staff fully trained in BIM and are converting the drawings received by architects to fully collaborative BIM models in order to speed up the construction time, save material wastage and improved a more efficient sustainable project for the end users.

Other drivers are:

- reduce our asset costs and achieve greater operational efficiency,
- facilitate greater efficiency and effectiveness of construction supply chains

- assist in the creation of a forward-thinking sector on which we can base our growth ambitions.

In my option the Irish construction industry will end up following trends set by its competitors in Europe and North America rather than creating and setting their own trends and standards.

These trends show that buildings are becoming more complicated to build and are taking more resources to construct and operate. This is putting more emphasis to increasing lifecycle cost of buildings.

A barrier to the implementation of BIM in the AEC industry is a significant problem with lack of awareness and more importantly lack of training for construction professionals. According to a recent survey carried out by Royal Institute of the Architects of Ireland (RIAI) as illustrated in chapter 2 of the dissertation only 16% of architects are implementing BIM in their workplace, for BIM to be a viable and valuable tool within the AEC industry there has to be full commitment by the Irish Government to drive the process of implementation of BIM.

BIM needs to be at the forefront of academic courses such as Building Surveying, Quantity Surveying, Architecture, Structural Engineers, and Service Engineers in order for the AEC industry to embrace the benefits of BIM and in the long run the environment.

There's no question that BIM will transform the construction industry. The control of information relating to a building from its inception, through its life, to its demolition “cradle to grave”, will have as great affect upon the construction industry as the control of information relating to products had on the retail industry.

It wasn’t too long ago when nobody used emails in the work environment, today nearly all work communications are emailed based and this was made compulsory.

It is hoped that through the completion of this dissertation that I have highlighted the necessity to carry out periodic energy analysis at conceptual design stage rather than carrying out a provisional BER on completed drawings, and in doing so one hopes to enhance the industry in a new way of design to maximise energy efficiency.

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Appendices

Appendix "A"

1.0 Case Study – Site Location Map

Figure 36: Location of the proposed school, located approx 10km northwest of Mullingar town in the rural area of Slanemore. (source OSI)

Sonna National School is a mixed Catholic small primary school, situated 10km northwest of Mullingar in a rural setting. It also goes under the name Scoil Odhrán Naofa. The enrolment for year 2011/2012 was boys 50 and girls 46. Daithi O'Fiaich is the school principal to whom I appreciate his permission to use the school as the case study matter.

1.1 Case Study – Site Layout Map

Figure 37: Site Layout Map (source JM & Associates)

1.2 Case Study – Floor Plan & Elevations

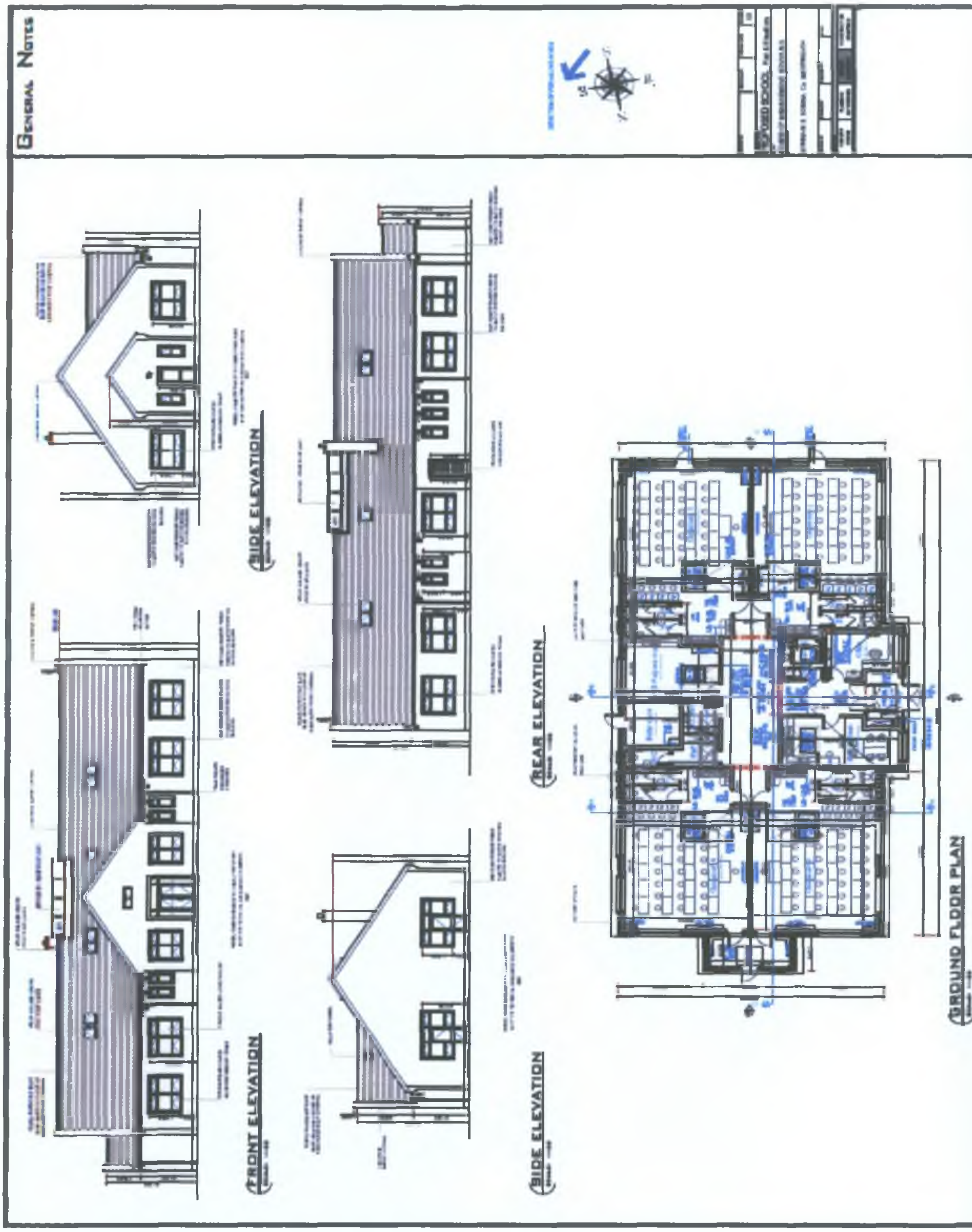


Figure 38: Floor plan and Elevations (source JM & Associates)

1.3 Case Study – Roof Plan & Sections

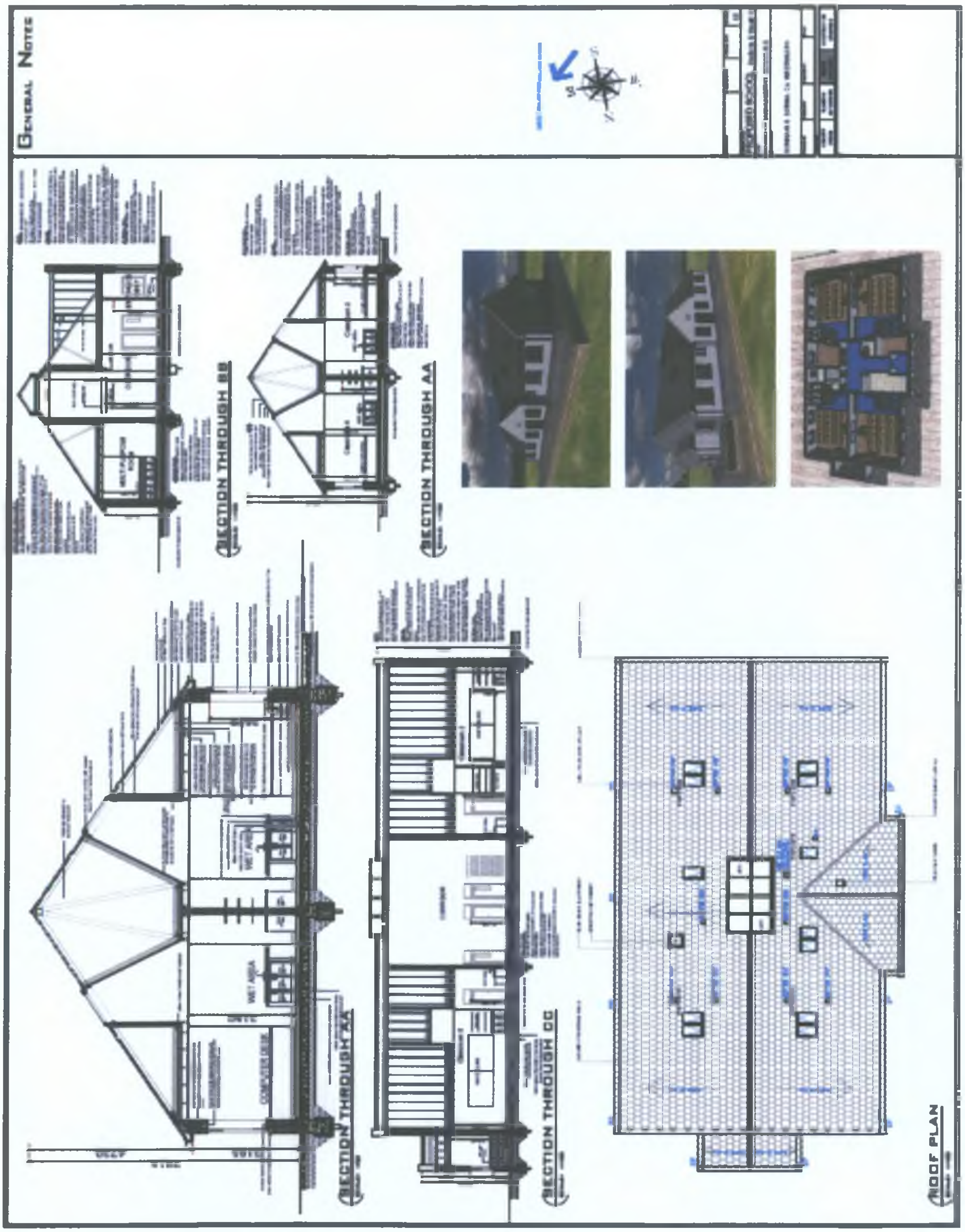
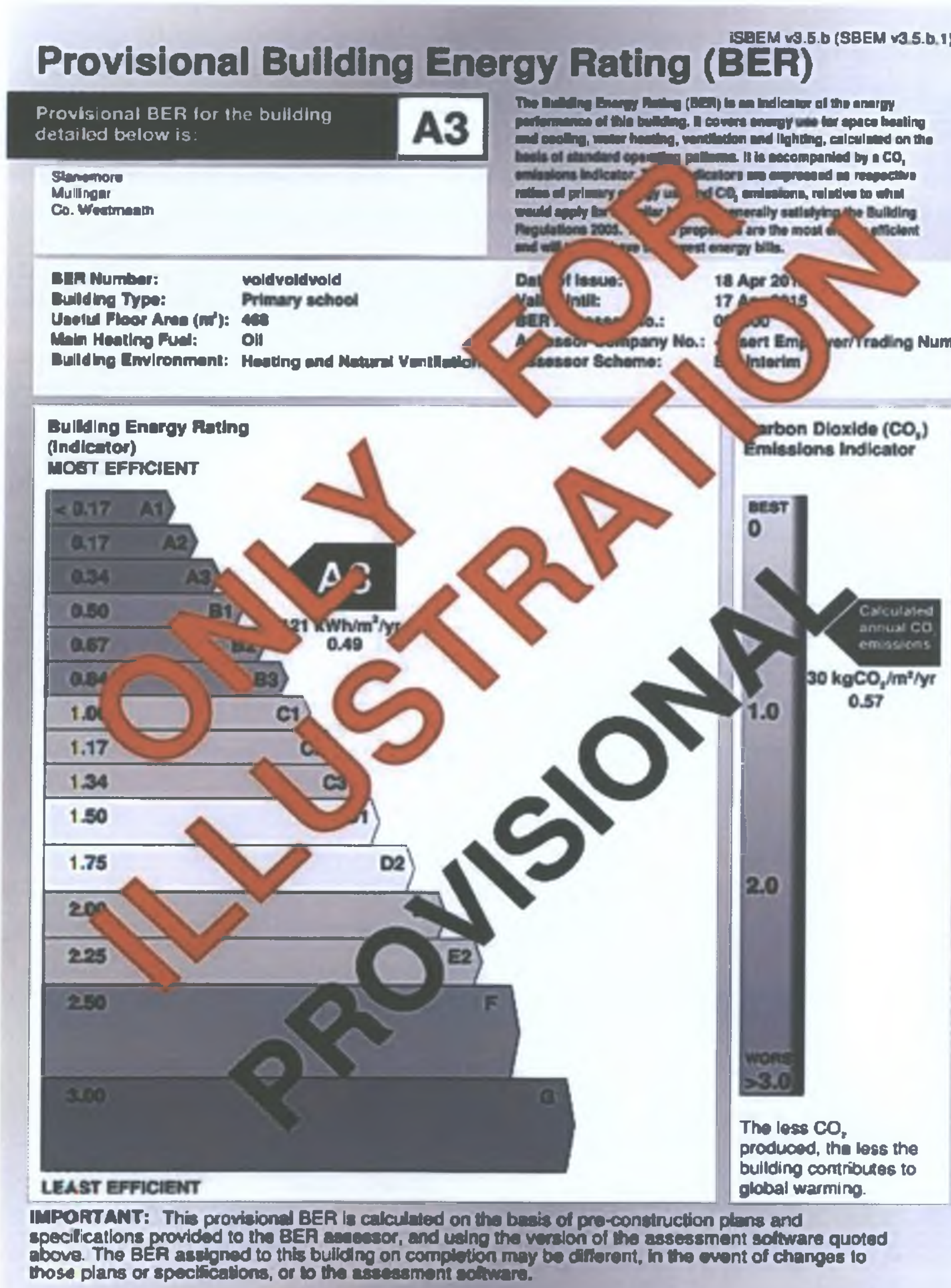


Figure 39: Roof Plan and Sections (source JM & Associates)

Appendix "B"

2.0 Case Study – Provisional Non-domestic BER Rating "A3"



2.1 SBEM Main Calculation Output Document

SBEM Main Calculation Output Document

Thu Apr 18 15:38:35 2013

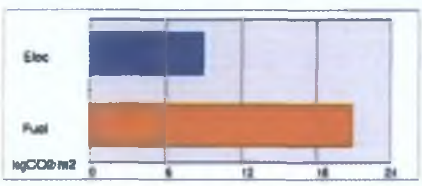
Building name

Sonna National School

Building type: Primary school

SBEM is an energy calculation tool for the purpose of assessing and demonstrating compliance with Building Regulations (Part L for England and Wales, Section 6 for Scotland, Part F for Northern Ireland, Part L for Republic of Ireland and Building Bye-laws Jersey Part 11) and to produce Energy Performance Certificates and Building Energy Ratings. Although the data produced by the tool may be of use in the design process, **SBEM is not intended as a building design tool.**

Building Energy Performance and CO2 emissions

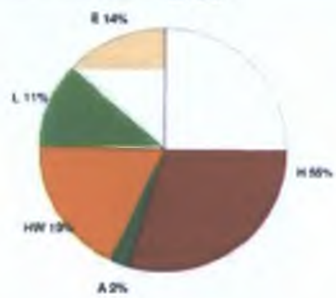


0 kgCO2/m2 displaced by the use of renewable sources.

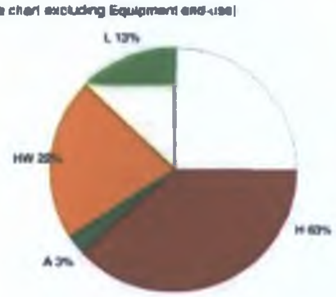
Building area is 467.814m2

Annual Energy Consumption

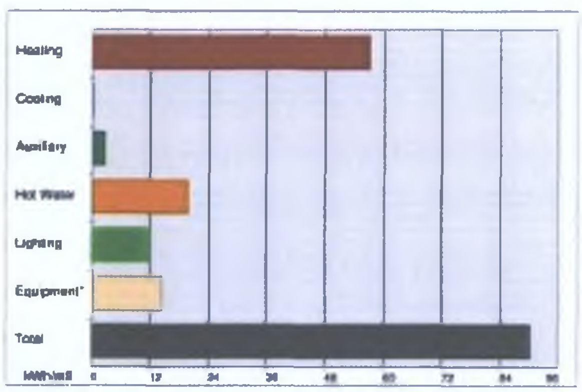
(Pie chart including Equipment end-use)

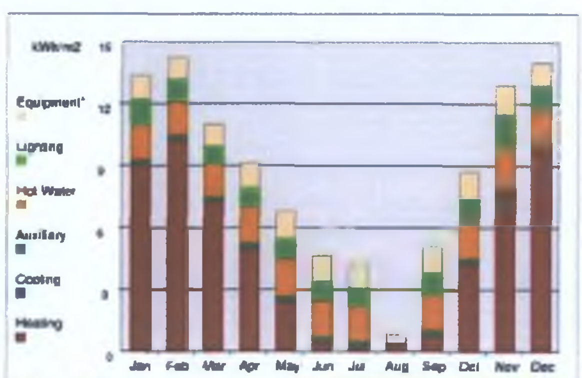


(Pie chart excluding Equipment end-use)



(*) Although energy consumption by equipment is shown in the graphs, the CO2 emissions associated with this end-use have not been taken into account when producing the rating.





2.2 Supplementary Report

Supplementary Report

Not for Official Submission

Building name

Sonna National School

Building type: Primary school | **Date:** Thu Apr [illegible]

This report lists recommendations for energy-efficien[illegible] impr[illegible] to the buildi[illegible]

Key to colour codes used in this report

Included by the calculation
Included by the user
Excluded by the user

Recommendations for [illegible]

HEATING accounts f[illegible]0.2% of the CO2 emissions
(If hot water is provided by the [illegible] system [illegible] the % of CO2 [illegible] hot water provision)
The overall energy [illegible] of [illegible]ATING provision [illegible]
The overall CO2 per[illegible] HEATING pro[illegible]on is [illegible]
The average [illegible] of HEATING [illegible]ion is GO[illegible]
The average [illegible] HEATING [illegible] GOOD

Ad[illegible] the co[illegible] heating syste[illegible]

Co[illegible]	EPC-H[illegible]
En[illegible] Impact:	MEDIU[illegible]
CO2 [illegible]	M[illegible]
CO2 S[illegible] Spent:	GO[illegible]
Applicable to:	Whole [illegible]

Comments:

Add local time [illegible] to heating system.

Code:	[illegible]C-H5
Energy Impact:	MEDIUM
CO2 Im[illegible]	MEDIUM
CO2 Sav[illegible] € Spent:	FAIR
A[illegible] to:	Whole building

Comm[illegible]:

Add local temperature control to the heating system.

Code:	EPC-H6
Energy Impact:	MEDIUM
CO2 Impact:	MEDIUM
CO2 Saved per € Spent:	FAIR
Applicable to:	Whole building

Comments:

Add optimum start/stop to the heating system.

Code:	EPC-H7
Energy Impact:	MEDIUM

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CO2 Impact: MEDIUM
CO2 Saved per € Spent: GOOD
Applicable to: Whole building

Comments:

Add weather compensation controls to heating system.

Code: EPC-H8
Energy Impact: MEDIUM
CO2 Impact: MEDIUM
CO2 Saved per € Spent: FAIR
Applicable to: Whole building

Comments:

Add time control to heating system.

Code: EPC-H2
Energy Impact: MEDIUM
CO2 Impact: MEDIUM
CO2 Saved per € Spent: GOOD
Applicable to: Radiators

Comments:

Add local time control to heating system.

Code: EPC-H5
Energy Impact: MEDIUM
CO2 Impact: MEDIUM
CO2 Saved per € Spent: FAIR
Applicable to: [illegible]

Comments:

Add local temperature control to the heating system.

Code: EPC-H[illegible]
Energy Impact: MEDIUM
CO2 Impact: MEDIUM
CO2 Saved per € Spent: FAIR
Applicable to: Radiators

Comments:

Add optimum start/stop to the heating system.

Code: EPC-H7
Energy Impact: MEDIUM
CO2 Impact: MEDIUM
CO2 Saved per € Spent: GOOD
Applicable to: Radiators

Comments:

Add weather compensation controls to heating system.

Code: EPC-H8
Energy Impact: MEDIUM
CO2 Impact: MEDIUM
CO2 Saved per € Spent: FAIR
Applicable to: Radiators

Comments:

Recommendations for COOLING

COOLING accounts for 0% of the CO2 emissions
The overall energy performance of COOLING provision is NOT APPLICABLE
The overall CO2 performance of COOLING provision is NOT APPLICABLE
The average energy efficiency of COOLING provision is NOT APPLICABLE
The average CO2 efficiency of COOLING provision is NOT APPLICABLE

There are no recommendations for COOLING

Recommendations for HOT-WATER

HOT-WATER accounts for 0% of the CO2 emissions
(If hot water is provided by the HVAC system, then hot water provision is included in the % of [illegible] emissions [illegible] to HEATING)
The overall energy performance of HOT-WATER provision is FAIR
The overall CO2 performance of HOT-WATER provision is POOR
The average energy efficiency of HOT-WATER provision is NOT APPLICABLE
The average CO2 efficiency of HOT-WATER provision is NOT A[illegible]ABLE

Improve insulation on HWS storage.

Code:	EPC-W3
Energy Impact:	LOW
CO2 Impact:	LOW
CO2 Saved per € Spe[illegible]	[illegible]OOD
Applicable to:	[illegible]ding

Comments:

Im[illegible]ve ins[illegible]tion[illegible] HWS stora[illegible]

Co[illegible]	EPC-W[illegible]
En[illegible] Impact:	LO[illegible]
CO2 [illegible]:	L[illegible]
CO2 S[illegible]pent:	GO[illegible]
Applicable to:	Sink

Comments:

Reco[illegible]endation[illegible] for LIGHTING

LIGH[illegible]G ac[illegible]nts for 24.8% of the CO2 emissions
The ove[illegible]nergy performance of LIGHTING provision is GOOD
The overal[illegible]CO2 performance of LIGHTING provision is GOOD

Consider replacing T8 lamps with retrofit T5 conversion kit.

Code:	EPC-L5
Energy Impact:	LOW
CO2 Impact:	LOW
CO2 Saved per € Spent:	FAIR
Applicable to:	Whole building

Comments:

Introduce HF (high frequency) ballasts for fluorescent tubes: Reduced number of fittings required.

Code:	EPC-L7

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Energy Impact:	LOW
CO2 Impact:	LOW
CO2 Saved per € Spent:	POOR
Applicable to:	Whole building

Comments:

Recommendations for RENEWABLES

Consider installing building mounted wind turbin

Code:	EPC-R2
Energy Impact:	LOW
CO2 Impact:	LOW
CO2 Saved per € Spent:	POOR
Applicable to:	Whole building

Comments:

Consider installing solar water hea

Code:	EPC-R3
Energy Impact:	LOW
CO2 Impact:	LOW
CO2 Saved per € Spe	OOR
Applicable to:	ing

Comments:

Co lling V.

Co	EPC-R
En Impact:	LOW
CO act:	L
CO2 pent:	PC
Applicab	Whol ing

Comments:

Reco mendatio or OVERHEATING

The of so paces in the building OVERHEATING is High risk

Some sp s have a significant risk of overheating. Consider solar control measures such as the application of reflective coating or shading devices to windows.

Code:	EPC-V1
Energy Impact:	MEDIUM
CO2 Impact:	MEDIUM
CO2 Saved per € Spent:	POOR
Applicable to:	Whole building

Comments:

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Recommendations for ENVELOPE

There are no recommendations for ENVELOPE

Recommendations for FUEL-SWITCHING

Consider switching from oil or LPG to natural gas.

Code:	EPC-F1
Energy Impact:	HIGH
CO2 Impact:	HIGH
CO2 Saved per € Spent:	GOOD
Applicable to:	Radiators

Comments:

Consider switching from oil or LPG to biomass.

Code:	EPC-F4
Energy Impact:	HIGH
CO2 Impact:	HIGH
CO2 Saved per € Spent:	GOOD
Applicable to:	Radiators

Comments:

Recommendations for AUXILIARY

AUXILIARY accounts for 5% of the CO2 emissions
The overall energy performance of AUXILIARY provision is FAIR
The overall CO2 performance of AUXILIARY provision is FAIR

There are no recommendations for AUXILIARY

Recommendations for OTHER

There are no recommendations for OTHER

Phelim Martin

SBEM Data Reflection Report — Actual Building

Date: Thu Apr 18 15:36:35 2013

Project name: Sonna National School **Building type:** Primary school **Building area [m2]:** 467.814

General

Building address	Stonemore Mullingar Co. Westmeath
Building area [m2]	-6666
Weather	DUB
Building rotation [degrees]	0
Special conservation status	NO
Project complexity	Level 3

Energy assessor / Certifier

Name	<as name>
Telephone number	<as phone>
Address	<as address> Information not provided by the user <as city>
Assessor number	000000
Qualification	NOS5
Accreditation scheme	SEI Interim AS
Employer name	<as trade name>
Employer address	<as trade address>

Owner

Name	Unoccupied / not constructed
Telephone number	Information not provided by the user
Address	Information not provided by the user Information not provided by the user

Analysis

Compliance checked with	None
Asset rating	*Republic of Ireland: Building Energy Rating*
Stage	New Building - Provisional

Software

SBEM version	v3.5.b.1
Interface to SBEM	iSBEM
Interface version	v3.5.b

Envelope/Door constructions

Name	U-value [W/m2K]	Adjusted U-value	Km [kJ/m2K]	Metal clad
External Walls	0.27	NO	129	NO
Internal walls (unheated)	0.27	NO	180	NO
Internal walls (heated)	0.27	NO	180	NO
Main roof	0.16	NO	8.55	NO
Lower Rear Roof	0.16	NO	8.55	NO
Lower roof side entrance	0.16	NO	8.55	NO
Main Floor	0.25	NO	36	NO
Wooden louvers door	3	NO	11.25	NO

Window/Rooflight constructions

Name	U-value [W/m2K]	Solar transmittance	Light transmittance
Glazed Door / Windows	1.961	0.72	0.8
Smaller roof lights	2.115	0.72	0.8
Larger roof light AOV	2.298	0.72	0.8

Summary of objects

Object type	Total number	Total related area [m2]
Envelope/Door constructions	8	-
Window/Rooflight constructions	3	-
HW systems	2	-
SE systems	0	0
PV systems	0	0
Wind generators	0	-
CHP generators	0	-
HVAC systems	2	-
Zones	22	467.814
Envelopes	152	2084.22
Doors	1	1.97
Windows/Rooflights	24	97.36

Project building services

Electric power factor	<0.9
Submetering and M&T for lighting systems	NO
Emission factor for district heating [kgCO2/kWh]	0.293
Primary energy factor for district heating [kWh/kWh]	1.2

Notes

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Hot water systems

Name	Default DHW	Sink
Generator Type	Using Central Heating boiler	Using Central Heating boiler
Fuel type	Oil	Oil
Seasonal efficiency	0.97	0.97
Uses CHP	NO	NO
Storage system	NO	YES
Storage volume [litres]	-	160
Storage losses [MJ/month]	-	1481.57
Secondary circulation	-	NO
Circulation losses [W/m]	-	-
Pump power [kW]	-	-
Loop length [m]	-	-

Heating, ventilation, and air conditioning systems		
Name	Zones without HVAC system	Radiators
Type	No Heating or Cooling	Central heating using water: radiators
Heat source	-	LTHW boiler
Heating fuel type	-	Oil
Heating seasonal efficiency	-	0.97
Uses CHP	-	NO
Uses variable speed pumps	-	NO
Generator radiant efficiency	-	-
Packaged chiller type	-	-
Cooling fuel type	-	-
Cooling seasonal energy efficiency ratio	-	-
Cooling nominal energy efficiency ratio	-	-
Mixed mode operation	-	-
Heat recovery system	-	-
Heat recovery seasonal efficiency	-	-
Specific fan power [W/(l/s)]	-	-
Fanned air heaters auxiliary energy ratio	-	-
Submetering and M&T for this system	-	NO
Central time control	-	NO
Optimum stop/start control	-	NO
Local time control	-	NO
Local temperature control	-	NO
Weather compensation control	-	NO

Zone name: z0/05 | **Activity:** Storage area | **Multiplier:** 1

Area [m2]: 3.714 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC systems, ventilation, and exhaust

Name	Zones without HVAC system
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	YES
Exhaust air flow rate [l/s.m2]	4.4
SFP for mechanical exhaust [W/(l/s)]	1.5
Exhaust fans location	Extract system serving a single room

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.428

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-F-COMPACT
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.08
Wall-not ground floor	0.07	0.16
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/05/s	(1) z0/05/e	(1) z0/05/n	(1) z0/05/w	(1) z0/05/c	(1) z0/05/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	6.734	6.18	6.734	6.18	3.714	3.714
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Unheated	Conditioned	Conditioned	Exterior	Underground
Construction name	Internal walls (heated)	Internal walls (unheated)	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor

Notes

Zone name: z0/06 | **Activity:** Plant room | **Multiplier:** 1

Area [m2]: 6.648 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC systems, ventilation, and exhaust	
Name	Zones without HVAC system
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system	
Name	Default DHW
Dead leg length in this zone [m]	0

General Lighting and controls	
Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	NONE
Occupancy sensing parasitic power [W/m2]	-

Display lighting	
Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]		
Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes							
(Multiplier) Name	(1) z0/06/sl	(1) z0/06/e	(1) z0/06 n	(1) z0/06/wl	(1) z0/06/c	(1) z0/06/f	(1) z0/06 n.1
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall
Area [m2]	10.985	8.097	6.129	6.18	8.848	8.848	1.959
Orientation	South	East	North	West	Horizontal	Horizontal	North
Adjacent space	Conditioned	Exterior	Conditioned	Conditioned	Exterior	Underground	Conditioned
Construction name	Internal walls (heated)	External Walls	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor	Internal walls (heated)

Doors	
(Multiplier) Name	(1) z0/06/e.d
In envelope	z0/06/e
Area [m2]	1.97
Type	Personnel
Construction name	Wooden louvers door

Notes

Zone name: z0/16 | **Activity:** Circulation area (corridors and stairways) | **Multiplier:** 1

Area [m2]: 6.452 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Zones without HVAC system
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-F-COMPACT
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	NONE
Occupancy sensing parasitic power [W/m2]	-

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system

Name	Default DHW
Dead leg length in this zone [m]	0

Envelopes

(Multiplier) Name	(1) z0/16/si	(1) z0/16/ei	(1) z0/16/ni	(1) z0/16/w	(1) z0/16/c	(1) z0/16/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	6.257	10.234	6.257	10.234	6.452	6.452
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Exterior	Underground
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	External Walls	Main roof	Main Floor

Notes

Zone name: z0/01 | **Activity:** Classroom | **Multiplier:** 1

Area [m2]: 61.581 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	BOTH
Type of photoelectric control	PH-SWITCHING
Different sensor for back of zone	YES
Photoelectric control parasitic power [W/m2]	0.064726
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system

Name	Default DHW
Dead leg length in this zone [m]	0

Envelopes

(Multiplier) Name	(1) z0/01/si	(1) z0/01/e	(1) z0/01/n	(1) z0/01/wi	(1) z0/01/c	(1) z0/01/f	(1) z0/01/ni
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall
Area [m2]	10.107	26.902	14.929	27.234	62.58	61.581	6.997
Orientation	South	East	North	West	Horizontal	Horizontal	North
Adjacent space	Conditioned	Exterior	Exterior	Conditioned	Exterior	Underground	Conditioned
Construction name	Internal walls (heated)	External Walls	External Walls	Internal walls (heated)	Main roof	Main Floor	Internal walls (heated)

Windows & rooflights

(Multiplier) Name	(1) z0/01/e/g	(1) z0/01/n/g	(1) z0/01/rl
In envelope	z0/01/e	z0/01/n	z0/01/c
Area [m2]	8.66	4.33	1.49
Glazing name	Glazed Door / Windows	Glazed Door / Windows	Smaller roof lights
Surface area ratio	1	1	1.3
Area ratio covered	1	1	1
Shading system	All other cases	All other cases	Manual external
Transmission factor	1	1	1
Display	NO	NO	NO

Notes

Zone name: z0/02 | **Activity: Toilet** | **Multiplier: 1**

Area [m2]: 7.555 | **Height [m]: 3.11** | **Air permeability @ 50pa [m3/hm2]: 10**

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-F-COMPACT
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	AUTO-ON-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.443

Envelopes

(Multiplier) Name	(1) z0/02/sl	(1) z0/02/e	(1) z0/02/n	(1) z0/02/wl	(1) z0/02/c	(1) z0/02/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	10.107	7.203	10.107	7.203	7.555	7.555
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Exterior	Conditioned	Conditioned	Exterior	Underground
Construction name	Internal walls (heated)	External Walls	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/02/e/g
In envelope	z0/02/e
Area [m2]	1.27
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

IT Sligo

Zone name: z0/03 | **Activity:** Classroom | **Multiplier:** 1

Area [m2]: 8.937 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.323

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	BOTH
Type of photoelectric control	PH-SWITCHING
Different sensor for back of zone	YES
Photoelectric control parasitic power [W/m2]	0.129452
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/03/si	(1) z0/03/ei	(1) z0/03/wi	(1) z0/03/c	(1) z0/03/f	(1) z0/03/sl.1	(1) z0/03/e	(1) z0/03/n	(1) z0/03/wl.1	(1) z0/03/c.1
Type	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall	Wall	Wall	Wall	Pitched roof
Area [m2]	11.967	7.203	7.203	8.937	8.937	8.082	4.015	8.086	5.956	8.77
Orientation	South	East	West	Horizontal	Horizontal	South	East	North	West	Horizontal
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Underground	Unheated	Exterior	Conditioned	Conditioned	Exterior
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor	Internal walls (unheated)	External Walls	Internal walls (heated)	Internal walls (heated)	Main roof

Envelopes - continued

(Multiplier) Name	(1) z0/03/f.1	(1) z0/03/sl.2	(1) z0/03/el.1	(1) z0/03/nl.1
Type	Floor or Ceiling	Wall	Wall	Wall
Area [m2]	8.77	8.734	1.938	8.731
Orientation	Horizontal	South	East	North
Adjacent space	Underground	Unheated	Unheated	Conditioned
Construction name	Main Floor	Internal walls (unheated)	Internal walls (unheated)	Internal walls (heated)

Windows & rooflights

(Multiplier) Name	(1) z0/03/e/g
In envelope	z0/03/e
Area [m2]	3.63
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/04 | **Activity:** Toilet | **Multiplier:** 1

Area (m2): 8.77 | **Height (m):** 3.11 | **Air permeability @ 50pa (m3/hm2):** 10

HVAC system, ventilation, and exhaust	
Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	YES
Exhaust air flow rate [l/s.m2]	4.4
SFP for mechanical exhaust [W/(l/s)]	1.5
Exhaust fans location	Extract system serving a single room

Hot water system	
Name	Sink
Dead leg length in this zone [m]	1.248

General Lighting and controls	
Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-F-COMPACT
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	AUTO-ON-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting	
Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.5	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

Notes

Zone name: z0/07 | **Activity:** Meeting room | **Multiplier:** 1

Area [m2]: 25.316 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust	
Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system	
Name	Sink
Dead leg length in this zone [m]	1.082

General Lighting and controls	
Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	BOTH
Type of photoelectric control	PH-SWITCHING
Different sensor for back of zone	YES
Photoelectric control parasitic power [W/m2]	0.129452
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting	
Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]		
Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes								
(Multiplier) Name	(1) z0/07/sl	(1) z0/07/e	(1) z0/07/n	(1) z0/07/wl	(1) z0/07/c	(1) z0/07/f	(1) z0/07/sl.1	(1) z0/07/wl.1
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall	Wall
Area [m2]	9.948	15.283	16.798	13.507	25.316	25.316	6.798	1.792
Orientation	South	East	North	West	Horizontal	Horizontal	South	West
Adjacent space	Conditioned	Exterior	Conditioned	Conditioned	Exterior	Underground	Conditioned	Conditioned
Construction name	Internal walls (heated)	External Walls	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor	Internal walls (heated)	Internal walls (heated)

Windows & rooflights	
(Multiplier) Name	(1) z0/07/e/g
In envelope	z0/07/e
Area [m2]	4.33
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/08 | **Activity:** Toilet | **Multiplier:** 1

Area [m2]: 7.522 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.806

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	AUTO-ON-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.26
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.16
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/08/s	(1) z0/08/e	(1) z0/08/n	(1) z0/08/w	(1) z0/08/c	(1) z0/08/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	10.091	7.191	10.091	7.191	7.522	7.522
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Exterior	Conditioned	Conditioned	Exterior	Underground
Construction name	Internal walls (heated)	External Walls	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/08/e/g
In envelope	z0/08/e
Area [m2]	1.27
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/09 | **Activity:** Classroom | **Multiplier:** 1

Area [m2]: 10.166 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	BOTH
Type of photoelectric control	PH-SWITCHING
Different sensor for back of zone	YES
Photoelectric control parasitic power [W/m2]	0.129452
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water systems

Name	Sink
Dead leg length in this zone [m]	0.828

Envelopes

(Multiplier) Name	(1) z0/09/e	(1) z0/09/n	(1) z0/09/wi	(1) z0/09/c	(1) z0/09/f	(1) z0/09/wl.1
Type	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall
Area [m2]	7.191	11.98	7.191	10.166	10.166	1.804
Orientation	East	North	West	Horizontal	Horizontal	West
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Underground	Conditioned
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor	Internal walls (heated)

Notes

Zone name: z0/11 | **Activity:** Classroom | **Multiplier:** 1

Area [m2]: 61.588 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC systems, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/l/s]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/l/s]	-
Exhaust fans location	-

Hot water system

Name	Default DHW
Dead leg length in this zone [m]	0

General Lighting and controls

Total wattage [W]	-
Design Illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	BOTH
Type of photoelectric control	PH-SWITCHING
Different sensor for back of zone	YES
Photoelectric control parasitic power [W/m2]	0.064726
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/11/s	(1) z0/11/e	(1) z0/11/n	(1) z0/11/w	(1) z0/11/c	(1) z0/11/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	22.087	26.907	10.881	26.907	61.588	61.588
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Exterior	Conditioned	Conditioned	Exterior	Exterior	Underground
Construction name	External Walls	Internal walls (heated)	Internal walls (heated)	External Walls	Main roof	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/11/s/g	(1) z0/11/w/g	(1) z0/11/rl
In envelope	z0/11/s	z0/11/w	z0/11/c
Area [m2]	6.48	8.67	1.48
Glazing name	Glazed Door / Windows	Glazed Door / Windows	Smaller roof lights
Surface area ratio	1	1	1.3
Area ratio covered	1	1	1
Shading system	All other cases	All other cases	Manual external
Transmission factor	1	1	1
Display	NO	NO	NO

Notes

Zone name: z0/12 | **Activity:** Toilet | **Multiplier:** 1

Area [m2]: 7.506 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.776

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	AUTO-ON-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/12/s	(1) z0/12/e	(1) z0/12/n	(1) z0/12/w	(1) z0/12/r	(1) z0/12/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	10.091	7.169	10.091	7.169	7.506	7.506
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Exterior	Underground
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	External Walls	Main roof	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/12/w/g
In envelope	z0/12/w
Area [m2]	1.27
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/13	Activity: Classroom	Multiplier: 1
Area [m2]: 11.198	Height [m]: 3.11	Air permeability @ 50pa [m3/hm2]: 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Sns
Dead leg length in this zone [m]	8.984

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	BOTH
Type of photoelectric control	PH-SWITCHING
Different sensor for back of zone	YES
Photoelectric control parasitic power [W/m2]	0.129452
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.08
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/13/ei	(1) z0/13/n	(1) z0/13/wi	(1) z0/13/c	(1) z0/13/f	(1) z0/13/wi.1
Type	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall
Area [m2]	8.958	12.158	9.81	11.198	11.198	1.841
Orientation	East	North	West	Horizontal	Horizontal	West
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Underground	Conditioned
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor	Internal walls (heated)

Notes

Zone name: z0/14	Activity: Cellular office	Multiplier: 1
Area [m2]: 14.505	Height [m]: 3.11	Air permeability @ 50pa [m3/hm2]: 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Default DHW
Dead leg length in this zone [m]	0

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	NONE
Occupancy sensing parasitic power [W/m2]	-

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.20
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/14/si	(1) z0/14/ei	(1) z0/14/ni	(1) z0/14/w	(1) z0/14/c	(1) z0/14/f	(1) z0/14/s	(1) z0/14/ei.1	(1) z0/14/ni.1	(1) z0/14/wi
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall	Wall	Wall	Wall
Area [m2]	9.911	9.073	6.257	8.219	14.505	14.505	4.058	1.841	7.716	2.024
Orientation	South	East	North	West	Horizontal	Horizontal	South	East	North	West
Adjacent space	Conditioned	Conditioned	Unheated	Exterior	Exterior	Underground	Exterior	Conditioned	Conditioned	Unheated
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	External Walls	Main roof	Main Floor	External Walls	Internal walls (heated)	Internal walls (heated)	Internal walls (unheated)

Windows & rooflights

(Multiplier) Name	(1) z0/14/w/g
In envelope	z0/14/w
Area [m2]	3.30
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/15 **Activity:** Toilet **Multiplier:** 1

Area [m2]: 5.423 **Height [m]:** 3.11 **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	YES
Exhaust air flow rate [l/s.m2]	4.4
SFP for mechanical exhaust [W/(l/s)]	1.5
Exhaust fans location	Extract system serving a single room

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.279

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-F-COMPACT
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/15/sl	(1) z0/15/el	(1) z0/15/nl	(1) z0/15/wl	(1) z0/15/c	(1) z0/15/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	6.837	9.079	6.837	9.079	5.243	5.423
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Conditioned	Conditioned	Conditioned	Exterior	Underground
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/15/rl
In envelope	z0/15/c
Area [m2]	0.75
Glazing name	Smaller roof lights
Surface area ratio	1.3
Area ratio covered	1
Shading system	Manual external
Transmission factor	1
Display	NO

Notes

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Zone name: z0/17 | **Activity:** Circulation area (corridors and stairways) | **Multiplier:** 1

Area [m2]: 41.345 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	NONE
Occupancy sensing parasitic power [W/m2]	-

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.16
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system

Name	Default DHW
Dead leg length in this zone [m]	0

Envelopes

(Multiplier) Name	(1) z0/17/si	(1) z0/17/ei	(1) z0/17/ni	(1) z0/17/wi	(1) z0/17/c	(1) z0/17/f	(1) z0/17/sl.1	(1) z0/17/ei.1	(1) z0/17/ni.1	(1) z0/17/wl.1
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall	Wall	Wall	Wall
Area [m2]	10.56	13.387	14.746	7.421	41.345	41.345	4.75	6.16	10.56	9.11
Orientation	South	East	North	West	Horizontal	Horizontal	South	East	North	West
Adjacent space	Conditioned	Conditioned	Conditioned	Unheated	Exterior	Underground	Conditioned	Unheated	Conditioned	Conditioned
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Internal walls (unheated)	Main roof	Main Floor	Internal walls (heated)	Internal walls (unheated)	Internal walls (heated)	Internal walls (heated)

Envelopes - continued

(Multiplier) Name	(1) z0/17/ei.2	(1) z0/17/wi.2
Type	Wall	Wall
Area [m2]	5.955	10.879
Orientation	East	West
Adjacent space	Conditioned	Conditioned
Construction name	Internal walls (heated)	Internal walls (heated)

Windows & rooflights

(Multiplier) Name	(1) z0/17/rl	(1) z0/17/rl.1
In envelope	z0/17/c	z0/17/c
Area [m2]	0.2	13.92
Glazing name	Smaller roof lights	Larger roof light AOV
Surface area ratio	1.3	1.3
Area ratio covered	1	1
Shading system	Manual external	Manual external
Transmission factor	1	1
Display	NO	NO

Notes

Zone name: z0/18 | **Activity: Tea making** | **Multiplier: 1**

Area (m2): 23.014 | **Height (m): 3.11** | **Air permeability @ 50pa [m3/hm2]: 10**

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Sink
Dead leg length in this zone [m]	0.436

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.28
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Envelopes

(Multiplier) Name	(1) z0/18/sl	(1) z0/18/el	(1) z0/18/n	(1) z0/18/wl	(1) z0/18/c	(1) z0/18/f	(1) z0/18/sl.1	(1) z0/18/nl	(1) z0/18/w	(1) z0/18/nl.1
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall	Wall	Wall	Wall
Area [m2]	14.748	10.879	7.074	0.792	23.014	23.014	6.076	9.952	9.461	6.876
Orientation	South	East	North	West	Horizontal	Horizontal	South	North	West	North
Adjacent space	Conditioned	Conditioned	Exterior	Conditioned	Exterior	Underground	Unheated	Conditioned	Exterior	Conditioned
Construction name	Internal walls (heated)	Internal walls (heated)	External Walls	Internal walls (heated)	Main roof	Main Floor	Internal walls (unheated)	Internal walls (heated)	External Walls	Internal walls (heated)

Windows & rooflights

(Multiplier) Name	(1) z0/18/w/g
In envelope	z0/18/w
Area [m2]	3.36
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/19 | **Activity:** Toilet | **Multiplier:** 1

Area [m2]: 7.541 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design Illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-F-COMPACT
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	AUTO-ON-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.29
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system

Name	Sink
Dead leg length in this zone [m]	1.433

Envelopes

(Multiplier) Name	(1) z0/19/s	(1) z0/19/e	(1) z0/19/n	(1) z0/19/w	(1) z0/19/c	(1) z0/19/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	10.091	7.203	10.091	7.203	7.541	7.541
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Exterior	Underground
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	External Walls	Lower Rear Roof	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/19/w/g
In envelope	z0/19/w
Area [m2]	1.27
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

Zone name: z0/20 **Activity:** Classroom **Multiplier:** 1

Area [m2]: 8.951 **Height [m]:** 3.11 **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

Hot water system

Name	Sina
Dead leg length in this zone [m]	0.926

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.26
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

[illegible]

(Multiplier) Name	(1) z0/20/sl	(1) z0/20/el	(1) z0/20/wl	(1) z0/20/c	(1) z0/20/f
Type	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	11.976	7.203	7.203	8.951	8.951
Orientation	South	East	West	Horizontal	Horizontal
Adjacent space	Conditioned	Conditioned	Conditioned	Exterior	Underground
Construction name	Internal walls (heated)	Internal walls (heated)	Internal walls (heated)	Main roof	Main Floor

[illegible]

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Zone name: z0/21 | **Activity:** Classroom | **Multiplier:** 1

Area [m2]: 61.581 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust	
Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls	
Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T05-F-T-H
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	MAN-ON-AUTO-OFF
Occupancy sensing parasitic power [W/m2]	0.3

Display lighting	
Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges (Psi values [W/mK])		
Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.29
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system	
Name	Default DHW
Dead leg length in this zone [m]	0

Envelopes							
(Multiplier) Name	(1) z0/21/si	(1) z0/21/ei	(1) z0/21/n	(1) z0/21/w	(1) z0/21/c	(1) z0/21/f	(1) z0/21/ni
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling	Wall
Area [m2]	10.09	27.234	15.081	26.902	61.581	61.581	6.977
Orientation	South	East	North	West	Horizontal	Horizontal	North
Adjacent space	Conditioned	Conditioned	Exterior	Exterior	Exterior	Underground	Conditioned
Construction name	Internal walls (heated)	Internal walls (heated)	External Walls	External Walls	Main roof	Main Floor	Internal walls (heated)

Windows & rooflights			
(Multiplier) Name	(1) z0/21/n/g	(1) z0/21/w/g	(1) z0/21/rl
In envelope	z0/21/n	z0/21/w	z0/21/c
Area [m2]	4.33	8.66	1.49
Glazing name	Glazed Door / Windows	Glazed Door / Windows	Smaller roof lights
Surface area ratio	1	1	1.3
Area ratio covered	1	1	1
Shading system	All other cases	All other cases	Manual external
Transmission factor	1	1	1
Display	NO	NO	NO

Notes

Zone name: z0/22 | **Activity:** Circulation area (corridors and stairways) | **Multiplier:** 1

Area [m2]: 10.823 | **Height [m]:** 3.11 | **Air permeability @ 50pa [m3/hm2]:** 10

HVAC system, ventilation, and exhaust

Name	Radiators
Destratification fans	NO
Ventilation type	Natural
SFP for local mechanical supply & extract [W/(l/s)]	-
Heat Recovery system	-
Heat recovery seasonal efficiency	-
High pressure drop air treatment required	NO
Local mechanical exhaust	NO
Exhaust air flow rate [l/s.m2]	-
SFP for mechanical exhaust [W/(l/s)]	-
Exhaust fans location	-

General Lighting and controls

Total wattage [W]	-
Design illuminance [Lux]	-
Lamp and ballast efficacy [Lumens/W]	-
Lamp type	C-T08-F-H-L
Air-extracting luminaires	NO
Controls	MANUAL
Type of photoelectric control	-
Different sensor for back of zone	-
Photoelectric control parasitic power [W/m2]	-
Automatic daylight zoning	YES
Percentage area controlled	-
Occupancy sensing	NONE
Occupancy sensing parasitic power [W/m2]	-

Display lighting

Efficient lamps	NO
Lumens per circuit wattage	-
Time control	NONE
Hours off	-
Fraction off	-

Thermal bridges Psi values [W/mK]

Junction type	Metal clad	Not metal clad
Roof-wall	0.6	0.12
Wall-ground floor	1.15	0.29
Wall-wall (corner)	0.25	0.09
Wall-not ground floor	0.07	0.18
Lintel (window/door)	1.27	0.53
Sill (window)	1.27	0.21
Jamb (window/door)	1.27	0.2

Hot water system

Name	Default DHW
Dead leg length in this zone [m]	0

Envelopes

(Multiplier) Name	(1) z0/22/s	(1) z0/22/e	(1) z0/22/n	(1) z0/22/w	(1) z0/22/c	(1) z0/22/f
Type	Wall	Wall	Wall	Wall	Pitched roof	Floor or Ceiling
Area [m2]	13.954	7.474	13.954	7.474	10.823	10.823
Orientation	South	East	North	West	Horizontal	Horizontal
Adjacent space	Conditioned	Exterior	Exterior	Exterior	Exterior	Underground
Construction name	Internal walls (heated)	External Walls	External Walls	External Walls	Lower roof side entrance	Main Floor

Windows & rooflights

(Multiplier) Name	(1) z0/22/n/g
In envelope	z0/22/n
Area [m2]	3.45
Glazing name	Glazed Door / Windows
Surface area ratio	1
Area ratio covered	1
Shading system	All other cases
Transmission factor	1
Display	NO

Notes

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Appendix "C"

3.0 Case Study – Green Building Studio Data Outputs

3.1 Conceptual Mass – Original Design

https://gbs.autodesk.com/gbs/Scheme/EnergyAndCarbonResults?RunId=0xmYUU1E... 20/04/2013

Building Details and Assumptions

Note: Details shown below are for the Base Run Original Drawing.xml

Updating your building assumptions

Building Summary - Quick Stats

Number of People:	127 people
Average Lighting Power Density:	12.91 W / m² ↓
Average Equipment Power Density:	10.76 W / m²
Specific Fan Flow:	4.4 LPerSec / m²
Specific Fan Power:	1.419 W / LPerSec
Specific Cooling:	12 m² / kW
Specific Heating:	6 m² / kW
Total Fan Flow:	2,262 LPerSec
Total Cooling Capacity:	42 kW
Total Heating Capacity:	80 kW

↑ higher than typical value
↓ lower than typical value

Base Run Construction

Roofs	R20 over Roof Deck U-Value: 0.25	509 m²
Exterior Walls	R11.4 8in CMU Wall U-Value: 0.46	321 m²
Interior Walls	R0 Metal Frame Wall U-Value: 2.35	279 m²
Slabs On Grade	Uninsulated concrete slab U-Value: 0.16	509 m²
Fixed Windows	North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (4 windows) U-Value: 1.74 W / (m²-K), SHGC: 0.40 , Vlt: 0.60	44 m²
	Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (12 windows) U-Value: 1.74 W / (m²-K), SHGC: 0.40 , Vlt: 0.60	85 m²

> 3D VRML View

Base Run Hydronic Equipment

Note: this information should not be used for sizing purposes.

Domestic Hot Water	Average Demand	25,859

Base Run Air Equipment

Note: this information should not be used for sizing purposes.

Packaged Single Zone	Supply Fan Flow	470 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	9
	Heating Capacity	17
Packaged Single Zone	Supply Fan Flow	329 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	6
	Heating Capacity	12
Packaged Single Zone	Supply Fan Flow	175 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	3
	Heating Capacity	6
Packaged Single Zone	Supply Fan Flow	517 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	9
	Heating Capacity	18
Packaged Single Zone	Supply Fan Flow	770 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	15
	Heating Capacity	27

https://gbs.autodesk.com/gbs/Scheme/EnergyAndCarbonResults?RunId=0xmYUU1E... 20/04/2013

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My Projects > **Design Option 3**

Run List | Run Charts | Project Defaults | Project Details | Project Members | Utility Information | Weather Station

Name	Design Option 3
Building Type [1]	School Or University
Schedule [1]	24/5 Facility
Project Type [2]	Actual Project: A new or existing building project Test Project: For Learning or demonstration only
Address [3]	[illegible]
City [3]	Mullingar
State/Province [3]	Westmeath
Postal Code [1]	
Country [3]	Ireland
Time Zone [3]	[illegible] Standard Time
Currency [3]	Euro (EUR)
Notes	
Data Access	Do not share any data associated with the project Share only summary data. For example, the building type or floor area. Share all project data
Contact Preference	Do not contact me Only Autodesk may contact me Autodesk partners may contact me regarding this project
Autodesk Green Building Studio Web Service Terms of Use (TOU)	Phelim Martin is authorized to accept the terms of the TOU and share project data with the GBS web service

[1] Cannot be changed if runs are present

[2] Green Building Studio maintains a database of building projects to track modeled vs actual energy use. This will help us better understand the energy use patterns for various building types in different climates.

[3] Cannot be changed once a project has been created

Update | Cancel

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Version [illegible]

https://gbs.autodesk.com/GBS/Project/ProjectDetails?ProjectID=Jn8P47JxXhc%3d 22/04/2013

AUTODESK.

Original Drawing

Original Drawing Analysis (4)

Analyzed at 4/19/2013 12:07:29 PM

Revit Energy Analysis Result

Building Performance Factors

Location:	DUBLIN AIRPORTER (DUB), Dublin International Airport, Co. Fingal, Ireland
Weather Station	142982
Outdoor Temperature:	Max: 33°C/Min: -2°C
Floor Area	509 m²
Exterior Wall Area	321 m²
Average Lighting Power:	12.82 W / m²
People	127 people
Exterior Window Ratio	0.40
Electrical Cost	$0.15 / kWh
Fuel Cost	$1.12 / Therm

Energy Use Intensity

Electricity EUI:	83 kWh / sm / yr
Fuel EUI:	392 MJ / sm / yr
Total EUI	690 MJ / sm / yr

Life Cycle Energy Use/Cost

Life Cycle Electricity Use	1,267,012 kWh
Life Cycle Fuel Use	5,980,392 MJ
Life Cycle Energy Cost	$112,805

*30-year life and 6.1% discount rate for costs

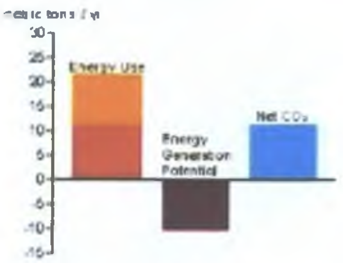
Renewable Energy Potential

Roof Mounted PV System (Low efficiency)	12,215 kWh / yr
Roof Mounted PV System (Medium efficiency)	24,430 kWh / yr
Roof Mounted PV System (High efficiency)	36,645 kWh / yr
Single 15' Wind Turbine Potential	992 kWh / yr

*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems

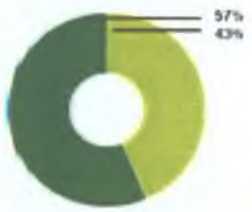
1

Annual Carbon Emissions



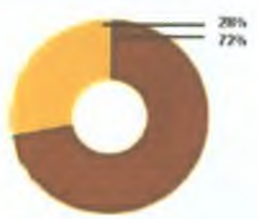
	(metric tons / yr)
Electricity Consumption	11
Fuel Consumption	8
Roof PV Potential (High Efficiency)	-9
Single 15' Wind Turbine Potential	0
Net CO_2	11

Annual Energy Use/Cost



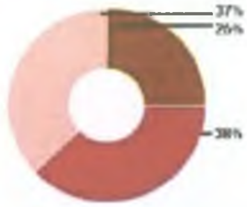
Electricity	43%	$6,166	42,233	kWh
Fuel	57%	$2,124	189,346	MJ
		$8,290		

Energy Use: Fuel



			(MJ)
HVAC	72%	$1,530	143,663
Domestic Hot Water	28%	$593	[illegible]
		$2,123	189,346

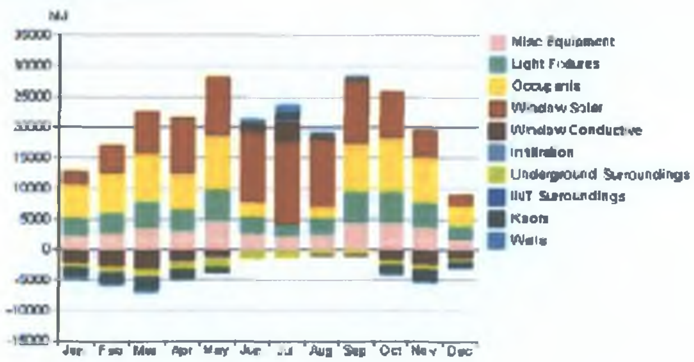
Energy Use: Electricity



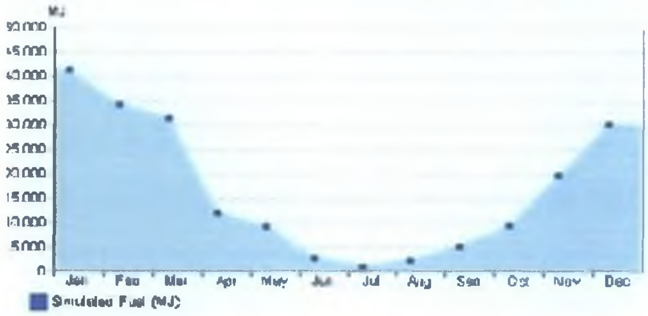
			(kWh)
HVAC	26%	$1,843	10,969
Lighting	38%	$2,332	18,972
Misc Equipment	37%	$2,280	18,691
		[illegible]	47,232

Monthly Heating Load

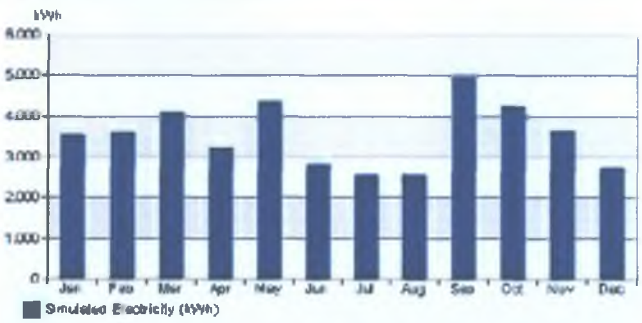
Monthly Cooling Load



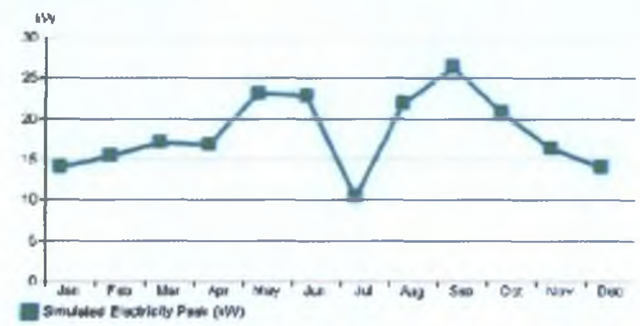
Monthly Fuel Consumption



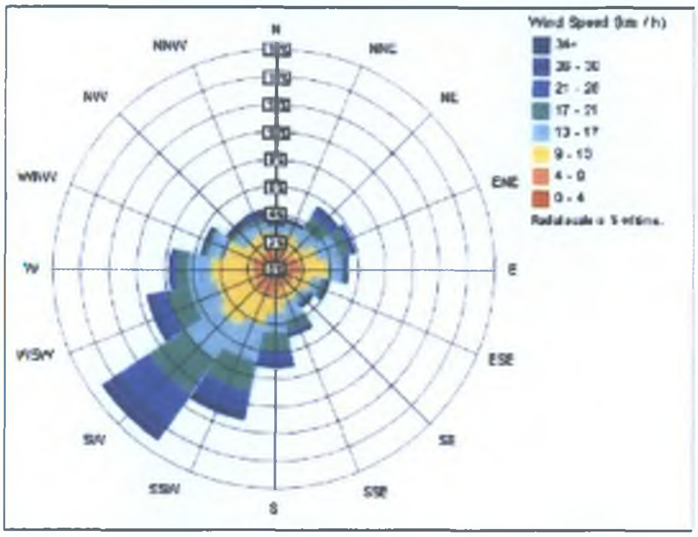
Monthly Electricity Consumption



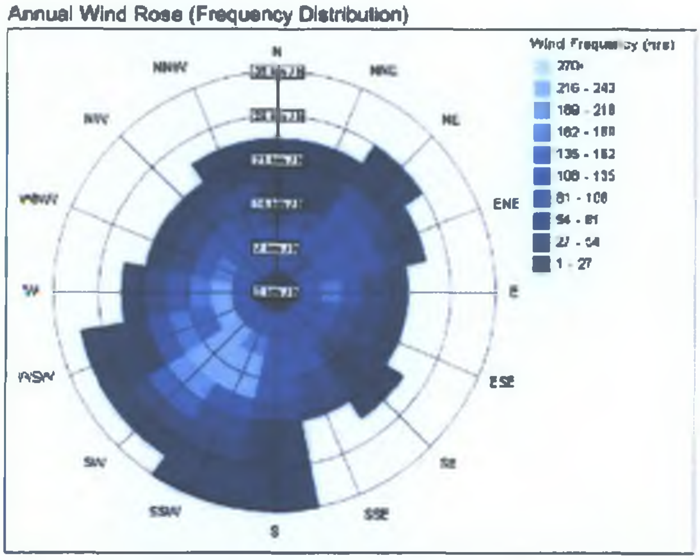
Monthly Peak Demand



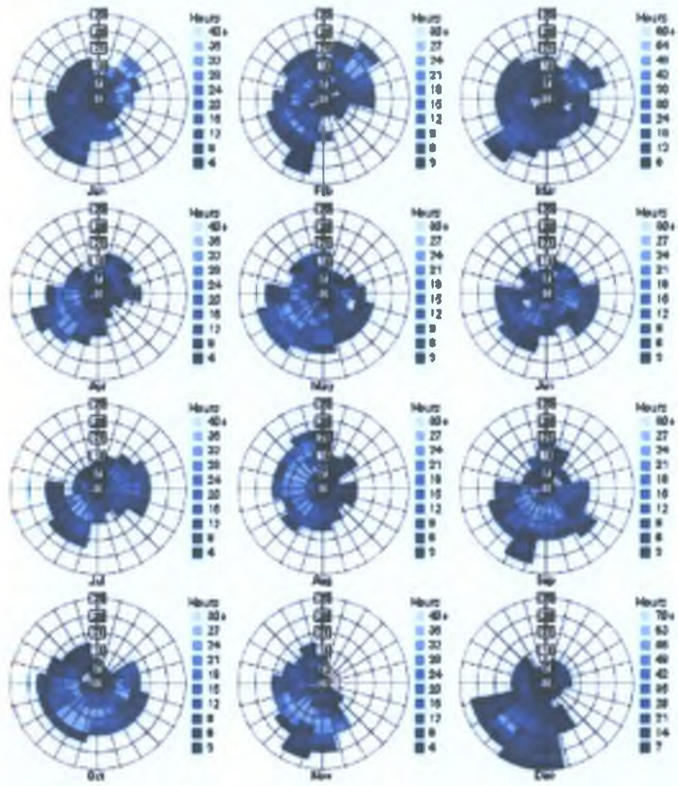
Annual Wind Rose (Speed Distribution)



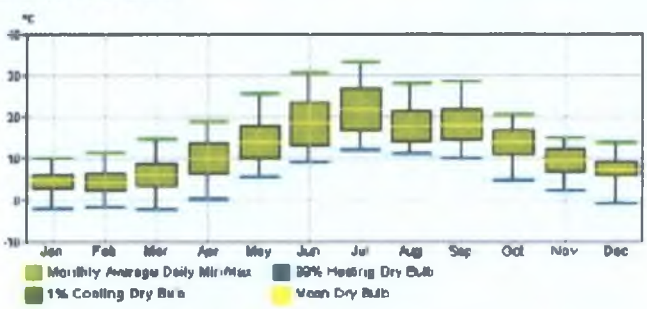
Annual Wind Rose (Frequency Distribution)



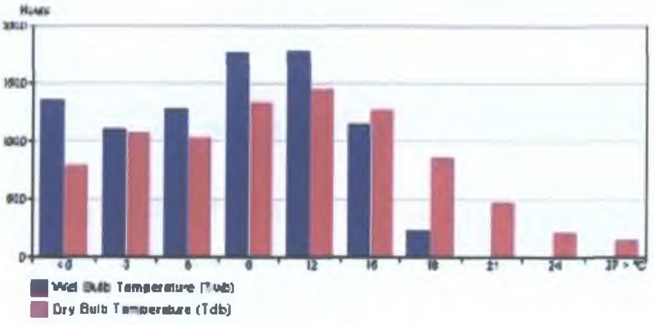
Monthly Wind Roses



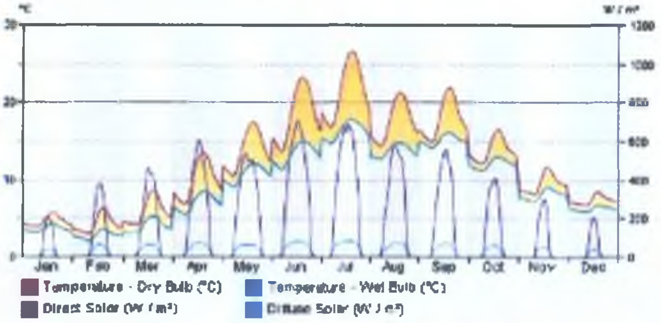
Monthly Design Data



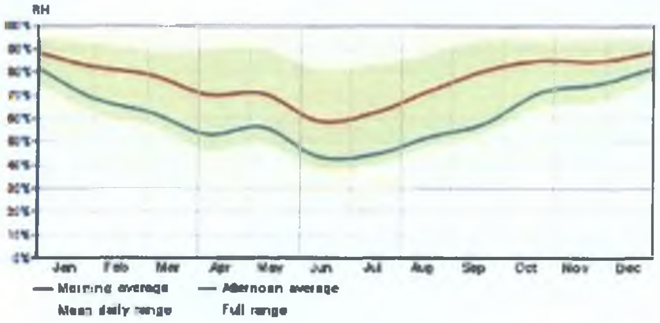
Annual Temperature Bins



Diurnal Weather Averages



Humidity



Revit Energy Analysis Data

3.2 Conceptual Mass – Design Option 2

https://gbs.autodesk.com/gbs/Scheme/EnergyAndCarbonResults?RunId=c%2bqiLpM... 20/04/2013

Building Details and Assumptions

Note: Details shown below are for the Base Run Design Option 2.xml

Updating your building assumptions

Building Summary - Quick Stats

Number of People:	127 people
Average Lighting Power Density:	12.91 W / m² ↓
Average Equipment Power Density:	10.76 W / m²
Specific Fan Flow:	4.6 LPerSec / m²
Specific Fan Power:	1.419 W / LPerSec
Specific Cooling:	12 m² / kW
Specific Heating:	6 m² / kW
Total Fan Flow:	2,321 LPerSec
Total Cooling Capacity:	42 kW
Total Heating Capacity:	82 kW

↑ higher than typical value
↓ lower than typical value

Base Run Construction

Roofs	R20 over Roof Deck U-Value: 0.25	509 m²
Exterior Walls	R11.4 8in CMU Wall U-Value: 0.46	332 m²
Interior Walls	R0 Metal Frame Wall U-Value: 2.36	334 m²
Slabs On Grade	Uninsulated concrete slab U-Value: 0.16	509 m²
Fixed Windows	North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (3 windows) U-Value: 1.74 W / (m²-K), SHGC: 0.40 , Vlt: 0.60	25 m²
	Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (9 windows) U-Value: 1.74 W / (m²-K), SHGC: 0.40 , Vlt: 0.60	108 m²

> 3D VRML View

Base Run Hydronic Equipment

Note: this information should not be used for sizing purposes.

Domestic Hot Water	Average Demand	25,291

Base Run Air Equipment

Note: this information should not be used for sizing purposes.

Packaged Single Zone	Supply Fan Flow	623 LPerSec
	Annual Supply Fan Run Time	2,845 Hours
	Cooling Capacity	11
	Heating Capacity	22
Packaged Single Zone	Supply Fan Flow	613 LPerSec
	Annual Supply Fan Run Time	2,845 Hours
	Cooling Capacity	11
	Heating Capacity	22
Packaged Single Zone	Supply Fan Flow	389 LPerSec
	Annual Supply Fan Run Time	2,845 Hours
	Cooling Capacity	7
	Heating Capacity	14
Packaged Single Zone	Supply Fan Flow	697 LPerSec
	Annual Supply Fan Run Time	2,845 Hours
	Cooling Capacity	13
	Heating Capacity	25

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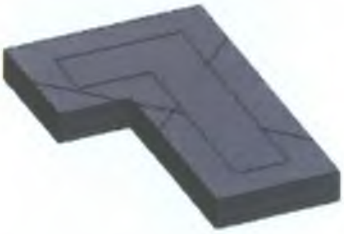
AUTODESK.

Design Option 2 (1)

Design Option 2 Analysis (1)

Analyzed at 4/19/2013 2:04:51 PM

Revit Energy Analysis Result



Building Performance Factors

Location:	Dublin Airport (DUB), Swords Road, Co. Dublin, Ireland
Weather Station	142982
Outdoor Temperature:	Max: 33°C/Min: -2°C
Floor Area	509 m²
Exterior Wall Area	332 m²
Average Lighting Power:	12.92 W / m²
People	127 people
Exterior Window Ratio	0.40
Electrical Cost	$0.17 / kWh
Fuel Cost	$1.22 / Therm

Energy Use Intensity

Electricity EUI:	181 kWh / sm / yr
Fuel EUI:	706 MJ / sm / yr
Total EUI	1,357 MJ / sm / yr

Life Cycle Energy Use/Cost

Life Cycle Electricity Use	2,761,390 kWh
Life Cycle Fuel Use	10,790,077 MJ
Life Cycle Energy Cost	$268,386

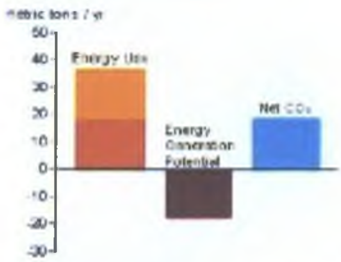
*30-year life and 6.1% discount rate for costs

Renewable Energy Potential

Roof Mounted PV System (Low efficiency)	28,509 kWh / yr
Roof Mounted PV System (Medium efficiency):	57,017 kWh / yr
Roof Mounted PV System (High efficiency)	85,526 kWh / yr
Single 15' Wind Turbine Potential	992 kWh / yr

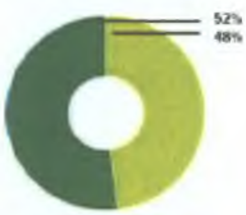
*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems

Annual Carbon Emissions



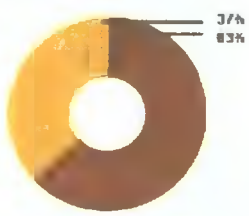
	(metric tons / yr)
Electricity Consumption	18
Fuel Consumption	17
Roof PV Potential (High Efficiency)	-17
Single 15' Wind Turbine Potential	0
Net CO_2	18

Annual Energy Use/Cost



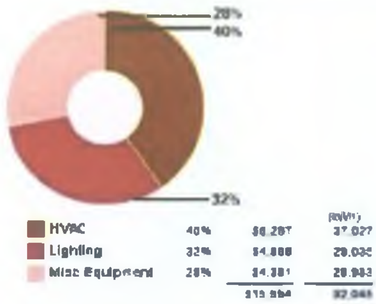
Electricity	48%	$15,558	92,048	kWh
Fuel	52%	$4,148	359,335	MJ
		$19,706		

Energy Use: Fuel

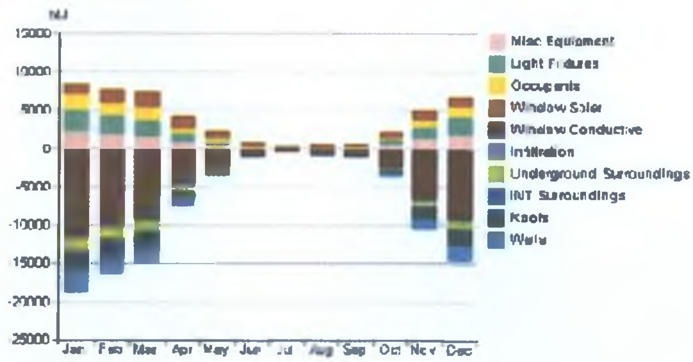


			(MJ)
HVAC	63%	$2,630	227,822
Domestic Hot Water	37%	$1,518	131,513
		$4,148	359,336

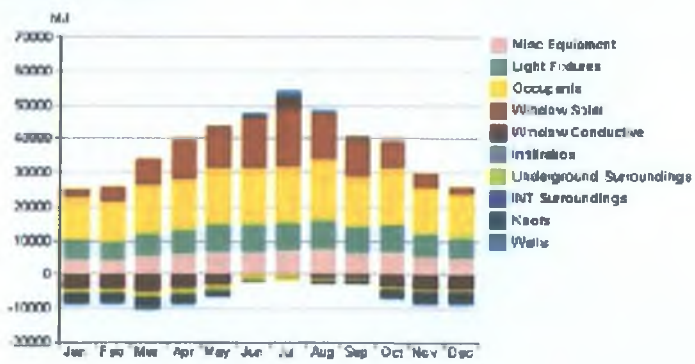
Energy Use: Electricity



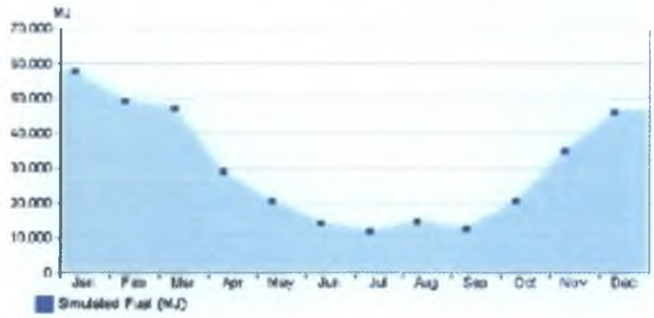
Monthly Heating Load



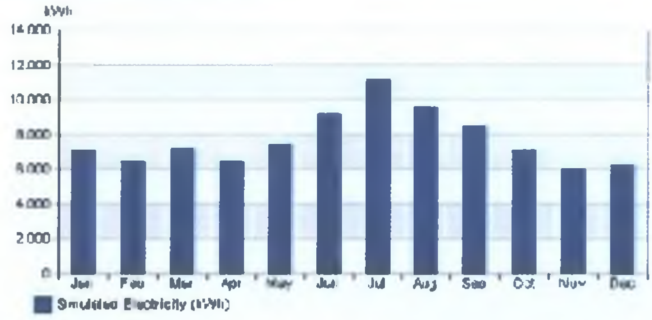
Monthly Cooling Load



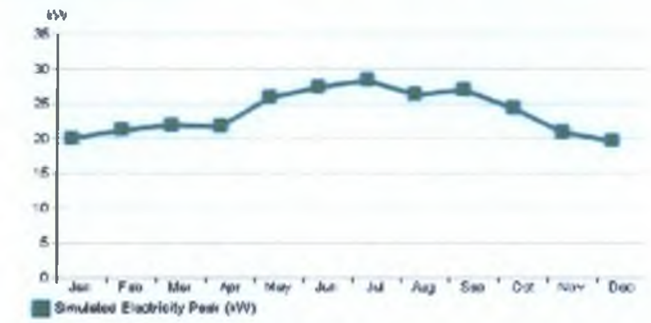
Monthly Fuel Consumption



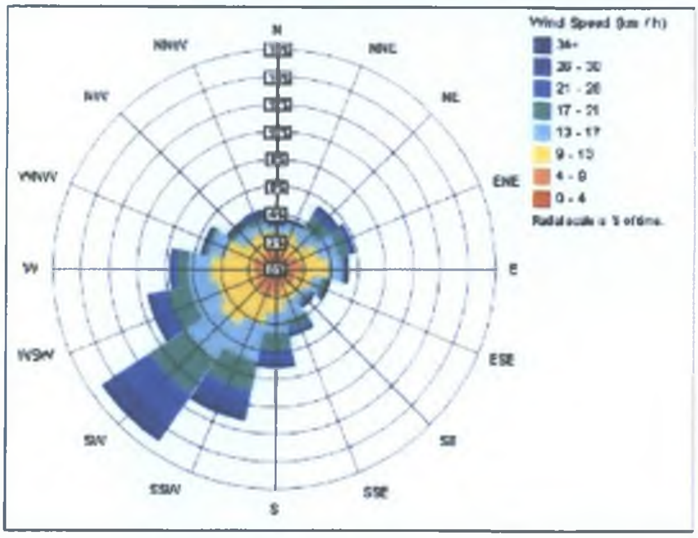
Monthly Electricity Consumption



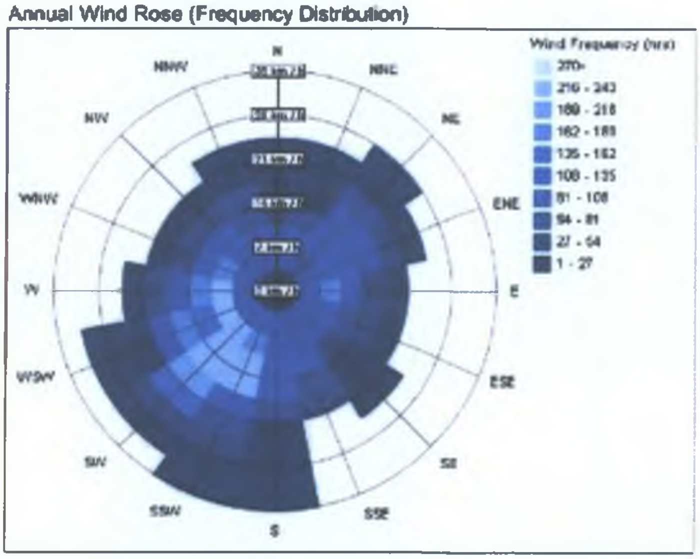
Monthly Peak Demand



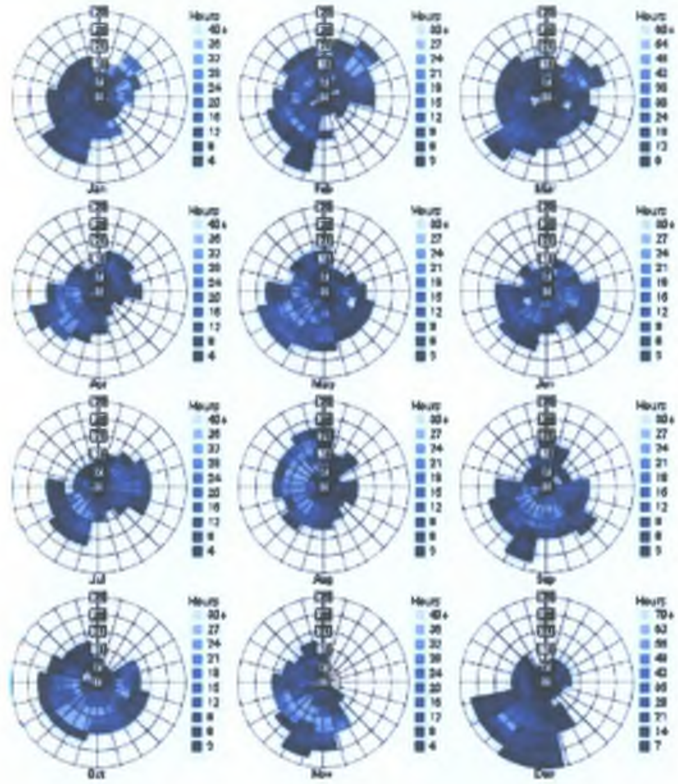
Annual Wind Rose (Speed Distribution)



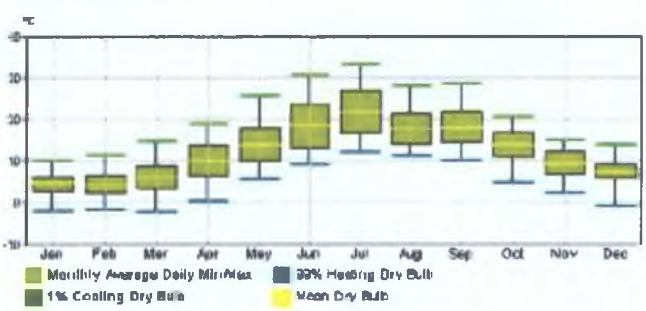
Annual Wind Rose (Frequency Distribution)



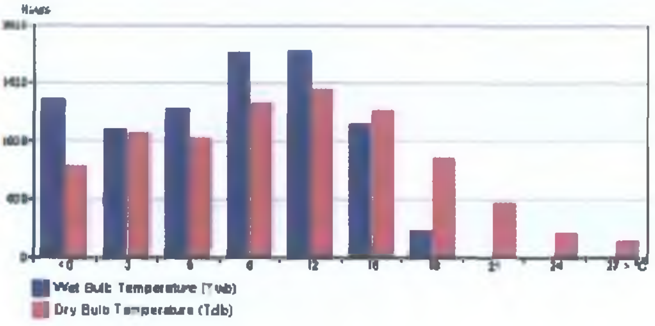
Monthly Wind Roses



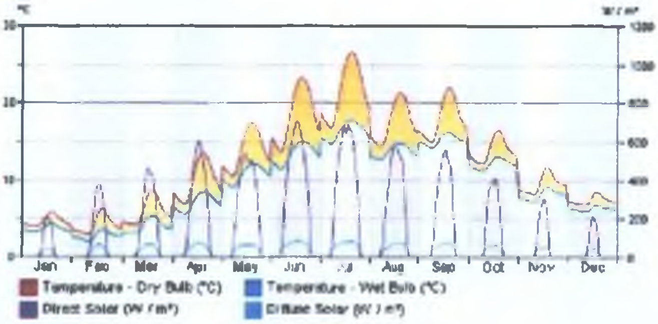
Monthly Design Data



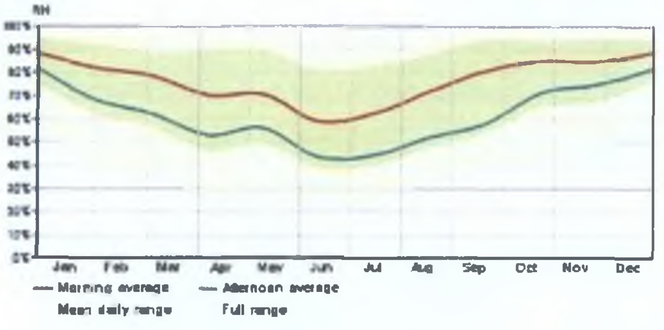
Annual Temperature Bins



Diurnal Weather Averages



Humidity



Revit Energy Analysis Data

3.3 Conceptual Mass – Design Option 3

Autodesk Green Building Studio

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My Projects | Dashboards | My Profile | My Account | Welcome, Phelim!

My Projects > Design Option 3

Run List | Run Charts | Project Defaults | Project Details | Project Members | Utility Information | Weather Station | Notes

Run Name: Design option 3.xml

Energy and Carbon Results | US EPA Energy Star | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

Project Template Applied: Design Option 3_default

Location: Mullingar, Westmeath

Building Type: SchoolOrUniversity

Floor Area: 509 m²

Electric Cost: €0.30 / kWh

Fuel Cost: €0.01 / MJ

Utility Data Used: Project Default Utility Rates

1 Base Run

2 Design Alternative

Create a Design Alternative to improve your building performance.

Energy, Carbon and Cost Summary

Annual Energy Cost €26,961

Lifecycle Cost €367,205

Annual CO_2 Emissions

Electric 16.5 Mg

Onsite Fuel 9.4 Mg

Large SUV Equivalent 2.6 SUVs / Year

Annual Energy

Energy Use Intensity (EUI) 940 MJ / m² / year

Electric 81,773 kWh

Fuel 188,785 MJ

Annual Peak Demand 24.6 kW

Lifecycle Energy

Electric 2,453,201 kW

Fuel 5,663,535 MJ

Assumptions

Carbon Footprint

Base Run Carbon Neutral Potential

Annual CO_2 Emissions	Mg
Base Run	26.0
Onsite Renewable Potential	-15.8
Natural Ventilation Potential	-4.6
Onsite Biofuel Use	-9.4
Net CO_2 Emissions	-3.8
Net Large SUV Equivalent	-0.4 SUVs / Year

Assumptions

Electric Power Plant Sources in Your Region

Fossil	81 %
Nuclear	N/A
Hydroelectric	4 %
Renewable	14 %
Other	N/A

Assumptions

LEED, Photovoltaic, Wind Energy, and Natural Ventilation Potential

Note: Details shown below are for the Base Run Design option 3.xml

LEED Daylight (more details)

Percentage of building area with glazing factor over 2%: **64.4% - No LEED Credit**

LEED Water Efficiency (more details)

	L / yr	€ / yr
Indoor	1,315,199	€2,113
Outdoor	696,701	€479
Total	2,011,900	€2,591

Photovoltaic Potential (more details)

Annual Energy Savings:	60,812 kWh
Total Installed Panel Cost:	€711,326
Nominal Rated Power:	90 kW
Total Panel Area:	644 m²
Maximum Payback Period:	29 years @ €0.30 / kWh

Wind Energy Potential

Annual Electric Generation: 2,716 kWh

Assumptions

Natural Ventilation Potential

Total Hours Mechanical Cooling Required:	2,616 Hours
Possible Natural Ventilation Hours:	2,515 Hours
Possible Annual Electric Energy Savings:	18,486 kWh
Possible Annual Electric Cost Savings:	€5,601
Net Hours Mechanical Cooling Required:	101 Hours

Assumptions

Energy End Use Charts

Note: Details shown below are for the Base Run Design option 3.xml

https://gbs.autodesk.com/GBS/Scheme/EnergyAndCarbonResults?RunID=Px7uVrfx... 20/04/2013

Building Details and Assumptions

Note: Details shown below are for the Base Run Design option 3.xml

Updating your building assumptions

Building Summary - Quick Stats

Number of People:	127 people
Average Lighting Power Density:	12.91 W / m²
Average Equipment Power Density:	10.76 W / m²
Specific Fan Flow:	4.6 LPerSec / m²
Specific Fan Power:	1.418 W / LPerSec
Specific Cooling:	12 m² / kW
Specific Heating:	6 m² / kW
Total Fan Flow:	2,331 LPerSec
Total Cooling Capacity:	43 kW
Total Heating Capacity:	82 kW

higher than typical value
lower than typical value

Base Run Construction

Roofs	R20 over Roof Deck U-Value: 0.25	509 m²
Exterior Walls	R11.4 8in CMU Wall U-Value: 0.46	332 m²
Interior Walls	R0 Metal Frame Wall U-Value: 2.36	334 m²
Slabs On Grade	Uninsulated concrete slab U-Value: 0.16	509 m²
Fixed Windows	North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (5 windows) U-Value: 1.74 W / (m²-K), SHGC: 0.40, Vlt: 0.60	41 m²
	Non-North Facing Windows: Pewter Double, U-SI 1.74, U-IP 0.31, SHGC 0.4, VLT 0.6 (7 windows) U-Value: 1.74 W / (m²-K), SHGC: 0.40, Vlt: 0.60	92 m²

> 3D VRML View

Base Run Hydronic Equipment

Note: this information should not be used for sizing purposes.

Domestic Hot Water	Average Demand	25,853

Base Run Air Equipment

Note: this information should not be used for sizing purposes.

Packaged Single Zone	Supply Fan Flow	566 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	11
	Heating Capacity	20
Packaged Single Zone	Supply Fan Flow	462 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	8
	Heating Capacity	16
Packaged Single Zone	Supply Fan Flow	616 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	11
	Heating Capacity	22
Packaged Single Zone	Supply Fan Flow	697 LPerSec
	Annual Supply Fan Run Time	6,024 Hours
	Cooling Capacity	13
	Heating Capacity	25

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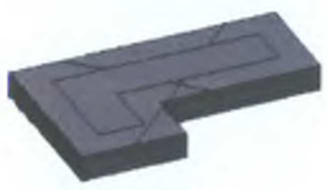
AUTODESK.

Design option 3

Design option 3 Analysis (1)

Analyzed at 4/19/2013 2:01:42 PM

Revit Energy Analysis Result



Building Performance Factors

Location:	DUBLIN AIRPORTER (DUB), Dublin International Airport, Co. Fingal, Ireland
Weather Station:	[illegible]
Outdoor Temperature:	Max: 33 °C/Min: -2 °C
Floor Area:	509 m²
Exterior Wall Area:	332 m²
Average Lighting Power:	12.92 W / m²
People:	127 people
Exterior Window Ratio:	0.40
Electrical Cost:	$0.15 / kWh
Fuel Cost:	$1.12 / Therm

Energy Use Intensity

Electricity EUI:	180 kWh / sm / yr
Fuel EUI:	699 MJ / sm / yr
Total EUI:	1,349 MJ / sm / yr

Life Cycle Energy Use/Cost

Life Cycle Electricity Use:	2,756,031 kWh
Life Cycle Fuel Use:	10,679,664 MJ
Life Cycle Energy Cost:	$234,330

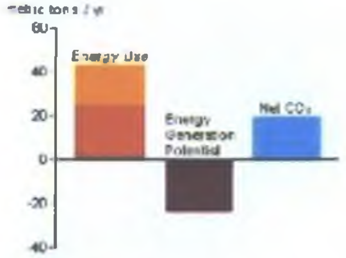
*30-year life and 6.1% discount rate for costs

Renewable Energy Potential

Roof Mounted PV System (Low efficiency):	28,420 kWh / yr
Roof Mounted PV System (Medium efficiency):	56,840 kWh / yr
Roof Mounted PV System (High efficiency):	85,261 kWh / yr
Single 15' Wind Turbine Potential:	982 kWh / yr

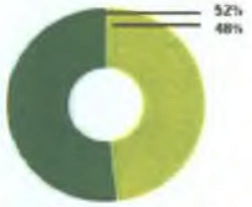
*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems

Annual Carbon Emissions



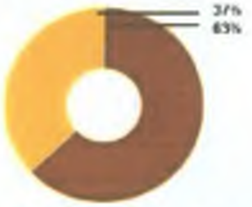
	(metric tons / yr)
Electricity Consumption	24
Fuel Consumption	17
Roof PV Potential (High Efficiency)	-23
Single 15' Wind Turbine Potential	0
Net CO_2	18

Annual Energy Use/Cost



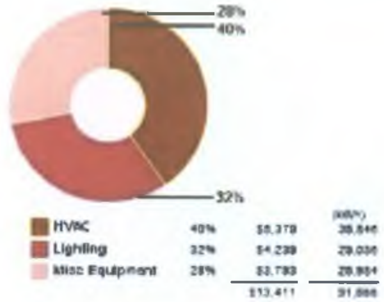
Electricity	48%	$13,413	91,867	kWh
Fuel	52%	$3,792	355,988	MJ
		$17,205		

Energy Use: Fuel

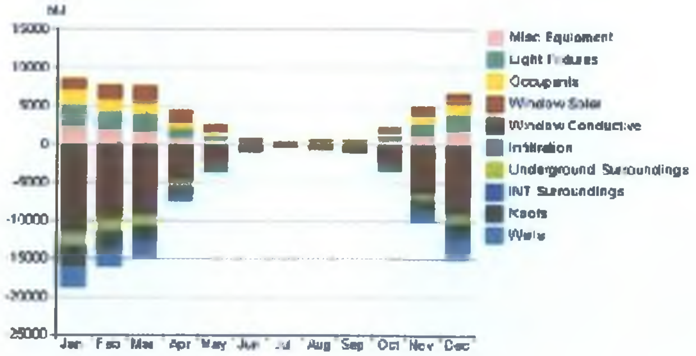


			(MJ)
HVAC	63%	$2,391	224,475
Domestic Hot Water	37%	$1,400	131,513
		$3,791	355,988

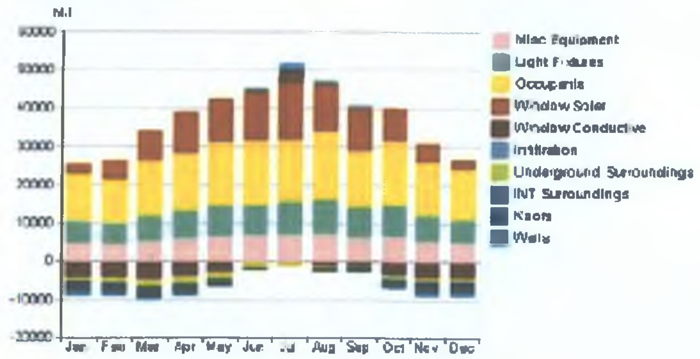
Energy Use: Electricity



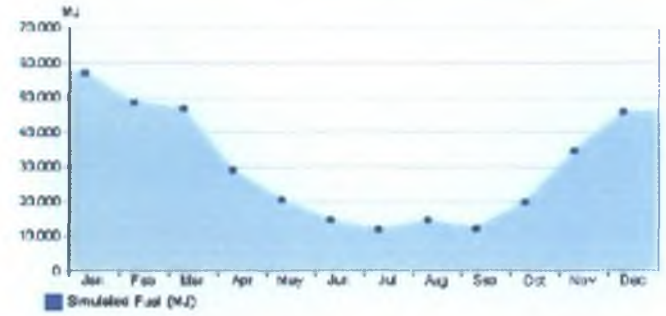
Monthly Heating Load



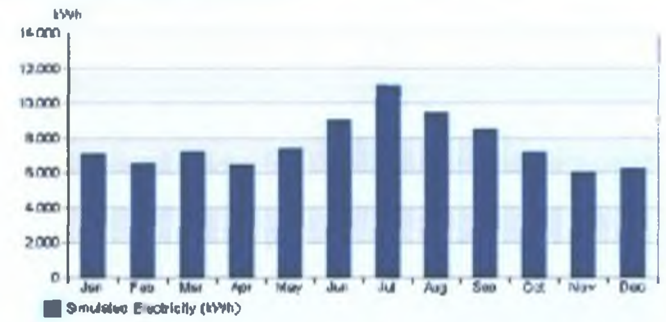
Monthly Cooling Load



Monthly Fuel Consumption

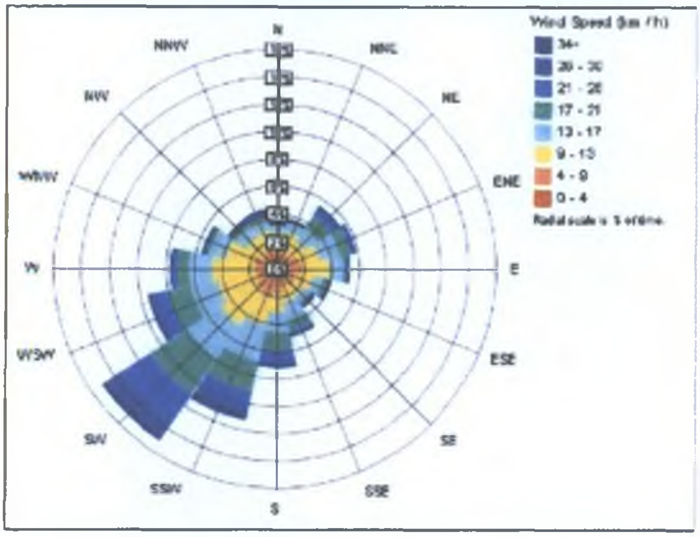


Monthly Electricity Consumption

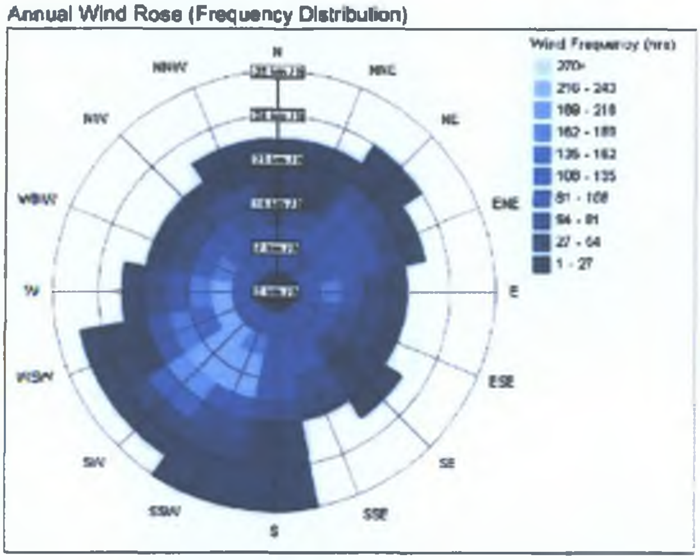


Monthly Peak Demand

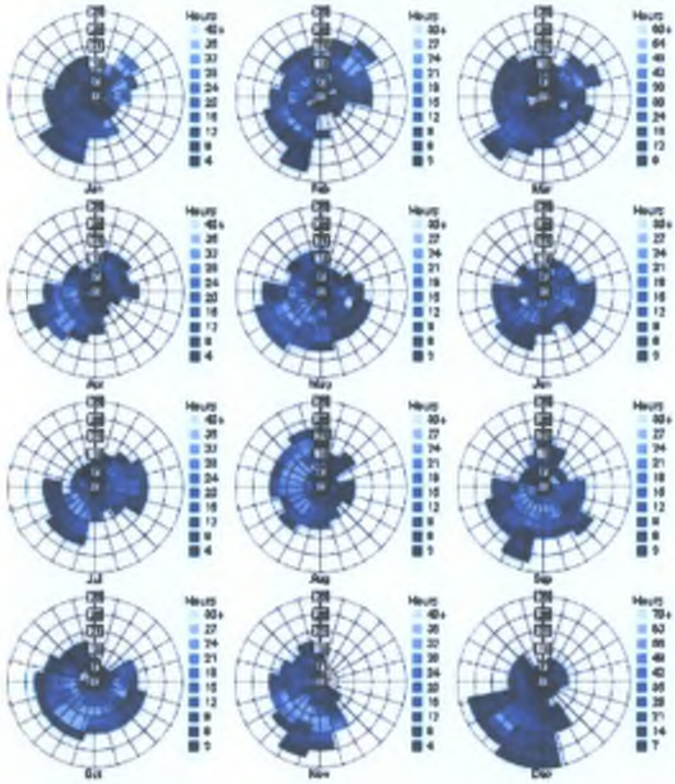
Annual Wind Rose (Speed Distribution)



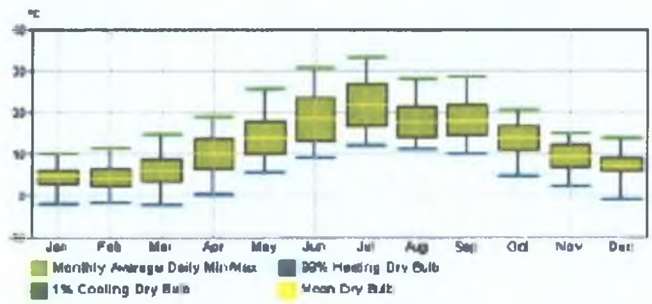
Annual Wind Rose (Frequency Distribution)



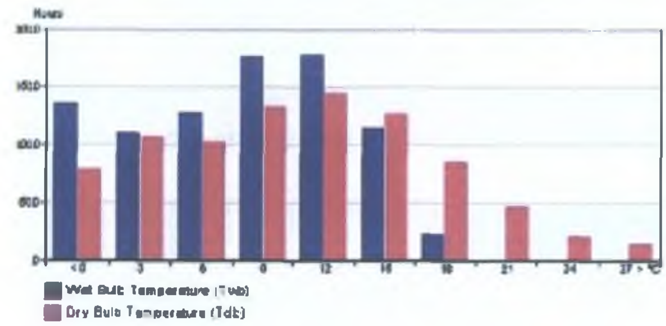
Monthly Wind Roses



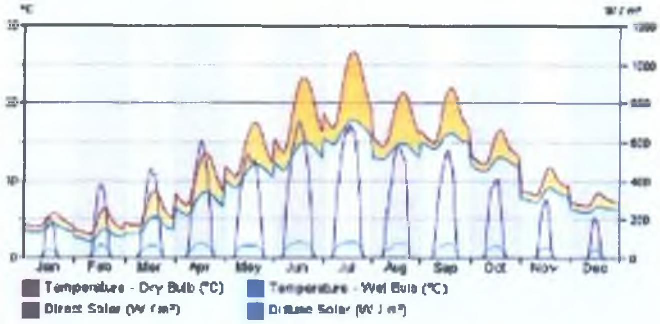
Monthly Design Data



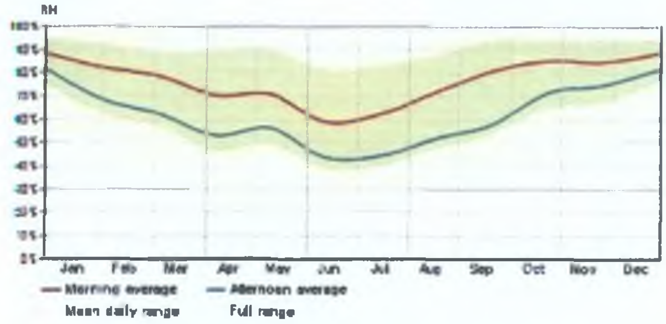
Annual Temperature Bins



Diurnal Weather Averages



Humidity



Revit Energy Analysis Data

3.4 Case Study – Green Building Studio Data Outputs

(Note: only a sample of the data outputs there is over 40 pages of data)

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Appendix "D"

4.0 Daylight – Skyscanner

Ultimate analysis of daylight:

Daylight is changing constantly and indeed this factor may partly explain our preference for natural light. The quantity, direction and "quality" of day-light changes from season to season, day to day and hour to hour, or on some days more rapidly as clouds pass and weather conditions change.

To keep up with these changes, and to utilise daylight to the full, a control system capable of operating across the boundary of artificial lighting and day-light is required. There are such systems available to track and trace the natural day-lighting, through the use of skyscanners. This is a sophisticated device capable of detecting subtle changes in daylight. With the use of photocells and an infrared censor the device continuously registers the condition of the sky through all of its changes. A distinction is made between diffuse light and direct sunlight and the devices management system processes this information and uses it to best control the luminaries and blinds.

The skyscanner is positioned at the highest point of the building, in an un-shaded position, and is precisely orientated to North. By measuring data about the intensity and direction of solar radiation, the system is able to take account of the direct sunlight or sky-light, reflected light of adjoining buildings and shadowing.

With impressive accuracy the system can progressively open and close blinds as the edge of the shadow moves.

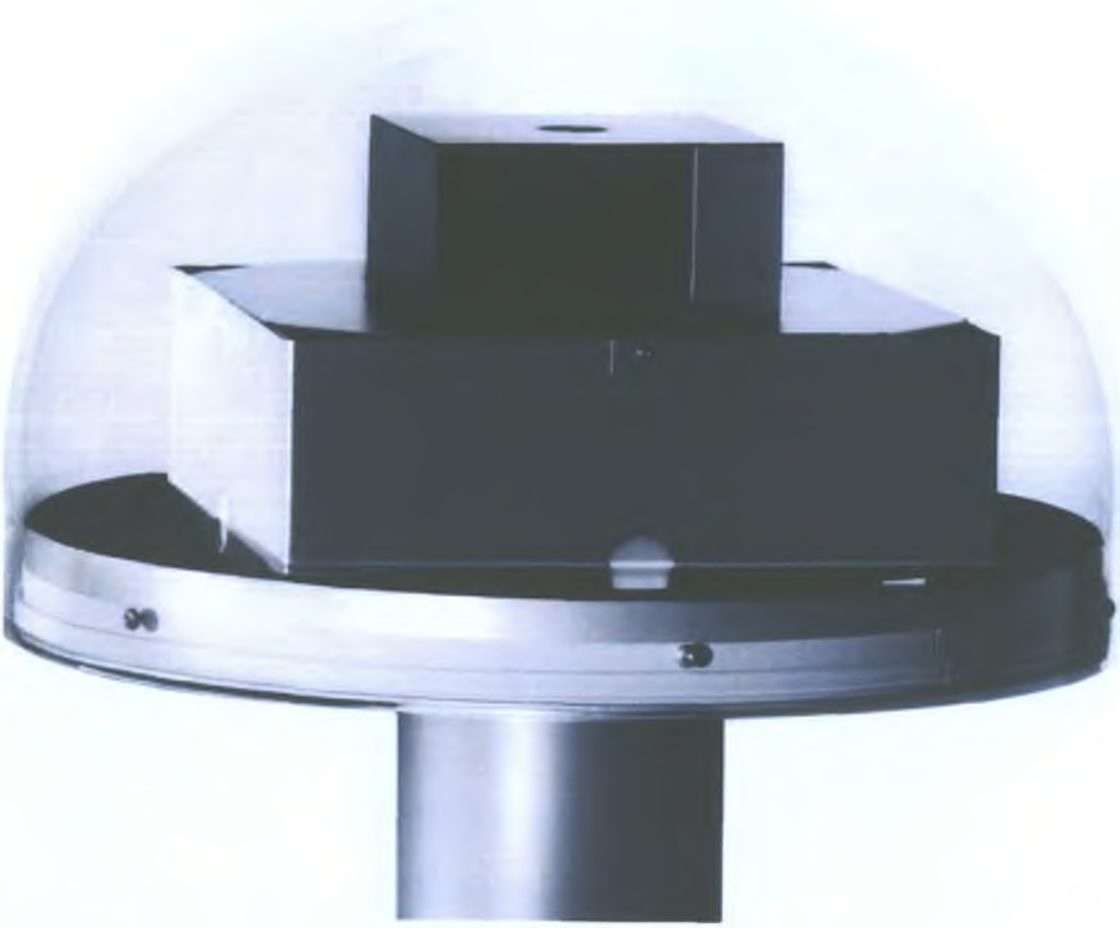

Figure 40: Skyscanner - Lux Jalousien

Appendix "E"

5.0 Energy Management Diagnostic Questionnaire

Site Name:	[illegible] National School, [illegible], Co [illegible]	[illegible]	1680
Participants:	Mr. [illegible] (Site facility manager)	Score:	17%
Energy Advisor:	Phelim Martin	Date:	20th April 2011

Question:	Assessment:				Additional Comments:
1. Is there Senior Management commitment to Energy Management ?	No interest	Interest but no commitment	[illegible]	Full commitment	
2. Is there a [illegible] appointed to sponsor Energy Management ?	No	Informal appointment	Formal appointment but low priority	Formal appointment	
3. Is there a Co-ordinator appointed to manage Energy Management?	No	Informal appointment	Formal appointment but low priority	Formal appointment	
4. Is there an Energy Management Team ?	No	Informal team	Formal team - does not meet regularly / function well	Formal team meet regularly & function well	
5. Is there an Energy Policy ?	No policy	Informal policy	Incomplete policy	Complete, formal well-communicated policy	
6. Have you undertaken an overview of past & present energy consumption ?	Not at all	Informally (no quantification)	Informally (some quantification)	Yes, formally (quantification assessment)	
7. Have you [illegible] significant energy use & identified significant energy users ?	Not at all	Informally (no quantification)	Informally (some quantification)	Yes, formally (quantification assessment)	
8. Have you identified the key factors that influence energy consumption and Energy Performance Indicators ?	Not at all	Informally (no quantification)	Informally (some quantification)	Yes, formally (quantification assessment)	
9. Do you [illegible] energy-saving opportunities ?	Rarely / never	Informally and infrequently	Informally but regularly	Formally and regularly	
10. Do you set (Energy) Objectives and Targets ?	No	Informally, but performance is not tracked	Informally and performance is tracked	Formally and performance is tracked	
11. Do you have an Energy Savings Programme Plan ?	No	Informally, unwritten programme	Informally written programme plan	Formally programme plan	
12. Are adequate resources formally allocated to Energy Management / energy saving activities ?	None allocated	Insufficient (Informal allocation)	Insufficient (formal allocation)	Full & sufficient resources allocated	
13. Do you implement your Energy Savings Programme Plan (Q. 11) ?	[illegible]	No implementation	Partial implementation	Full implementation	
14. Are energy-efficient practices and energy awareness promoted amongst employees ?	Not at all	Informally and infrequently	Informally but regularly	Formal, ongoing programme	
15. Are key personnel trained in energy efficient practices ?	Not at all	Informally	Yes, but not all relevant personnel	Yes (all relevant personnel)	
16. Are significant energy users designed, operated & maintained to optimise energy efficiency ?	Not at all	Efficiency considered, but [illegible]	Informally, but ad hoc	Yes (informal procedures in place)	
17. Do you measure & monitor energy performance & check against targets ?	No (never)	Ad hoc measurement & monitoring only	Yes, but don't check against targets	Yes (continuously)	
18. Do you identify and implement corrective actions ?	No (never)	[illegible]	Yes, but not as a continuous, ongoing process	Yes (continuous improvement)	
19. Do you periodically review your Energy Management System & identify improvements ?	No (never)	[illegible]	Informally only	Yes (always looking to improve)	
20. Is there periodic management review of Energy Management ?	No (never)	[illegible]	Incomplete review	Formal review	

What do you consider to be the 3 most important barriers to developing, implementing and maintaining a full and effective Energy Management System within your organisation ? (e.g. Resources, [illegible], [illegible], lack of competent personnel etc.)

	Barrier: [illegible]
	Barrier: Management Time
	Barrier: [illegible]

NOTE:

Commitment: relates to questions 1 - 5 above

Identification: relates to questions 6 - 9 above

Plan: relates to questions 10 - 12 above

Action: relates to questions 13 - 16 above

Review: relates to questions 17 - 20 above

Appendix "F"

6.0 Good House Keeping

The greatest potential resource in achieving lighting efficiency could be right in front of you — your staff.

Savings are easily achievable in all organisations and need not require any initial outlay. Many opportunities are within the control of staff which is an ideal way of involving people and raising awareness.

'Switch off' policy:

Make switching off lights an official policy. Then publicise the policy as part of an awareness campaign. One way to remind staff to switch off the lights is to place 'switch off' stickers above light switches and posters around the workspace

Label light switches:

A common problem in workplaces is that people are not sure which switches control which lights. Consequently more lights are left on when they are not needed.

A simple and effective solution is to label switches with the areas they control. This will aid employees to select only those lights they need for the work being carried out, for example when working on an isolated industrial process or when a meeting room is not required. Lights in unoccupied areas can then be switched off.

Set controls:

Lighting requirements will vary at different times and in different parts of a building throughout the day. Ensure that lighting controls are set to match demand, that is, when required during business hours. As well as considering control equipment, ensure that staff members understand the importance of switching off.

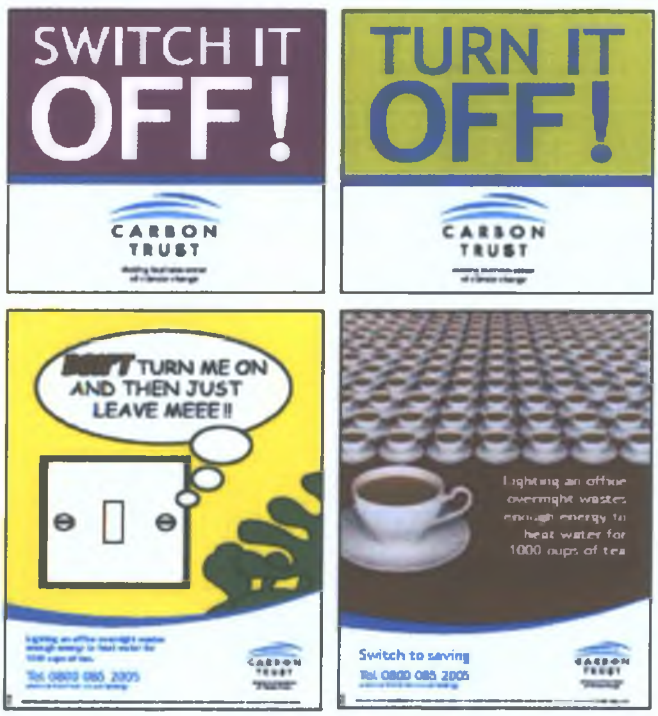

Figure 41: Carbon Trust – Lighting awareness poster.

Lighting costs can be reduced by 20% by only using electric lighting when the space is occupied and when there is insufficient daylight.

Maintaining existing systems:

Making improvements to lighting efficiency does not have to involve expensive refurbishment — just making the most of what you have can save.

Check sensors:

Make sure the sensors are operating properly. One simple check is to obscure daylight sensors — this should bring the lights on. Check timers on lights are showing the correct time and that the settings meet business requirements. Make sure these are altered when the clocks change during the year.

Establish a maintenance programme:

Maintenance can reduce costs by up to 15% as well as improving light output and appearance. List equipment that should be maintained with notes on frequency of actions.

Keep an ongoing schedule of maintenance activity to ensure nothing is inadvertently missed.

Replace failing lights:

Maintenance is an excellent time to change for efficiency. Failing lamps and dirty fittings reduce the quantity (and sometimes the quality) of light that enters the room. As well as costing in terms of energy, this can lead to unnecessary use of task lighting, and even have safety implications.

Replace blackened, flickering, dim or failed lamps immediately. During any maintenance, consider if there are more efficient alternatives available.

A maintenance schedule can be adapted to accommodate individual circumstances. For example, industrial premises may have many lights mounted at height (high bay). Replacing all of them at the same time ensures that all lights in an area are the same age and reduces the risk of failure. It can be cheaper to operate this way, especially if equipment is required to reach the lamps (such as a cherry picker).

Without regular maintenance, light levels can fall by at least 50% in 2-3 years.

Always replace or remove fluorescent tubes that are not working. The ballast uses around 25% of the energy of a lamp and fitting for mains frequency lighting, and around 10% for high frequency lighting. Significant amounts of energy will still be consumed even when the failed tube is not lit, so removing it is important.

The main strategies for lighting control include: local switching and dimming, presence detection, daylight linked and time operated.

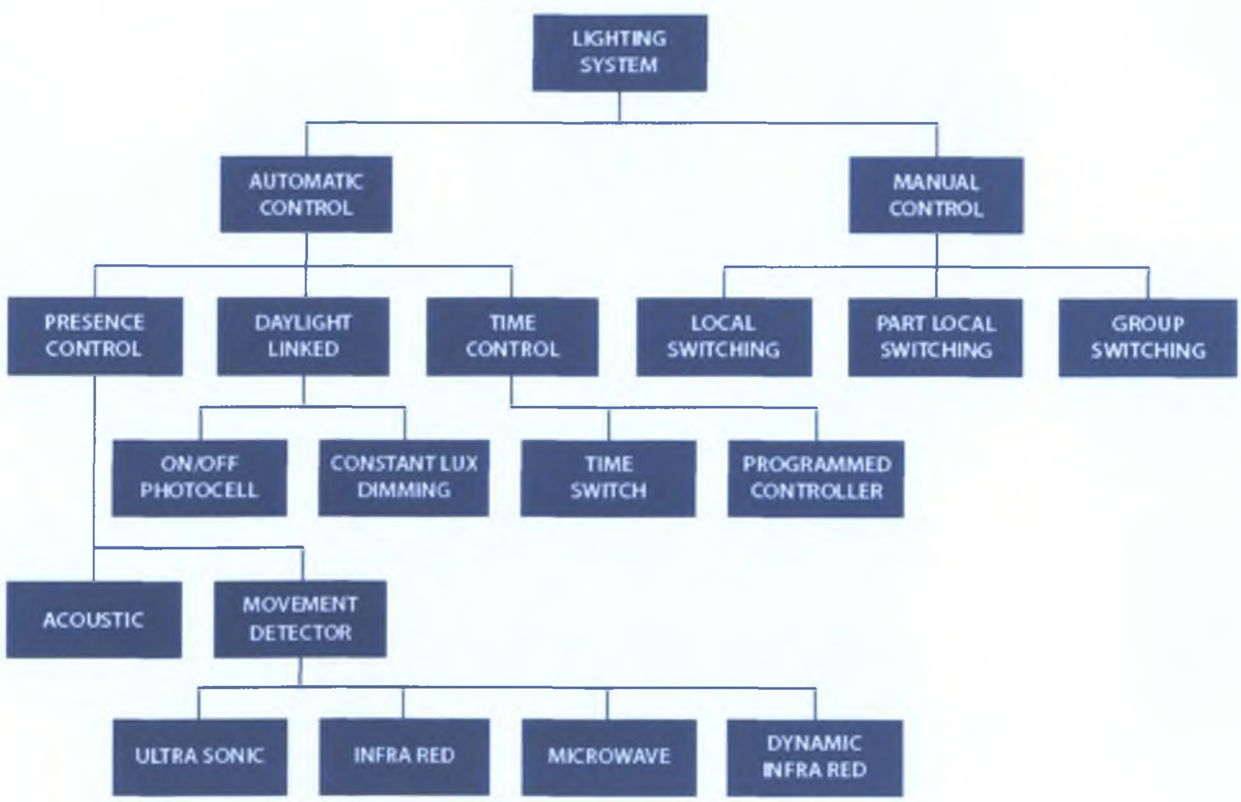

Diagram 2: Effective strategies for lighting control.