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An Energy Survey of the Church Lane Building at DIT

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An Energy Survey of the Church Lane Building at DIT

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An Energy Survey of the Church Lane Building at DIT

by

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A Thesis submitted for the award of MSc in Building Services Engineering

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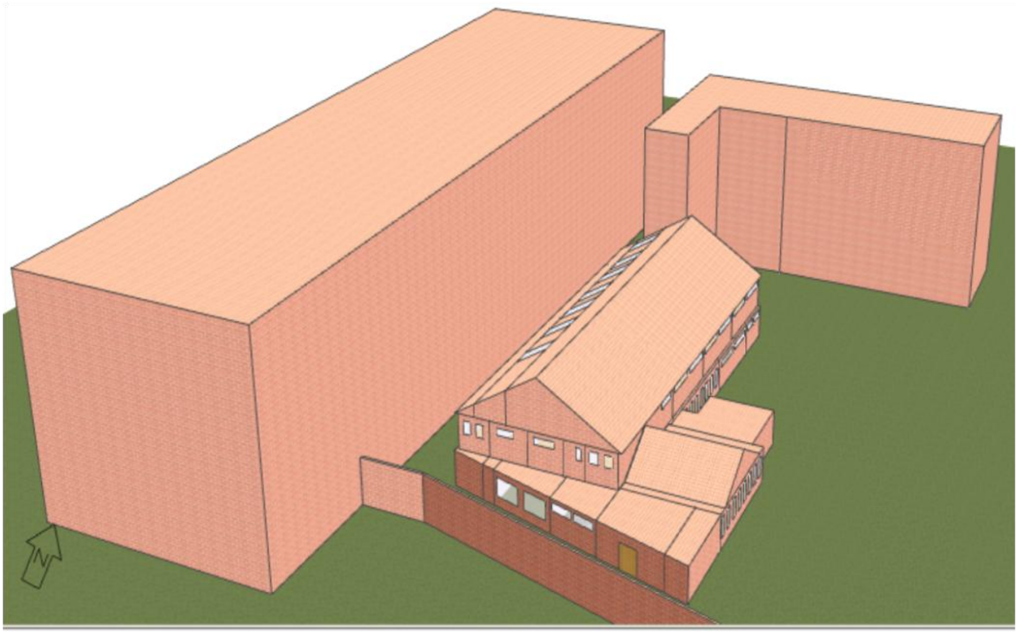
Dissertation Tutor: Prof. A.J. Reynolds

Abstract

Within the European Union, the collective governments have introduced broad energy policies in order to increase energy efficiency and improve energy performance in new and existing buildings, within each member state.

The following dissertation considers energy and how energy is used within the context of global and local consumption in an extensive literature review. Where does the future lie for Ireland and its energy sources? Policies, standards and regulations associated with energy efficiency and the Energy Performance of Buildings Directive (EPBD) are defined and briefly explained. The status of how well the response from the commercial building market to Building Energy Assessment initiatives is discussed. Finally, the literature review explores some of the latest methods to improve energy consumption patterns within buildings. This literature review is intended to recognise the latest changes that may affect the Church Lane building should it undergo any improvements to its energy performance.

This dissertation will include an analysis of the current condition of an existing educational facility using the Dynamic Simulation Modelling (DSM) software IES<VE>. Using this software a comprehensive analysis of the daylighting, thermal performance of the heating system, and a Building Energy Rating (BER) shall be carried out for the building. The results will be compared with the existing building's electrical energy consumption, artificial lighting, heating requirements and current BER. Finally, energy efficient improvements and their installation costs to reduce the building's energy consumption will be explored. This method of analysing a building, DSM, will be critiqued in terms of suitability for this type of building following the process.



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Glossary

BACS	Building Automation and Control System
BEMS	Building Energy Management System
BER	Building Energy Rating
BRE	Building Research Establishment
DCLG	Department for Communities and Local Government
DEC	Display Energy Certificate
DIT	Dublin Institute of Technology
DSM	Dynamic Simulation Modelling
EU	European Union
EPBD	Energy Performance of Buildings Directive
GHG	Green House Gas
HVAC	Heating Ventilation Air Conditioning
IEA	International Energy Agency
IES<VE>	Integrated Environmental Solutions <Virtual Environment>
I.S. EN	Irish Standard European Normative
LENI	Lighting Energy Numeric Indicator
LTHW	Low Temperature Hot Water
NCM	National Calculation Methodology
NEAP	Non-domestic Energy Assessment Procedure
SBEM	Simplified Building Energy Model
SEAI	Sustainable Energy Authority of Ireland
TBM	Technical Building Management
TPES	Total Primary Energy Supply

Chapter 1: Introduction

1.1 Preface

With reference to Fig. 1 the cost of oil over the most recent twelve month period of available data illustrates the uncertainty of oil-related energy costs globally for consumers.

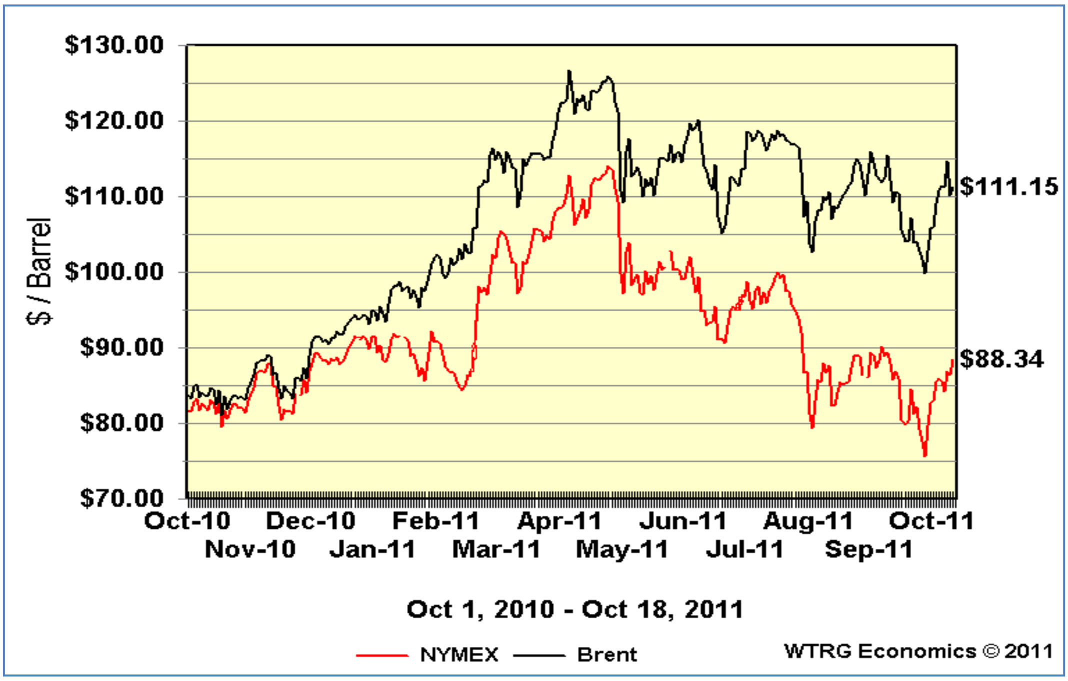


Figure 1: NYMEX and BRENT Crude Oil Futures [2]

> *Global energy use was set to fall in 2009 — for the first time since 1981 on any significant scale — as a result of the financial and economic crisis, but demand is set to resume its long-term upward trend once the economic recovery gathers pace. By 2030, the Reference Scenario, which assumes no change in government policies, sees world primary energy demand a dramatic 40% higher than in 2007.* [1]

Currently, the global economy is in recession but there is no doubt that the current rate of development in both China and India, and Africa in the future, will continue and these countries and regions' demand on carbon based fuels and other sources of electrical generation will increase. This is turn increases demand for energy and as the aforementioned countries develop their buildings will be more modern and energy efficient. Unless the current building stock in Ireland and the UK improves in terms of energy efficiency, our economies will become less competitive in the global market.

This dissertation entitled; *An Energy Survey of the Church Lane Building at DIT* suggests changes to the current day-to-day practice for one building. This building's energy performance needs to be improved for the following reasons;
At present, the thermal comfort and user satisfaction for the building is not ideal. For example; the lighting levels in some rooms are in some cases too high and in others not uniform, the heating system comprises of basic On/Off control, and the ageing thermal properties of the structure do not maintain the required heating set points during the coldest periods of the year.

1.2 Aims and Objectives

The aim of this project is to produce a comprehensive energy performance analysis of the Church Lane building and recommend improvements that will demonstrate how the energy performance of this building can be enhanced.
It is intended that the dissertation will introduce the reader to two commonly used building energy performance tools currently in use by industry, IES<VE> and iSBEM. These tools will be utilised in performing an energy analysis of the building.

Practical solutions form part of the recommended improvements, including simple and effective control strategies using building automation devices which will be suitable for this building and its users.

It is the author's intention to approach this dissertation such that the design of the control strategies for the building shall be easy to implement for the building facilities management team. This should enable the changes to be made in an easy and cost effective way.

Finally, the design shall include a means by which to collect historical data of the building's energy performance which should be made available to all in order to promote energy awareness and energy efficiency. It is suggested that this approach can be applied to most buildings.

1.3 Limitations

The Church Lane building was originally used for a woodwork furniture making business. Its original use and activities were a major factor in the design and construction of the building. Now its current activities include; administration offices, lecturers' office space, electrical trade installation workshops, small classrooms for groups of undergraduate and postgraduate students of fewer than 35 students, and a variety of student laboratory space. This is an all together different purpose than originally planned.

The exact specification of the construction materials is unavailable. To define the building's physical characteristics, visual observations and the typical methods of construction during the 1950's in Ireland have been employed. The building is in use from September to June for academic purposes but is occupied by administration and technical services throughout the year.

1.4 Literature Review

This literature review is divided into the following sections; Energy, Policies and Regulations, Building Energy Assessment and Energy Saving Methodologies.

Energy

The upward trend in Brent Crude Oil Futures since 1995, seen below in Fig.2, clearly signals that the cost of carbon based fuels will adversely affect the overall operational costs of any business or service. This is particularly so in the UK and Ireland as these governments mainly purchase oil and gas through Brent Future Contracts. A futures contract is a means for any economy to purchase ahead of time, their oil and gas needs so that retail prices remain relatively stable. Sometimes this method of purchasing fuels can have adverse effects if the price of oil and gas drops during oversupply to the market, which occurred between 2008 and 2009. [2]

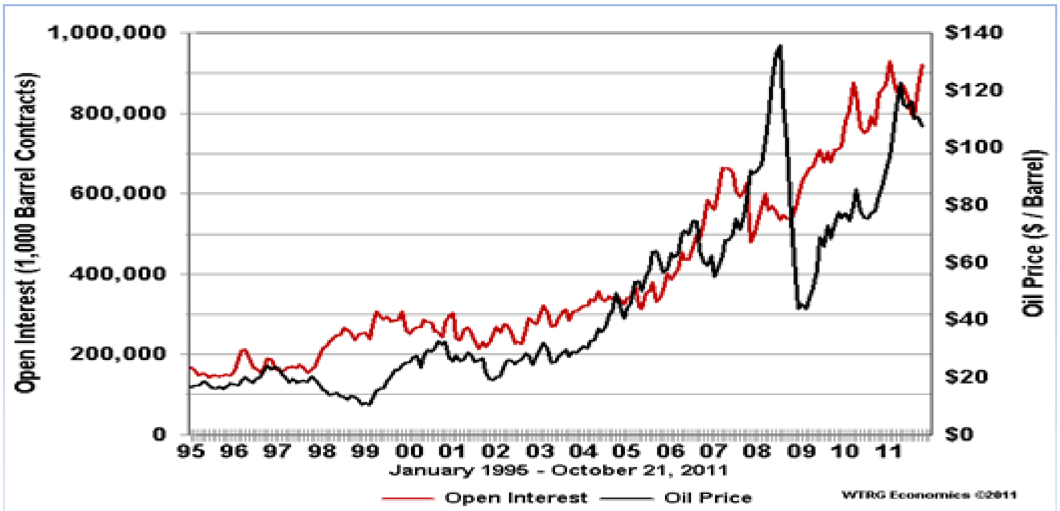


Figure 2: Historical Look at Brent Futures Contracts [2]

Since the downturn in the global economy in 2007 and the internal problems created due the catastrophic collapse of the property market, Ireland has entered austere times, see below in Fig.3.

> *Ireland's economy, which has contracted in recent years, is a minnow in terms of the global economy, had a GDP of €156bn for 2011, compared to €190bn in 2007 when the economy was at its peak* [3].

Figure 3: Gross Domestic Product for Ireland Since 2000 [3]

National growth began to decrease in early 2007, as shown in Fig. 4. Following this, a reduction of approximately €34bn in tax income occurred due to the collapse of the property market in Ireland and the current global financial recession. Ireland has been hit hard financially by these events. Ireland received approximately €90bn bailout from the EU and IMF which will be difficult to repay in the short term due to lack of confidence in the Irish financial situation internationally. A large proportion of the Government tax income came from property transaction taxes prior to the property collapse; this revenue has now been severely curtailed. Currently an annual property tax on new and existing buildings is being introduced which will offer a more sustainable tax income, much like in other countries.

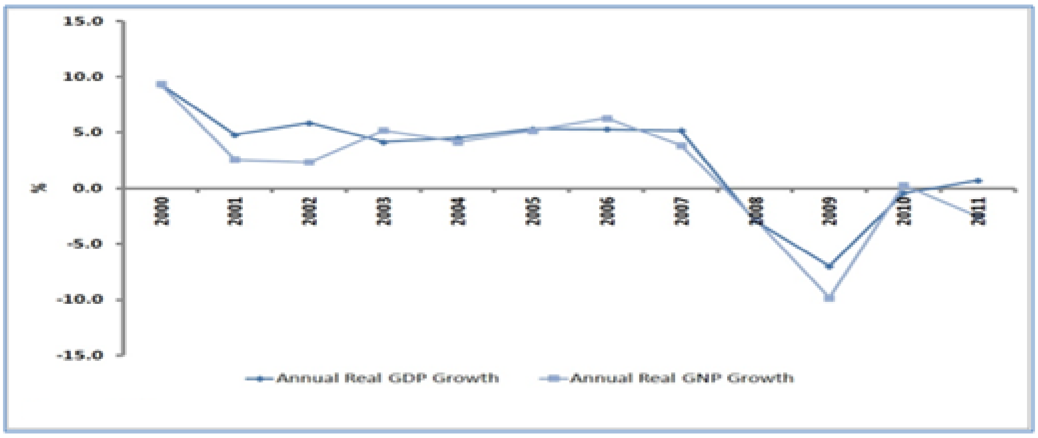


Figure 4: Irish Growth in GDP v GNP Since 2000 [3]

The economic picture is grim at present and every effort is being made to save money and ensure that the national building stock is as energy efficient as possible. In this regard, particular efforts have been made with the public sector building stock, with the added benefit of providing valuable employment. Reducing these buildings' energy costs is doubly economical. According to one European Union agency, Eurostat [4], Ireland's energy costs have almost doubled over the last 10 years for gas and electricity, see Figs. 5 and 6.

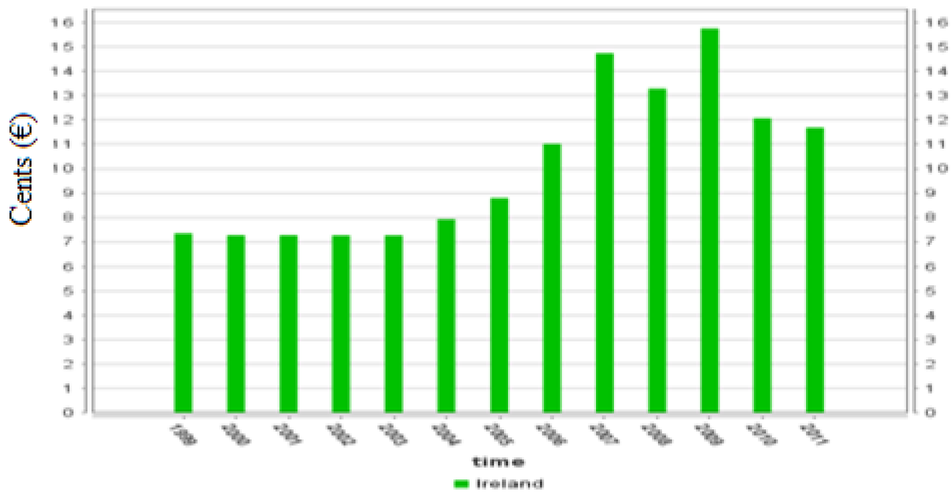


Figure 5: Ireland's Gas Prices for Medium Sized Industries [4a]

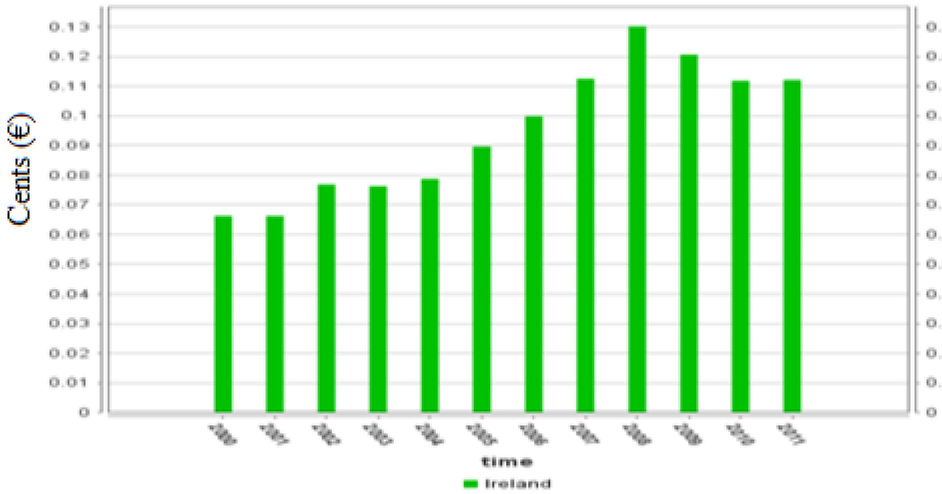


Figure 6: Ireland's Electricity Prices for Medium Sized Industries [4b]

The general increase of energy prices has a knock on effect for Irish businesses and reflects an uncertain future for these businesses operating in highly competitive economic markets. Therefore, it is essential to Ireland’s economic recovery and success that businesses become more energy efficient and less reliant on carbon based fuels for their energy needs.

The increased costs of the Total Primary Energy Supply (TPES) are directly linked in Ireland to electricity production as natural gas and oil predominately produce the electrical generating capacity for the whole country. Thus, with mainly carbon based fuels being used, any fluctuations or long term increases in natural gas and oil prices will have a very negative effect for Ireland’s long term economic recovery. It is therefore imperative that consumers minimize any inefficient equipment in their buildings to support a more sustainable future.

Since 1999, when records were made available to the Eurostat agency in Brussels, the upward trend of energy consumption for Ireland has been a sign of increased industrial and commercial activity which is very positive, see Figs. 7 and 8.

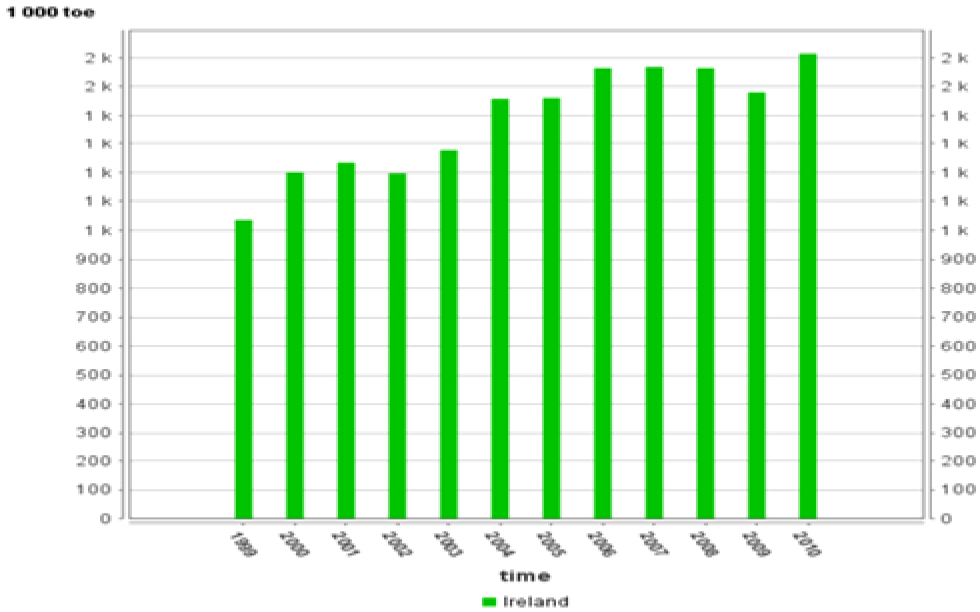


Figure 7: Ireland's Recent Gas Consumption Medium Sized Industries [4c]

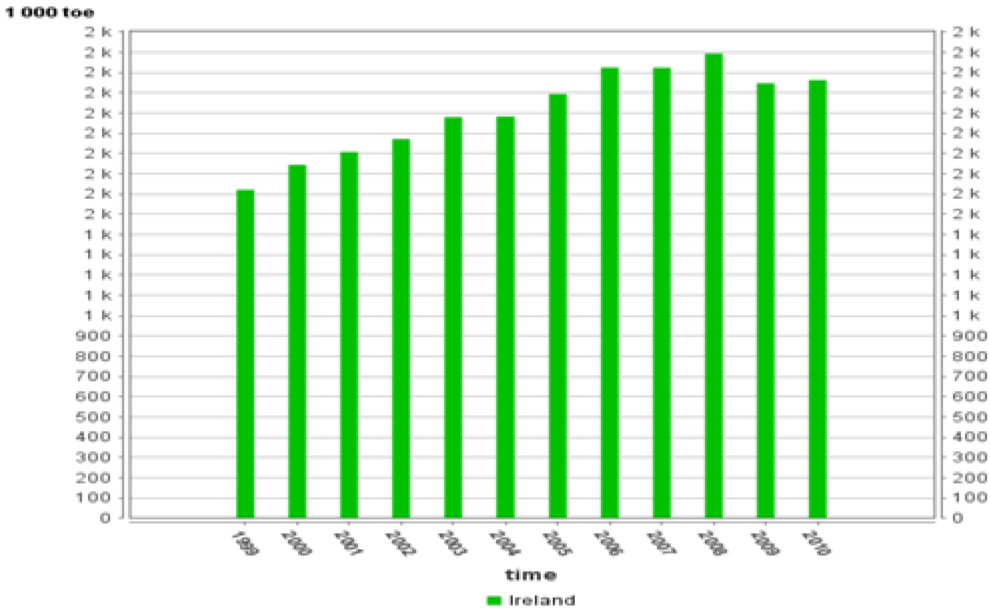


Figure 8: Ireland's Recent Electricity Consumption Medium Sized Industries [4d]

The outlook is not all negative. It is anticipated that energy suppliers will develop more on-shore and off-shore wind farms in Ireland which will in turn connect to the UK via a submerged interconnecting link, currently being commissioned. This 500 MW High Voltage Direct Current (HVDC) connection will provide Ireland a link into the European electricity network, but Ireland will still have to rely on carbon based fuels for security of supply. With the increased economic activity since 1999 the generating capacity is reaching its peak capacity. This interconnector cannot come soon enough. By 2020 the Governments in Ireland and Northern Ireland [5] set a target of 4000MW of wind connected to an all-island grid, representing 40% penetration of the national contribution from renewable sources, see Fig. 9. Looking past the 2020 timeline, the future plans for wind energy are significant.

> *Given favourable developments in policy and infrastructure, Ireland can achieve deployment of between 11GW - 16GW of onshore wind and 30GW of offshore wind by 2050.* [6]

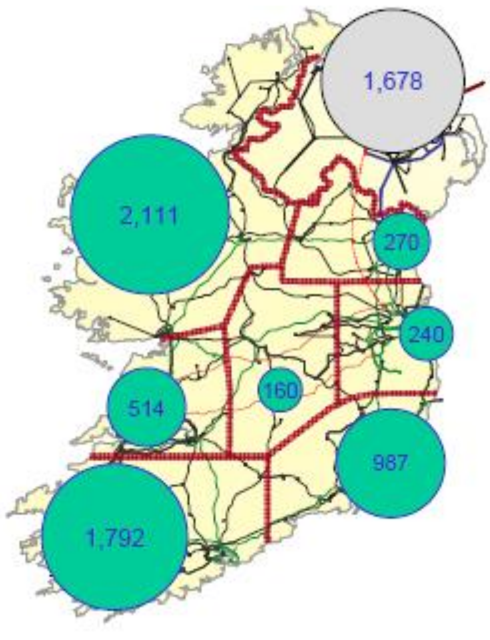


Figure 9: Geographic Distribution of Future Wind Farms in Ireland [7]

Interestingly enough, as part of the The Sustainable Energy Authority of Ireland (SEAI), Ireland's national energy authority, Wind Energy Roadmap to 2050, policy makers are planning to convert consumers to all electric systems to heat and cool their buildings to reduce the country's reliance on imported carbon based fuels.

By connecting via the UK and further on through to the European Grid, Ireland's energy consumers open themselves to market risk by entering an open and competitive energy market. By allowing a more open energy market, Irish consumers may or may not benefit from this changeover in the long term. Since 1991, consumers in the UK have paid the price of electricity and gas deregulation. Both have increased by approximately 20% [8].

> *In 2006, Dublin city consumed 22 TWh of primary energy in the form of oil, gas, electricity and renewable energy and, in the process, emitted 5 million tonnes of carbon dioxide* [9].

If Dublin city energy consumers were to reduce their annual energy bill by 20% by 2020 this would represent an annual saving of approximately €440 million. This saving is based on an energy price of 10¢ per kWh.

The Dublin Institute of Technology (DIT) has been involved in third level education for over one hundred and twenty years, educates over 20,000 students annually and is currently based on six campus sites in the city centre. The DIT will soon relocate all its activities to a new education and research campus in the north-west corner of Dublin city centre, at the Grangegorman site.

In 2004, a number of universities in Dublin and the DIT formed an energy monitoring group, $\mathbf{e^3}$. The 90 selected buildings are being monitored for energy consumption and are attempting to reduce their energy needs by 10% by the end of 2012. Creating awareness amongst staff is also part of the $\mathbf{e^3}$ scheme, in order to encourage everyone to contribute in the energy savings drive. Much has been achieved since the initiative began.

> *This initiative involved four major educational institutions across the city and has achieved €5.5m in savings since its inception* [10].

In 2009/2010 the annual energy bill for DIT was approximately €2m. With DIT moving to a new campus by 2020, a dramatically reduced operational budget has been imposed by management and there are no major improvements planned for the existing buildings. However, more can be done to reduce the operational costs of the buildings, in particular the Church Lane building.

An energy management system (EMS) comprises of a set of well-planned procedures aimed at reducing a company's energy costs and, in the case of manufacturing, increase productivity as defined by *Gordic et al* [11].

The $\mathbf{e}^{\mathbf{3}}$ initiative is based on the I.S. EN 16001 *Energy Management Systems* Standard. This standard is in the process of changing to the latest Energy Management Systems standard, I.S. EN 50001. The $\mathbf{e}^3$ initiative encourages building managers to replace older and obsolete equipment with the latest energy efficient equipment instead of repairing the older equipment. The structure of the $\mathbf{e}^3$ initiative is based on the I.S. EN 16001 standard.

It is designed to;

- ***COMMIT*** *– demonstrate this by appointing a management representative and allocate them adequate financial and/or human resources to run the system.*
- ***IDENTIFY*** *- Identify the opportunities for improving energy efficiency*
- ***PLAN*** *- Schedule a programme of work to ensure that the potential benefits identified in the opportunities for improvement will be realised.*
- ***TAKE ACTION****- Implement a plan of work to realise the identified objectives and opportunities for improved energy efficiency.*
- ***REVIEW*** *- a statement of performance against the organisation's goals and objectives. The performance statement is ideally a summary of the organisation's energy performance, the tasks conducted, and the lessons learned.*[10]

The requirements of I.S. EN 16001 can be applied to and met by any organisation that wishes to improve its energy efficiency. When this standard was being developed, several organisations that have already implemented an EMS confirmed that they had seen many direct and indirect benefits attributable to implementing I.S. EN 16001, including:

- *energy cost savings*
- *reduced greenhouse-gas emissions*
- *reduced carbon footprint*
- *increased energy awareness among staff*
- *greater knowledge of equipment efficiencies*
- *informed decision-making processes*
- *structured approach to the Right First Time methodologies* [12]

Other indirect benefits that organisations cited are:

- *positive publicity*
- *improved corporate image*
- *improved operational efficiencies*
- *improved maintenance practices* [12]

While the challenge in successfully implementing I.S. EN 16001 varies from organisation to organisation, a number of common pitfalls have been identified.

The following list is indicative only but may help in implementing an EMS programme:

- *Making your system too complex*
- *Focusing on doing and not recording*
- *Focusing on the technical aspects and ignoring the system*
- *Maintaining two systems*
- *Not seeing the value in internal audits*
- *Restricting communication*
- *Not giving enough resources to the system* [12]

Policies, Standards and Regulations

Ireland's *National Energy Efficiency Action Plan 2009 – 2020* [13] has been surprisingly progressive despite their recent financial crisis. Ireland has set an ambitious target of 40% of all electrical generation from renewable sources.

Fossil fuels accounted for 96% of all energy use in Ireland in 2007. The Government has committed to achieving by 2020 a 20% reduction in energy demand across the whole of the economy through energy efficiency measures. A national target of 20% equates to 31,925 Gigawatt hours (GWh) saved in 2020. Recognising that Government must lead by example, they are challenging the public sector to achieve a 33% reduction in public sector energy usage over the same period.

> *We will assist public sector agencies with buildings over 1,000m^2 to improve their BER as displayed on their Display Energy Certificates initially to a D1 level or better.* [13]

According to the IEA [5], its organisation promotes sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change. Buildings account for 40%, transport 40% and industry 20% of total energy consumption in Ireland [5].

Since 2002, the EU has introduced simple yet effective policy in relation to energy management. The Energy Performance of Buildings Directive (EPBD) first introduced in 2002 was designed to meet the following requirements:

- *A common methodology for calculating the integrated energy performance of buildings.*
- *Minimum standards on the energy performance of new buildings and large existing buildings that are subject to major renovation.*
- *Systems for the energy certification of new and existing buildings and, for public buildings, prominent display of this certification and other relevant information. Certificates must be less than five years old.*
- *Regular inspection of boilers and central air-conditioning systems in buildings and in addition an assessment of heating installations in which the boilers are more than 15 years old.* [14]

This directive has since been recast in 2010 expanding the original requirements:

- *All existing buildings undergoing major renovation should meet certain energy efficiency criteria (the original directive set this demand only for buildings larger than 1 000 m²). It also stipulates that certification must be based on life-cycle analyses.*
- *The public sector should be a leading example in investing in energy efficiency in buildings: it states that, by 2018, all new public buildings must be near zero energy and all existing public buildings over 500 m² must be certified and display certificates (from 2015 this demand will cover all public buildings of more than 250 m²).*

- *Member states must ensure all new buildings are close to zero energy in 2020, and must launch new financing schemes to overcome investment barriers.*
- *The recast demands that certificates be shown at the time of advertising a building for sale or rental, rather than at the time of signing a purchase or lease agreement, as was previously stipulated.*
- *Large public buildings must be certified regularly at least once every 10 years.*
- *The directive specifically mentions rented buildings with the aim of ensuring that the owner, who does not normally pay the charges for energy expenditure, should take the necessary action.* [15]

The European EPBD was transposed into Irish legislation mainly through the Building Control Bill 2005 and Statutory Instrument SI No. 666 of 2006 European Communities (Energy Performance of Buildings) Regulations 2006. [5]

The SEAI was appointed as the Issuing Authority for building energy-rating certificates. The Department of Education and Science and the National Qualifications Authority of Ireland are responsible for maintaining the quality of assessor training. The energy performance certification of buildings has now become part of the normal public procurement process for engineering and architectural practices, when designing new buildings and designing major existing buildings refurbishments in Ireland. [16]

There are a number of European Normative standards related to the EPBD. Each standard describes clearly how the common methodology of assessment can be achieved. All standards related to the EPBD directive are summarised in the “umbrella document”: *Explanation of the general relationship between various CEN standards and the Energy Performance of Buildings Directive TR 15615-CEN-BT-WG.* [17]

Some directives are not relevant to the Church Lane building [18-21]. This building is heated using a previously designed and currently operational hydronic heating method; redesign is not necessary. As this installation is heating only and uses radiators, the air-conditioning and ventilation standards are not relevant. There will be an appraisal of the energy saving technologies available and the potential savings outlined in an indicative table; however it is not necessary to produce an economic calculation to the level of detail described in the related standard.

Whereas the following standards and publications provide the latest information for building developers, designers, building users, energy assessors and other related professions. These standards ensure both a harmonised methodology and industry best practices are applied to buildings throughout the EU in so far as reasonably practical:

- I.S. EN15217:2007 – *Energy Performance of Buildings – Methods for expressing energy performance and for energy certification of buildings.*

This standard describes the calculation methodology behind an energy certificate for a new or existing building. This standard addresses how the format of the energy certificate should be presented to the customer and a clear indication of when and who performed the evaluation. This standard ensures that the assessor is registered to a recognised professional body. [22]

- I.S. EN15603: 2008 - *Energy Performance of Buildings – Overall energy use and definition of energy ratings.*

This standard specifies a general framework for the assessment of overall energy use of a building, and the calculation of energy ratings in terms of primary energy, CO_2 emissions or parameters defined by national energy policy. It defines the energy services to be taken into account for setting energy performance ratings for planned and existing buildings. [23]

- CIBSE Knowledge Series (KS12) - *Refurbishment for energy efficiency: an overview*

The introduction of energy performance certificates (EPCs) may result in tenants demanding better energy performance from their buildings. Retrofit for energy efficiency should not be undertaken in isolation from the other drivers and considerations relating to building refurbishment. Examples included are; occupancy comfort, health and productivity, future flexibility and adaptability of services and maintenance and upkeep issues. [24]

- I.S. EN 15251: 2007 *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*.

This standard addresses the minimum requirements for the environmental conditions inside the majority of building types constructed in Ireland and the EU. [25]

- I.S. EN15232: 2012 - *Energy performance of buildings – Impact of Building Automation, Controls and Building Management*

This European Standard specifies: a structured list of Building Automation and Control System (BACS) and Technical Building Management (TBM) functions which have an impact on the energy performance of buildings. BACS efficiency class defines four different BACS efficiency classes: A, B, C, D are defined both for non-residential and residential buildings in relation to Heating, Cooling, Ventilation, Lighting and Domestic Hot Water. [26]

- *Class A corresponds to high-energy performance BACS and TBM.*
- *Class B corresponds to advanced BACS and some specific TBM functions.*
- *Class C corresponds to standard BACS.*
- *Class D corresponds to non-energy efficient BACS. Building with such systems shall be retrofitted.*

  ***NOTE**: New buildings shall not be built with Class D systems.* [26]

- CIBSE 2009, Guide H - *Building Control Systems*

A correctly installed Building Energy Management System (BEMS) will contribute to economic growth by; reducing energy costs, enhancing the building performance and informing the workforce.
The scale and complexity of the control system should be appropriate to the building and its operation; highly effective and reliable control may be achieved with relatively simple control systems. [27]

After the building is occupied, it must be run to provide a satisfactory working environment for its occupants. Prompt response to any user problems is important in producing occupant satisfaction. A building survey asking occupants specific questions relating to the environment condition of the building can offer an energy management team an extraordinary insight into the perceived condition of the building by the occupants.

- CIBSE 2001, *Commissioning Code C - Automatic Controls*

The proper commissioning of a control system is crucial to ensure the correct operation of the control system and its associated building services plant. [28]

- *Energy consumption*
- *Indoor environmental conditions*
- *Maintenance requirements*
- *Safety requirements* [28]

In recognition of the importance of commissioning, the Building Research Establishment Environmental Assessment Method (BREEAM) awards points where evidence can be provided showing a client commitment to a firm commissioning period prior to, and immediately after occupation to ensure efficient operation of all services within a building. BREEAM is an assessment method recognising exceptional buildings, new and existing, which have undertaken significant steps to reduce the building's carbon emissions. [28]

The successful operation of a control system depends very much on the skill and knowledge of the system operator. As such, adequate training of system operators is essential. It is advantageous if the intended system operator(s) can be present during at least some of the commissioning stage [28]. This will allow the operator to become familiar with the system and develop experience while commissioning staff are on site. The degree of beneficial interaction between the operator and the commissioning engineers will depend on the ability of the operator.

- I.S. EN 15193: 2007: Energy performance of buildings - *Energy requirements for lighting*

This standard provides a standardised method of calculating the energy used by lighting in terms of kilowatt hours per square metre per year, Lighting Energy Numeric Indicator (LENI). This metric follows actual energy consumption and thus is a good way to discuss energy use. [29]

- CIBSE, 2012: Society of Light and Lighting: *Lighting Guide*

  Lighting is a major user of electrical energy, a use that needs to be reduced. (CIBSE, 2012)

The *Lighting Guide* is used by most professional lighting engineers and designers. It has recently been updated and a major emphasis is placed on energy consumption and the recently introduced lighting energy metric LENI. [30]

The *Lighting Guide* promotes energy efficient lighting design in terms of:

- ***The right amount of light*** - *It is always necessary to provide the correct amount of light for a particular task or activity.*
- ***Light in the right place*** - *The lighting requirements have given values for the required illuminances for given tasks.*
- ***Light at the right time*** - *It is therefore important for lights to be switched off or dimmed when no one is using them or if there is enough daylight available.*
- ***The right lighting equipment*** - *The choices of lighting equipment must be first driven by the lighting needs of a given installation.* [30]

- I.S. EN 12464-1: 2011 *Light and lighting* - *Lighting of work places* - *Part 1: Indoor work places*

This is the most recent lighting documentation for lighting levels for workplaces. This standard contains the minimum luminance levels for a wide variety of buildings and activities within the specific buildings. [31]

- CIBSE 2011, Society of Light and Lighting: Lighting Guide – 05 – *Education Learning*

In response to growing concerns over a suitable learning environment for students in educational buildings the Society of Light and Lighting produced a comprehensive resource for this purpose. [32]

> *Whether by discussion, interaction, practical application or formal lecture, requires sufficient light to enable the pupils to see the visible information presented around them. Whether in a primary school classroom or a professional lecture theatre, whether for young or old, the quality of light chosen to provide in the learning environment will directly affect the learning experience and indeed our motivation to learn.*
> *If the occupant cannot see clearly what is written on the board, identify true colours, or read the facial expression and body language of the instructor, then the learning and experience will be compromised.* [32]

Building Energy Assessment

> *Energy audits and labelling identify opportunities to upgrade built environments and track the progress of existing energy efficiency investments.* [33]

As part of a review, *Dakwale et al* [34] reviewed a number of national energy performance and efficiency programmes. Each method demonstrated that with the introduction of some form of governmental energy efficient measures a significant reduction in energy consumption was shown. Potential tenants and investors reacted positively to newly built or refurbished properties which had installed the latest energy efficient features.

Performing a building energy assessment is an essential precursor to implementing energy saving measures in a building. If building's energy consumption is not measured and compared to a similar benchmark then sensible recommendations are not possible as the analysis and possible recommendations are usually based on guesswork.

> *Improving energy efficiency in buildings is one of the most cost-effective ways across all sectors to reduce energy consumption and hence greenhouse gas emissions. Energy certification increases awareness of energy consumption and enables consumers to compare buildings, thereby providing builders with an incentive to improve energy efficiency in buildings.* [16]

The original Energy Performance of Buildings Directive (EPBD) 2002/91/EC of the EU required that the energy performance of new buildings be evaluated with a calculation methodology that complies with the directive. Separately, the directive called for the production of energy performance certificates for many existing buildings. This uses the same calculation methodology, although this is not mandatory. In response, the UK Department for Communities and Local Government (CLG) commissioned the National Calculation Methodology (NCM) for the energy performance of buildings.

The Republic of Ireland has adopted a similar methodology in the form of the Non-domestic Energy Assessment Procedure (NEAP). The EPBD directive recast in 2010 makes reference to the calculation methodology which should include the thermal characteristics, heating and air-conditioning installations, the application of renewable resources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building.

Gonzalez et al [35] criticises the variety of energy performance methodologies used within the EU when the EPBD required that there would be one common methodology. In the defence of each country they must implement measures that are suitable and practical for their own environmental and financial conditions. In general, the overall energy performance indicator is based on kilo watt hours per square metres per annum and CO_2 emissions indicators are based on kilograms per square metre per annum.

Perez-Lombard et al [36] discuss the implementation of I.S. EN 15217 in terms of a common methodology for expressing energy efficiency and certification of buildings. They also conclude that the implementation of a common energy certification scheme in the EU is a complex task and requires a constructive approach to setting up such a programme.

Yet since the introduction of the EPBD, market take up on energy efficient technologies and completed energy performance certificates is relatively low. This is mainly due to the simple and unsurprising situation that developers who build buildings do not pay the energy bills. *Noailly* [37], pointed to this fact in the impact of environmental policy on technological innovation.

> *In many cases, certification and implementation of the identified savings do not present any net, long term economic cost to the owner, as the savings outweigh the costs of the investments. A key challenge, however, is that consumers tend to focus on short-term costs rather than long-term value (i.e. focus is on the incremental capital costs), and do not seize opportunities to improve efficiency that might require a pay-back time that exceeds what they would perceive as a good return on their investment.* [16]

Schliech [38] added in 2009 that the barriers present in the commercial and services sector of the German economy include; lack of information, lack of staff time, business strategies and priorities as compelling reason why this sector is less willing than large energy users to invest in energy efficient technologies.

The Irish government reaction is equally without any *real* commitment for existing and new public service buildings;

> *We will investigate the feasibility of applying a minimum standard beyond building regulations for new buildings (including significant renovations) intended for use by public sector bodies.* [13]

As of end May 2012, 304,253 energy ratings had been published by SEAI. These comprised 295,269 energy ratings for new and existing dwellings; and 8,984 energy ratings for buildings other than dwellings. Ireland clearly has a long way to go considering that there are approximately 1.6 million dwellings and circa 200,000 buildings other than dwellings in the Ireland. It can be clearly seen from Fig. 10 that the majority of non-domestic buildings evaluated so far in Ireland are not efficient. [39]

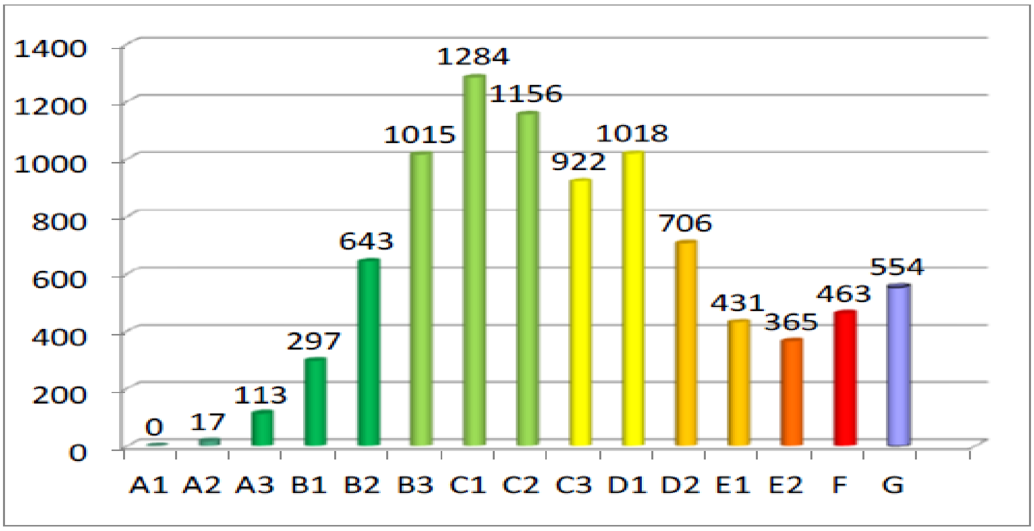


Figure 10: Number of Non-Domestic Buildings with BER - May 2012 [39]

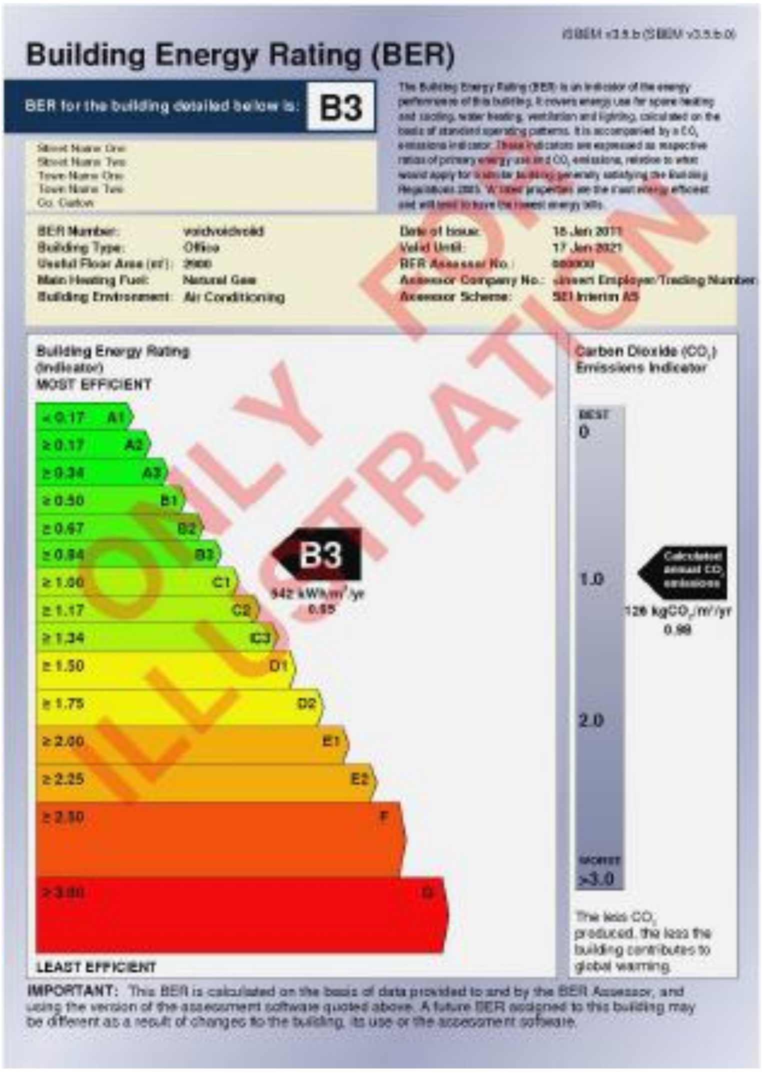
If the assessor who performed the BER evaluation has made extensive use of default values, some of the recommendations to improve the building may be based on uncertain assumptions. A number of buildings received a C1 rating, see Fig. 10. Either all these buildings are exactly equal to the default notional values for this type of construction, HVAC system and lighting type, or the assessors have used the default values rather than performing a detailed survey of the building. A *CIBSE* study completed in 2011 and a paper written by *Bordass et al*. in 2004, commented in relation to the credibility gap between the actual energy consumption and what is entered in the software for these energy surveys. [40]

The tool used in the UK and the Republic of Ireland is similar and was developed by Building Research Establishment (BRE). The Simplified Building Energy Model (SBEM) consists of a calculation methodology (as per the EU Directive), which runs together with a compliance checking module for Irish Building Regulations (BRIRL) and a Building Energy Rating Certificate generator (BERgen), which utilise some of the same data during the calculation. The user sees iSBEM, the interface software, which interweaves these components together and interacts with a series of databases to provide consistent data to the calculation while simplifying the user's need to obtain raw building construction data. SBEM is a compliance procedure and not a design tool. If the performance of a particular feature is critical to the design, even if it can be represented in SBEM, it is prudent to use the most appropriate modelling tool for design purposes. SBEM should not be used for system sizing.

The BER is a rating system of buildings based on Fig. 11. Where, the rating, '*A1'* is the most efficient building and the rating '*G'* is the least efficient in terms of Primary Energy and CO_2 Emissions, the ratings are calculated as follows:

$$\frac{Primary\ Energy\ Use_{Actual}}{Primary\ Energy\ Use_{Notional}}\,[kWh/m^2\ \ .annum] = BER$$

$$\frac{CO_2\ Emissions_{Actual}}{CO_2\ Emissions_{Notional}}\,[kgCO_2/m^2\ \ .annum] = CO_2\ Emissions\ Indicator$$



<u>Figure 11: BER Scale and Energy Labels [41]</u>

The actual building is the building being evaluated and the notional building is based on the criteria set out in *A User Guide to iSBEM Republic of Ireland Volume iSBEM version 3.5.b 3 December 2010* [42]. This manual is a version specifically adapted for the Republic of Ireland from the original User Guide which, together with the software tools described in it, was developed by the BRE for the Department for Communities and Local Government (DCLG). Recommendations are generated in SBEM automatically when all information about the building is entered and the ratings calculation performed. Some of the recommendations presented in SBEM will be cost prohibitive in the case of the Church Lane Building as DIT plan to discontinue use of all 39 existing buildings and move to a new single campus location. There are worthwhile simple low cost suggestions that do not appear as recommendations and these will be presented in the recommendations section of this dissertation.

> *The replacement of systems or building elements when they reach the end of their useful life, or during refurbishment, offers economic opportunities beyond those listed. Where the list of recommendations has identified a system, building element or end-use energy or carbon performance as being "poor", the opportunities for improvement will be especially high. In most cases, new elements and systems will also need to comply with building regulations performance standards. These recommendations do not cover the quality of operation or maintenance of the building and its systems. There are frequently significant opportunities for energy and carbon savings in these areas and a full "energy audit" to identify them is strongly recommended.* [41]

What is unclear however is whether BER evaluations were repeated on the same buildings after improvements were made? This would be a significant piece of marketing data for most buildings to encourage building owners and their tenants to improve the overall building energy performance.

Qian et al [43] discovered that to convince developers to implement the Building Energy Efficiency (BEE) programme was difficult. Their understanding and trust to invest in energy saving products was low unless government policies or incentives were introduced to reduce the operating and installation costs.

There are a number of scholarly articles published recently questioning the reality of energy performance certificates and how these certificates measure up to the actual building's energy performance.

Bordass et al [40] describe a building having a very good rating for the design estimate yet the building's energy performance was nearly three times the original estimate. Errors are suggested during the initial estimate by designers and the building's occupier is culpable of some misunderstandings related to the original activities planned for the building.

A comprehensive review of benchmarking DECs in the UK was completed for CIBSE in May 2011. Ten percent of the assessed buildings' results were disregarded due to assessors using 'default values'. Other abnormal areas and ratings were discarded. The distribution variety of energy ratings in the various building types is worthy of further discussion which is outside the scope of this document.

However, this figure is only 65% of the total number of public buildings expected to require a DEC in the impact assessment carried out for the introduction of DECs. The review also noted that only about half the buildings that should have renewed their DEC in line with the annual update requirement had done so. [44]

Nationally, in the UK emphasis has been placed on the inclusion of DECs for all commercial buildings and extensive discussion with all stakeholders has taken place. Recently, in a view held by policy makers, what is now needed is a successful and effective building energy rating system for all non-domestic buildings in the UK. This will demonstrate that the benefits of a wider requirement to obtain DECs will indeed outweigh the costs to the individual businesses.

Some lessons learned by the SEAI about implementation of the Energy Performance Certification programme in Ireland were highlighted in the IEA Policy Pathway document, *Energy Performance Certification of Buildings* [16]. These included; establishing active working groups, publishing an action plan for all stakeholders, being realistic about costs of development and implementation of the programme, ensuring that the energy rating scale is capable of motivating building developments towards more efficient outcomes, using the latest ICT technology to support this programme so information is gathered efficiently, service quality is high, and labour cost is lower with less administrative duties, and finally, ensuring a transparent and rigid audit of completed assessments is performed to guarantee the service to the building occupants or owners.

Desideri et al [45] in their Edua-RUE method highlight the purpose of completing a significant audit or survey with the intention of; determining energy consumption, detecting possible deficiencies in the building envelope and building services, installation and plant data, water consumption and proposing measures to improve the operation of the building. Once the data from the buildings had been collated the Edua-RUE programme was then able to suggest improvements which were implemented by the local educational institutions.

Energy Saving Methodologies

When rising energy prices point to the need for changes in buildings, there are a number of avenues to pursue:

The best ideas are the simple ones, such as implementing an energy awareness campaign, but they are usually short lived as enthusiasm levels recede amongst the occupants. Forming an Energy Action Committee demonstrates more commitment from management by selecting a team of people who are willing to encourage others and help identify any problems or issues that may occur whilst the building's energy operating patterns are altered.

CIBSE, *Guide F, Energy Efficiency in Buildings* provides the designer an in-depth template with the correct tools to begin an energy survey. An energy survey is an on-site technical investigation of the supply, use and management of energy to identify specific energy saving measures [46].

This guide is divided in three parts; Part A - Designing a new building, Part B – Operating and Upgrading an existing building, and Part C – Benchmarks for typical practice and good practice for a variety of buildings. Part B is where the pertinent topics are discussed and explained for this dissertation;

- *Managing the building*
- *Acquisition and refurbishment*
- *Maintenance and energy efficiency*
- *Energy audits and surveys*
- *Benchmarking, monitoring and targeting* [46]

The Irish Commission for Energy Regulation (CER), the national body responsible for all forms of consumer energy in Ireland, have recently announced that over the next six years Ireland will invest over €1bn in a smart metering programme for the domestic, commercial and industrial sectors. A significant problem currently exists for the electricity network in that the energy consumption patterns of all building occupants reaches peak levels during winter evening times when the majority of building occupants arrive home. It is hoped that a more constant consumption pattern can be achieved by encouraging users in all sectors to shift their energy use to other parts of the 24-hour period. The smart metering will provide continuous information to consumers and allow them to make informed decisions when to use energy. This will be encouraged by introducing variable tariffs over the 24-hour period. [47]

Since the introduction of the **e**^{3} initiative since 2004, the DIT has metered a number of buildings within its campus, acquiring data about electrical energy consumption and gas consumption in these buildings. This information is invaluable in terms of the building energy assessment process and for the building services management team to compare buildings for their thermal performance and electrical consumption characteristics. The poorer performing buildings can then have appropriate energy efficient technologies installed to improve the overall energy performance.

Once the energy consumption data is gathered then the process of analysis begins. *Ahmed et al* [48] highlighted the value of data mining in terms of the energy efficient operation of a building. The thermal comfort, visual comfort, operational processes and maintenance procedures must be considered within buildings. To measure and monitor humidity, temperature, air velocity, occupants' clothing and air quality requires complex sensing equipment and surveys. This may prove impractical in most cases if the equipment is unavailable or the participation of the occupants is restricted.

After metering and analysis, the next step in the survey process is to identify the areas in which energy can be saved. There are a number of solutions which can be employed to improve the overall building energy performance.

Daylight design now forms part of the latest building regulations when designing and constructing new buildings and major refurbishment of existing buildings. This affects both thermal and visual comfort. To limit the solar heat gains for buildings, external shading louvers have recently been employed with success in many buildings. The use of external automated louvers is explored at length in the article by *Hammad et al* [49] on energy saving potential in terms of cooling for an office building and points to research performed by others using internal automated venetian blinds and other types of shading systems.

Lowry et al [50] discusses the benefits of exploiting daylight for saving energy consumed by artificial lighting in buildings. The study points to a variety of glazing properties and how they contribute in their own unique way to the level or quantity of received daylight, better known as the daylight coefficient. *Bodart et al* [51] name visual comfort as an important factor in daylight design but there seems to be inconsistent results from a number of installations which have daylight control systems already incorporated in their design.

Lighting controls which incorporate daylight harvesting techniques can operate incorrectly due to inappropriate location of Occupancy/Daylight sensors, incomplete sequence of operation documentation, poorly completed drawings or not enough time allocated to commissioning.

Sustainable design of buildings does not set out to improve the quality of the building stock, but to improve without growth by reducing material throughout and improve functional quality and durability. Intelligent buildings may use some technologies that hamper sustainability, such as the latest air-conditioning control systems, rather than engineering the air-conditioning system out of the building.
A result of installing the latest intelligent building technologies is that these technologies have created a phenomenon called the Rebound Effect [52]: where energy efficient technologies are installed consumers does not necessarily consume less energy. They have a perception that the newly installed equipment is saving energy, but instead the occupant tends to use more energy.

Bulus et al [52] point out that this condition occurs due to a number of reasons; lack of training or information for the end user, general apathy developed by the user after a period of time, energy prices increasing and/or return on investment is longer than the life cycle of energy efficient technology. *Lowry et al* [53] commented on the findings of their user acceptance study of building management systems (BMS) noting that designers need to consider; ease of use in their graphical design, who uses the systems, practicality and necessity.
Some other barriers presented are the financial resources and confidence to undertake new technologies. *Kua et al* [54] go further and state that information about the BMS and how it operates need to be clearly explained to the designers, installers and end users. More importantly the end user is usually not required to analyze the data. The performance of part of or a complete BMS can be analyzed

to achieve optimum performance over time. *Doukas et al* [55] point out in their paper that effective energy management requires the use of tools and methodologies that support the decision making process. There usually is no short term solution to a complex control system such as a building.

One approach to all energy efficiency plans would be simply to measure, monitor and then manage the problem. After BEMS are installed into a building, then the facilities management team and/or information technology team are not given adequate time to solve local issues. Therefore, the BEMS is not given a *fair* chance to perform. This clearly has to change for any new technology to succeed.

1.5 General Overview and Structure of Dissertation

This dissertation is divided into a number of sections, this chapter, *Chapter 1: Introduction*, introducing the topic under discussion, describing the dissertation objectives, limitations, literature review, and a brief description of the dissertation contents, this section. *Chapter 2, Methods* describes the approach adopted, measurement means and software employed. *Chapter 3, Building Data,* describes the building in detail. *Chapter 4, Results,* contains the description of the information and relevant results tables and plots. *Chapter 5, Analysis,* includes the representation of results, the specific interpretations and enveloping interpretations. *Chapter 6, Recommendations & Conclusions,* Provides practical recommendations to achieve a higher energy performance. Identifies specific points that have been clarified or discovered, and specific actions to be taken. Identifies and justifies specific additional investigation(s) that may be required in to the future.

Chapter 2: Methodology and Building Data

2.1 Approach Adopted

This dissertation's author gathered the historical energy consumption data related to the Church Lane building and compared it to a computer model of the building in terms of energy consumption and CO_2 emissions, and the overall energy performance rating. The Church Lane building is an older structure, therefore using default values throughout the dynamic building energy simulation software (IES<VE>) model for construction materials, heating system and artificial lighting, would not reflect how the building truly performs.

IES<VE> was chosen for this dissertation for a number of reasons primary of which that it is widely used in the building services and energy management industries. This software is unique in that it provides the user complex thermal, solar, artificial lighting and daylighting calculations from first principles without any user programming. The user designs templates that emulate the building's components from floors to roofs, walls to windows, lighting and HVAC equipment. This software includes up-to-date databases containing detailed information on construction materials, HVAC and lighting equipment. There are other features available within IES<VE> such as life cycle cost analysis, natural ventilation and egress calculations, which are outside this dissertation's scope.

Other software packages were reviewed; Energy Plus, TRNSYS and SBEM. They were found unsuitable in that Energy Plus is a DSM software package that is widely used in North America and not applicable in Europe.

Another is too complex: TRNSYS is a software package designed for bespoke heating systems and unusual heating designs, too complex for this purpose. Yet another is too simple: the SBEM software is used to complete the National Calculation Methodology (NCM) energy performance certificate and building regulations compliance checks. SBEM is used within IES<VE>, as part of its compliance package, to obtain the BER for this building. [58]

By collecting the historical data and recording the specific types of construction materials of the building the analysis between the actual and simulated building is much more accurate. Too often these details are overlooked and the final energy performance certificate (BER) is not a true reflection of the building's energy performance. Using this information a reasonable comparison can be prepared alongside the IES<VE> software model provided, of course, the user populates the software with the relevant data. As can be seen from Fig. 12 below, primary data was gathered and recorded by various means from multiple sources for the purposes of this dissertation.

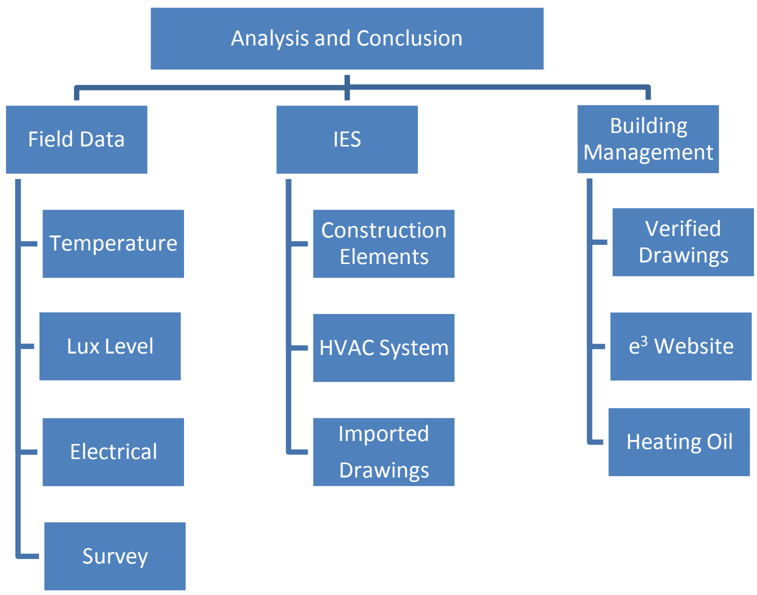


Figure 12: Flow Chart of Energy Audit Methodology

The most recent drawings of the building were supplied by the building maintenance office. Using a laser measurement device, these dimensions were verified in each room as there had been some minor alterations to some rooms since the last set of drawings were completed.

Annual heating oil consumption quantities from the heating oil supplier invoices over eight years were collected. These invoices were used to obtain an annual average consumption.

Electrical energy consumption data for the building was made available from existing data provided through the energy savings website, e^3.

A walk through survey of the building was necessary to identify the types of building constructions and type of lighting, and noting the quantity and energy consumption of all fixed electrical equipment apart from the standard general office equipment and personal computers for staff and students.

Each room’s temperature (°C) and lighting levels (Lux) were recorded using portable measurement equipment. An occupant satisfaction survey for the building occupants was also carried out. This survey recorded the occupant’s impression of the visual and thermal comfort and the general air quality, while the rooms were occupied.

Temperature and artificial lighting levels were recorded using the following portable measurement equipment:

- Lutron LX-101 Lux Meter
- Rapid 328 DMM with PT100 Temperature Sensor
- Bosch DLR130K Laser Measurement Device

Note: Data sheets for measurement equipment used are available in appendix B3.

This survey facilitated comment both on thermal and visual comfort levels in the building. Had a BMS been installed this information would have been readily available and therefore a much more accurate analysis of the building's thermal and visual performance would then have been possible. Assistance was provided in recording data by final year Electrical Services and Energy Management undergraduates for the purposes of this dissertation. The recorded data consisted of the following for each room:

- Artificial Ambient Lighting Levels
- Temperature Measurement
- Occupant Satisfaction Survey

The occupant satisfaction survey, see Fig. 13, by means of qualitative research, serves to humanise the data and further serves to triangulate the building data in terms of how it functions against occupant expectations.

The occupant satisfaction survey provided a valuable insight into occupant perceptions and use of the building. The author's intent is to compare the survey findings with actual recorded data and comment appropriately.

The final question in this survey, question 4, afforded the respondent to take ownership of the room and building by offering them an opportunity to provide constructive ideas to improve the individual space or the building as a whole. This is much like how a Post Occupancy Evaluation (POE) is carried out after a new building is completed and the intended occupants have occupied the building.

<u>Occupant Satisfaction Survey</u>

Room# CL- Time# Date#

We would like you to answer the following questions to better understand how this building performs. We may have already asked you on another day but it is important that you understand that the conditions might be different now. Thank you for your cooperation with this survey.

On a scale of 1-5 answer the following three questions, indicating what you believe is the current condition of the room you are in.

1=Very Poor; 2=Poor; 3=Average; 4=Good; 5=Very Good

1. What do you think about the lighting levels?
2. What do you think about the air quality?
3. What do you think about the temperature?

Please answer the following question constructively.

4. Are there any suggestions how it should be improved?

Figure 13: Occupant Satisfaction Survey - Church Lane

The date and time were recorded during the normal operational day of the scholastic calendar. By recording the date and time, accurate values for the outside temperature on the specific dates were compared with historical data files obtained from the national meteorological service.

The artificial lighting levels were recorded at a working plane height of 1.3 metres above finished floor level. Rooms above 55 m^2 required two different methods to be adopted while recording the illuminance levels.

- The location to record data in each room was determined as follows for each classroom and office less than 55 m^2 at four positions, 1.5 metres from each corner.
- For rooms above 55 m^2, six positions were recorded for the larger workshops and laboratories, four 1.5metres from corner and two 1.5 metres out from longest wall on either side of these particular rooms.

The recorded data were then averaged to comment appropriately in terms of average luminance on the working plane for each room.

The temperature values were recorded in the centre of each room at three different heights in order to obtain an average room temperature;

- Finished floor level
- Working plane height - 1.3 metres
- Average head height - 2.0 metres

Electrical energy consumption was measured, using the Hawk 5000, three phase data logger. This data was used to ascertain the specific load required to operate the building when it was unoccupied.

After the building dimensions and construction data was entered into the building performance software, IES<VE>, a number of performance analyses were calculated; thermal, building energy rating, daylighting and glare.

By utilising this software, simulated information for the building was generated which otherwise would need to have been gathered on-site over an extensive period. An energy performance simulation of the building was then carried out using the software and is discussed in detail in Chapter 3.

The simulated results were compared with the historical and measured data for the Church Lane Building. Finally, the problem areas were identified and cost effective recommendations were provided.

Normally, comparisons would be made with other buildings which have the same function, physical location and size as the building being surveyed. This would require that the Church Lane building was originally designed and constructed specifically for educational purposes. This is not the case as the building was originally designed to accommodate a woodwork furniture making business and has changed its use since the structure was built.

2.2 Building Construction Element Description

The U-Values chosen in Table 1 are indicative of the type of construction for the Church Lane building. The initial walk through of the building provided no reason to have higher quality constructions assigned to each component.

Table 1: Church Lane Building Construction Elements

Construction Detail	**Description of Construction Components**	**U – Value W/m²/K**
Internal Partition/Walls	Typical partition	2.103
Internal Partition/Walls	13mm plaster/105mm brick/13mm plaster	1.767
External Walls	Typical external wall	0.448
Internal Glazing – Original	4mm Pilkington single glazing	4.080
External Glazing - Original	Type 1 - Single clear float glazing	5.443
External Glazing – Rooflights	Typical rooflight	2.947
External Glazing – Double	Low-e double glazing (6mm+6mm)	1.950
External Doors - Entry	Aluminium/Glass (50/50)	6.000
External Doors - Emergency	Wooden door	2.161
Internal Doors	Typical curtain wall (door)	3.224
Pitched Roof	Type 2 – Un-insulated asbestos cement decking	4.414
Flat Roof	Type 1 - Insulated flat roof	0.248
Ground Floor	Type 3 – Un-insulated concrete floor	0.931
Internal Ceiling	Type 2 - Exposed ceiling with floor above	0.794

2.3 Historical Electricity and Oil Consumption Data

The following data was acquired through the buildings management offices.

In the 2009/10 academic year, the Church Lane building monitoring equipment recorded that the building consumed 207,552 kWh of electrical power and a heating oil equivalent of 188,094 kWh at a cost of €12,319. [10].

The heating oil requirement annually varies from 8,000 - 18,000 litres depending on a number of factors; severity of the annual winter conditions in Dublin city, timing of the deliveries, e.g. from 2008 to 2010 the larger delivery in 2008 offset a lower delivery in 2009 and then increased in 2010 [56].

The approximate conversion factor for one litre of heating oil to one kWh in Ireland is:

10.5 kWh = 1 litre [57]

The quantities of oil delivered in the 2009/2010 academic year is approximately the same as the heating oil equivalent provided from the e^3 website[10] when this conversion factor is applied, see Table 2 below.

Table 2: Church Lane Building Heating Oil Annual Consumption

Year	2005	2006	2007	2008	2009	2010	2011	2012
Litres	18,000	17,897	13,985	17,139	8,000	13,464	18,000	18,000
kWh	189,000	187,918	146,842	179,959	84,000	141,372	189,000	189,000

Since there were no significant improvements over the last eight years in terms of thermal performance for the building, the annual consumption in litres of heating oil has not changed significantly from year to year with the exceptions as previously noted. The average over eight years of heating oil consumed was 15,212 litres or a heating oil equivalent in terms of 159,726 kWh.

2.4 Daylight Factor Data

> *Daylight factor has been used to quantify the proportion of daylight available in an interior for many years. Unfortunately, daylight factor suffers from a serious limitation, namely that it assumes a uniform overcast sky. This is a problem in that real skies vary greatly from day to day and from climate to climate. Thus, a realistic evaluation of the energy impact of any proposed daylighting scheme demands that account be taken of the typical climate in which the building is situated as well as the orientation of the building.* [59]

To illustrate the point highlighted in the CIBSE lighting Handbook, the clear sky and overcast sky are compared to one another in Figs. 14-16 so that comment can be made. The daylight factors for the relevant rooms were calculated using the IES<VE> FlucsPro package. The program can perform lighting design and analysis:

- *Design - lumen and glare design calculations based on the CIBSE Code for Interior Lighting 1994, CIBSE TM5 1980 and CIBSE TM10 1985. This results in a light-fitting layout for each room.*

- *Analysis - analysis of both electric lighting and day lighting using the point-by-point method. The starting point for this would usually be light fittings placed by the user using LightPro or automatically placed as a result of the FlucsPro design calculations.* [60]

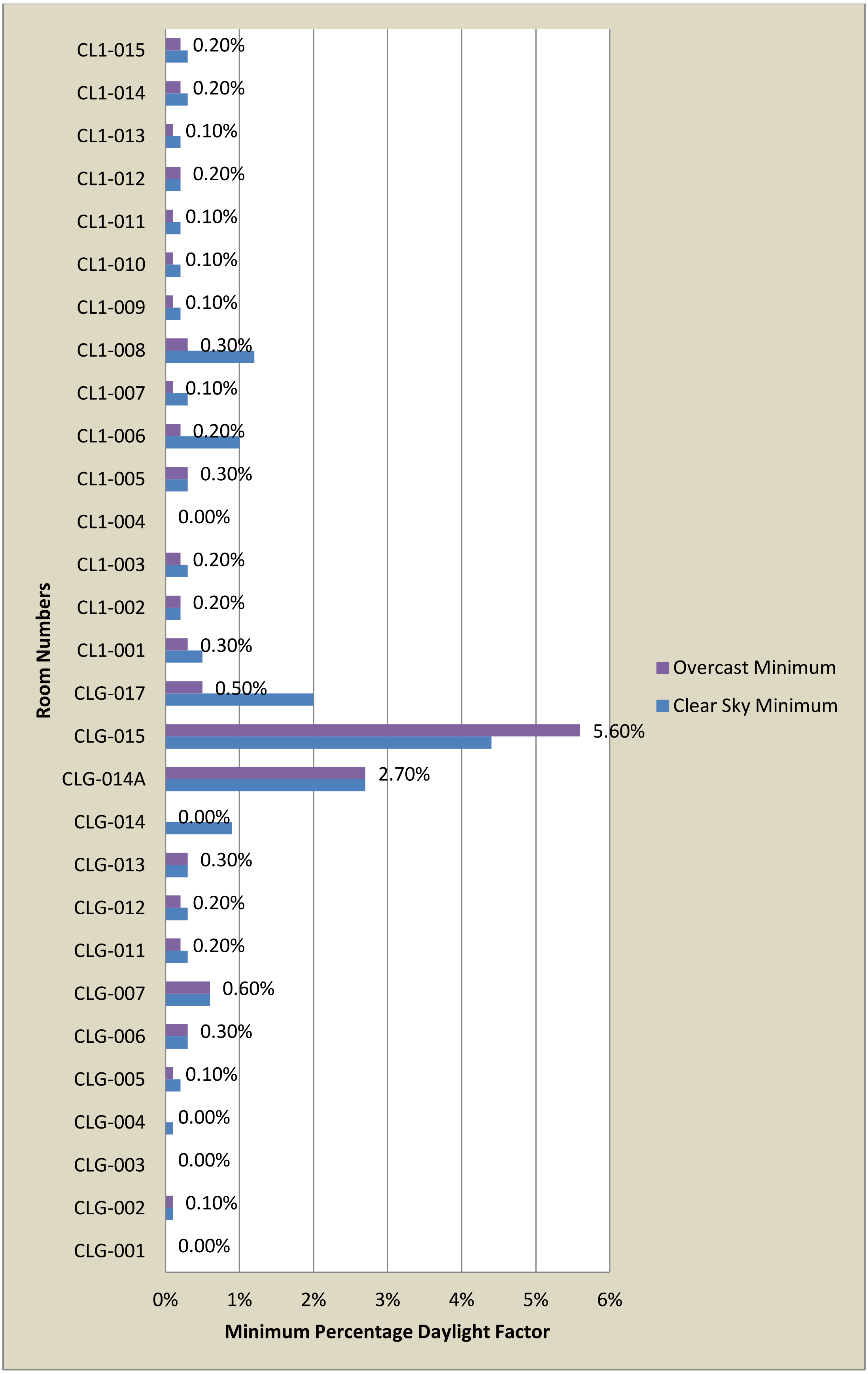


Figure 14: Minimum Daylight Factor for Church Lane Building

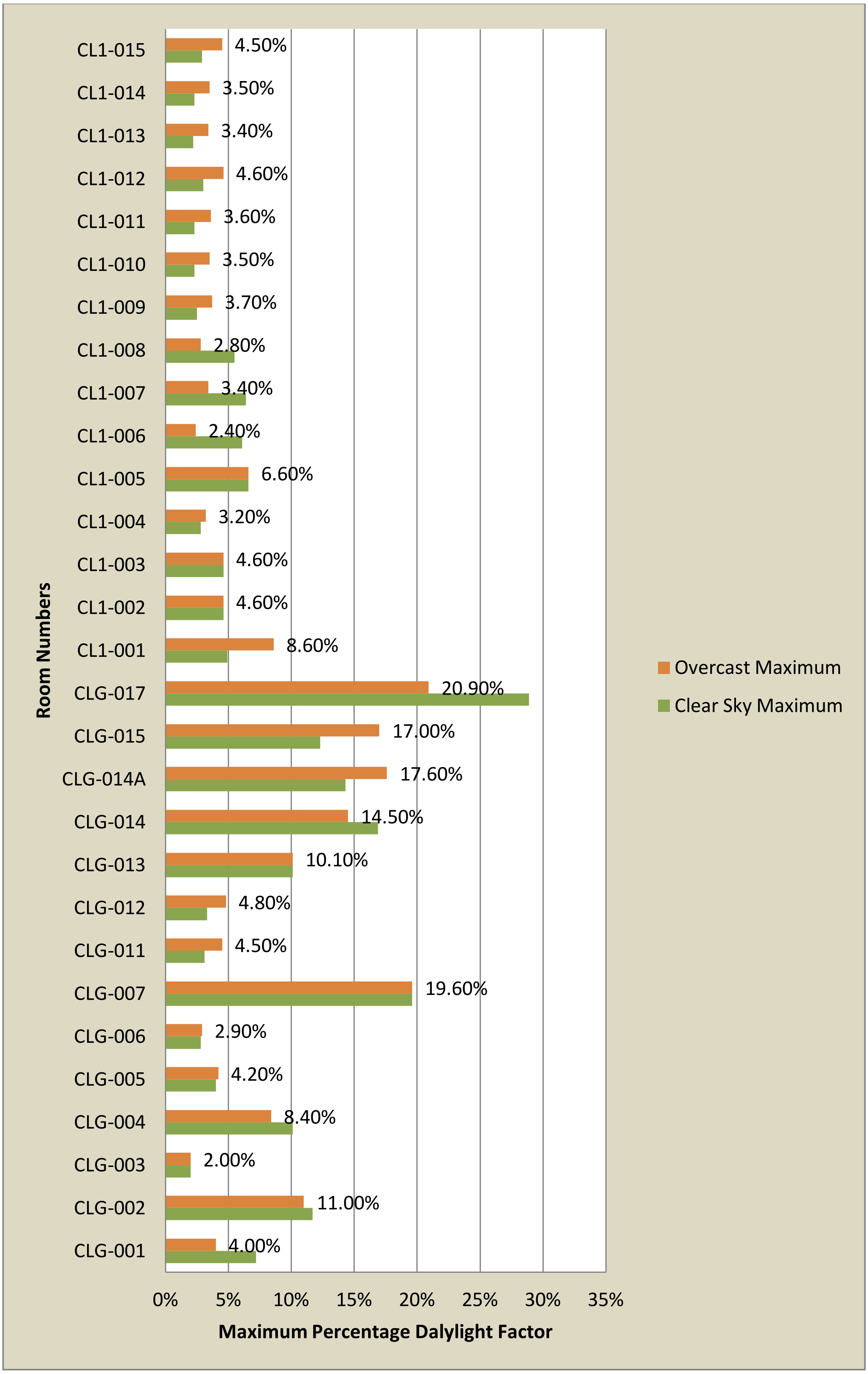


Figure 15: Maximum Daylight Factor for Church Lane Building

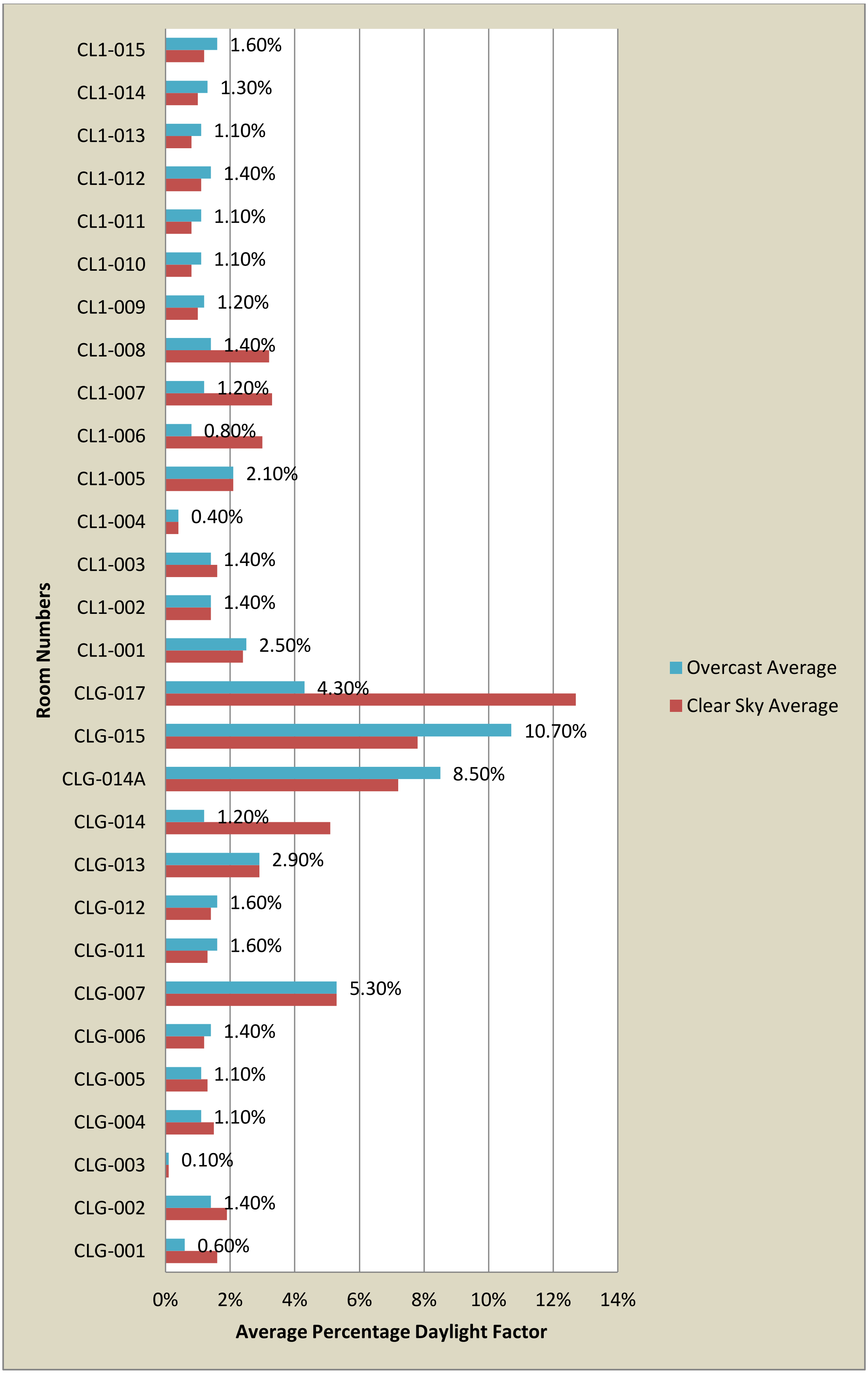


Figure 16: Average Daylight Factor for Church Lane Building

2.5 Room Temperatures and Lux Levels – Manually Recorded Data

The illuminance levels and temperature values shown here in Fig. 17 and 18 respectively were recorded in the teaching areas. This required the use of portable measurement equipment, previously described in section 2.1, technical data available in Appendix B3.

Figure 17: Average Working Plane Illuminance of Teaching Areas

Figure 18: Minimum and Average Room Temperatures of Teaching Areas

2.6 Occupant Satisfaction Survey – Environmental Conditions

From the occupant satisfaction survey the average results for the classrooms, laboratories and workshops are represented in the Fig. 19 below.

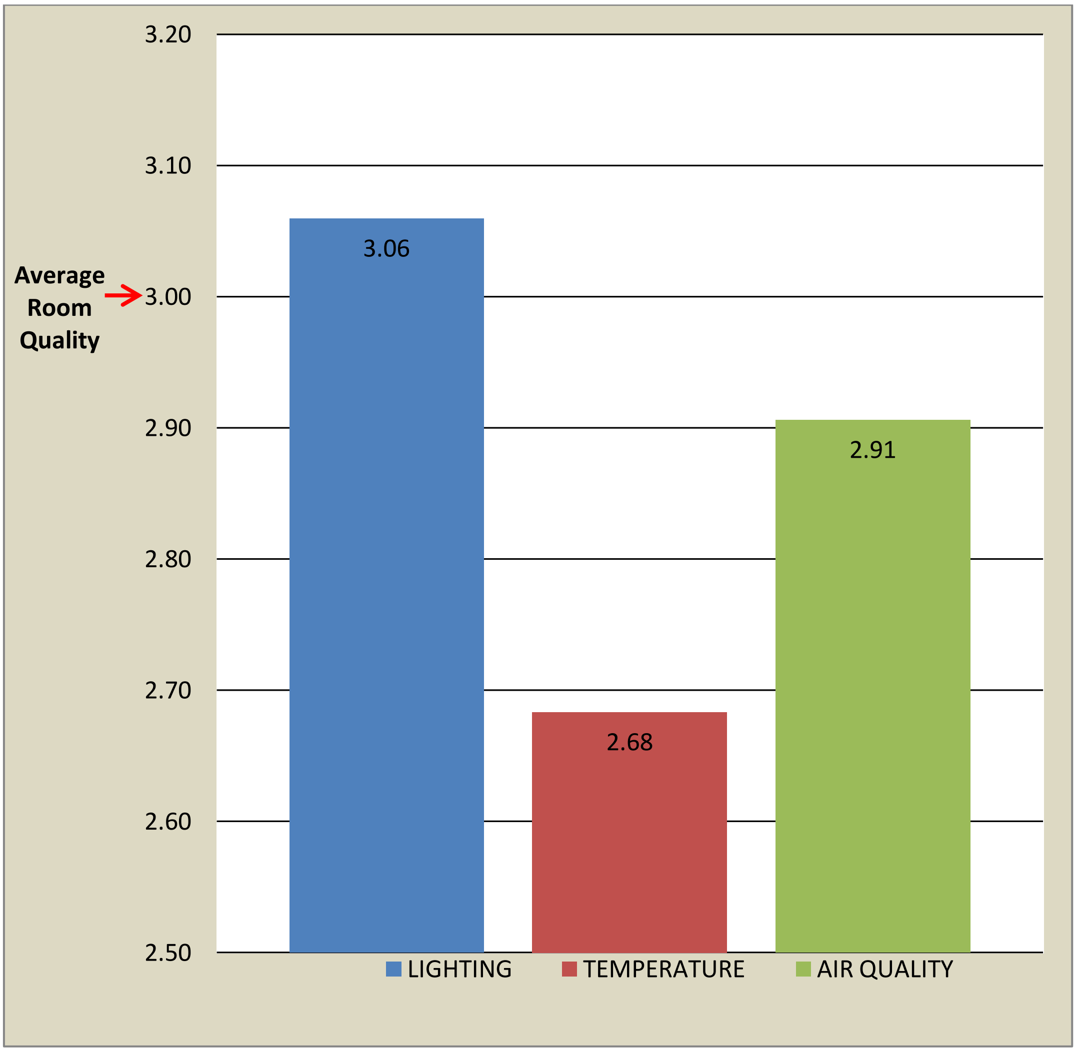


Figure 19: Occupant Satisfaction Survey Church Lane 2010/2011

2.7 Occupant Satisfaction Survey - Recommendations

As part of the occupant satisfaction survey the respondents were asked to suggest improvements to their own environment. Table 3 and the pie chart in Fig. 20 represent the results from this part of the occupant satisfaction survey.

Table 3: Church Lane Building Recommendation Survey

1	Install Interior Windows	Glazing	3.0%
2	Install New Windows	Glazing	6.1%
3	Automated Windows	Glazing	6.1%
4	**Repair Windows**	**Glazing**	**15.2%**
5	Install/Improve Insulation	Fabric	3.0%
6	Replace Heating System	HVAC	3.0%
7	**Increase Natural Ventilation**	**HVAC**	**9.1%**
8	**Improve Heating System**	**HVAC**	**18.2%**
9	**Improve Artificial Lighting**	**Lighting**	**12.1%**
10	**Increase Natural Daylight**	**Lighting**	**18.2%**
11	New Building	Rebuild	6.1%

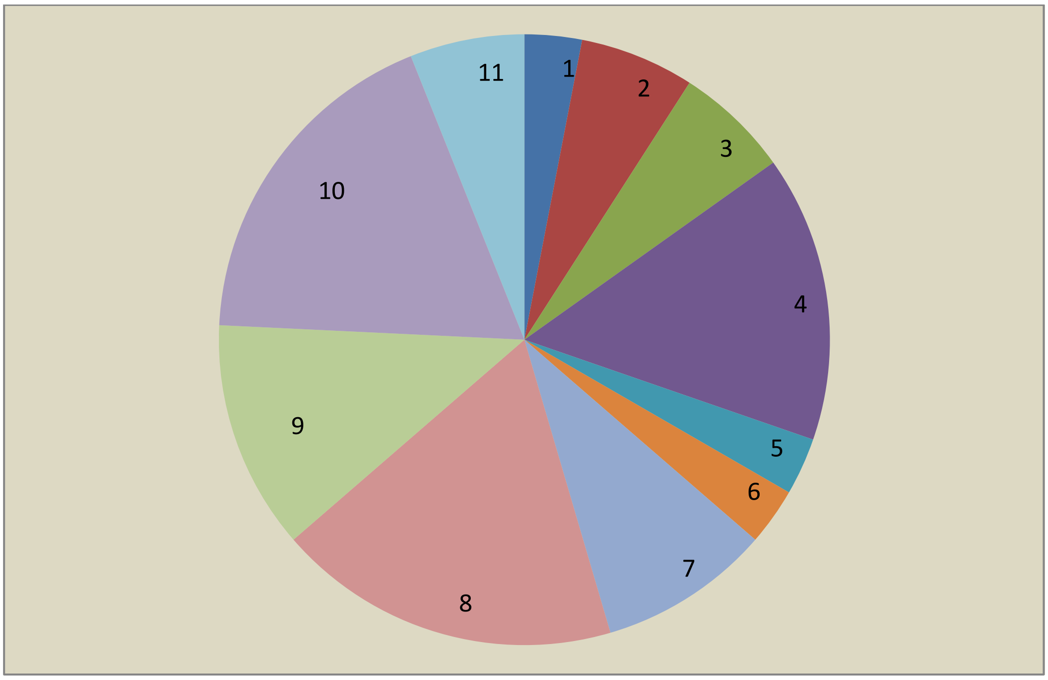


Figure 20: Distribution of Occupant Recommendations for Church Lane

2.8 Electrical Energy Consumption Data

The electrical energy consumption data in kWh for the Church Lane building represented here in Fig. 21 was obtained from the building monitoring equipment used by the e[3] energy saving initiative website over a one year period.

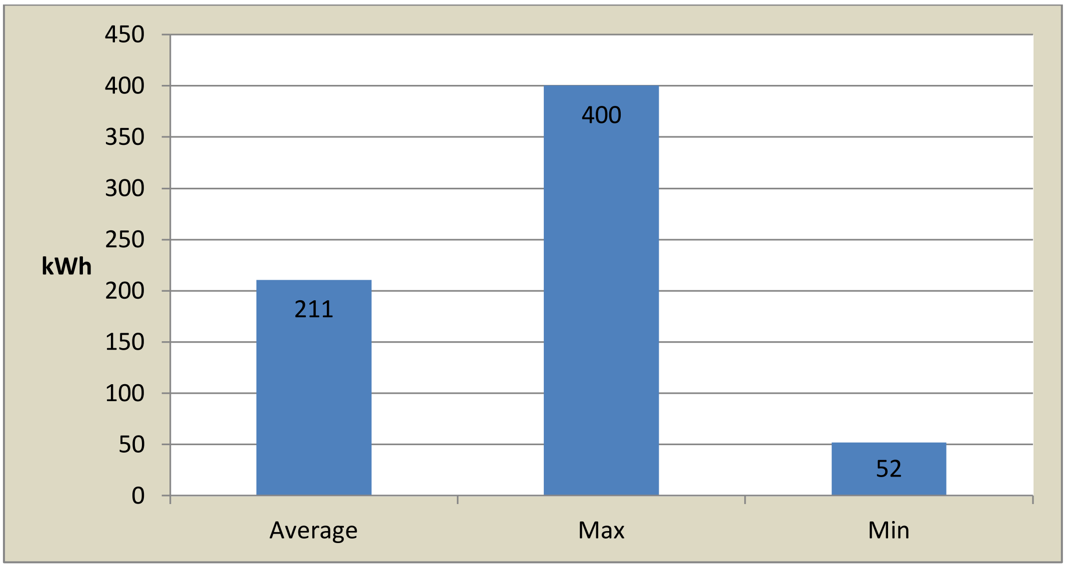


Figure 21: Annual Min, Max and Average Total Loads (kWh) 2010/2011

From this same source a peak 24 hour period was analyzed so that the maximum, minimum and average required electrical energy, in kilo-watts, for the Church Lane building could be observed, as can be seen below in Fig. 22.

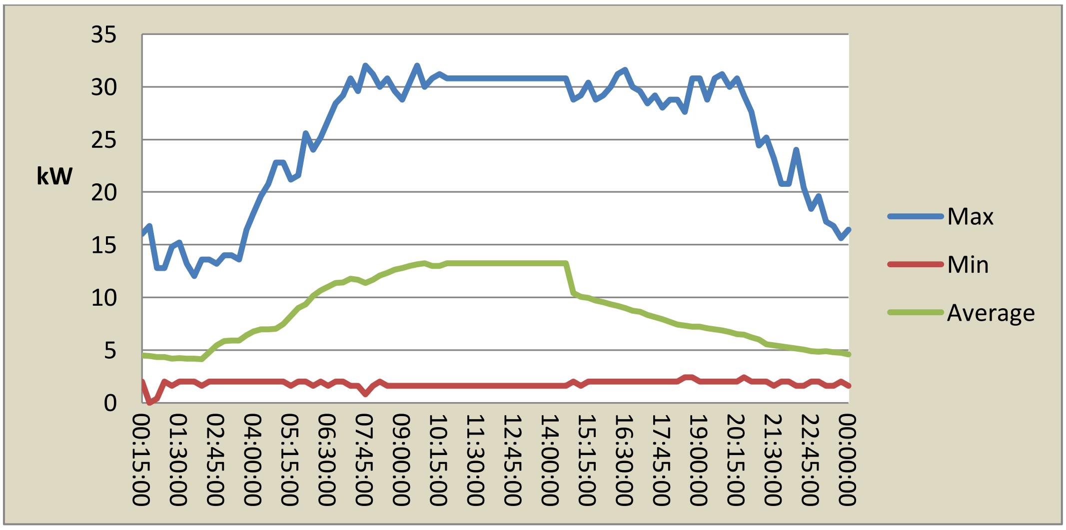


Figure 22: 24-Hour Max, Min and Average Peak Loads (kW) 2010/2011

Using the HAWK 5000 energy analyzer a weekend period was recorded to discover which loads were being used when the building was unoccupied. As seen in Fig. 23 there is a cyclical nature to the load, increasing and decreasing from circa 2.5kW to 5.2 kW at relatively regular intervals. This load was discovered to be the hot water heaters in the building by using the HAWK 5000 energy analyzer on the final circuits at the local distribution board in the building's electrical distribution room.

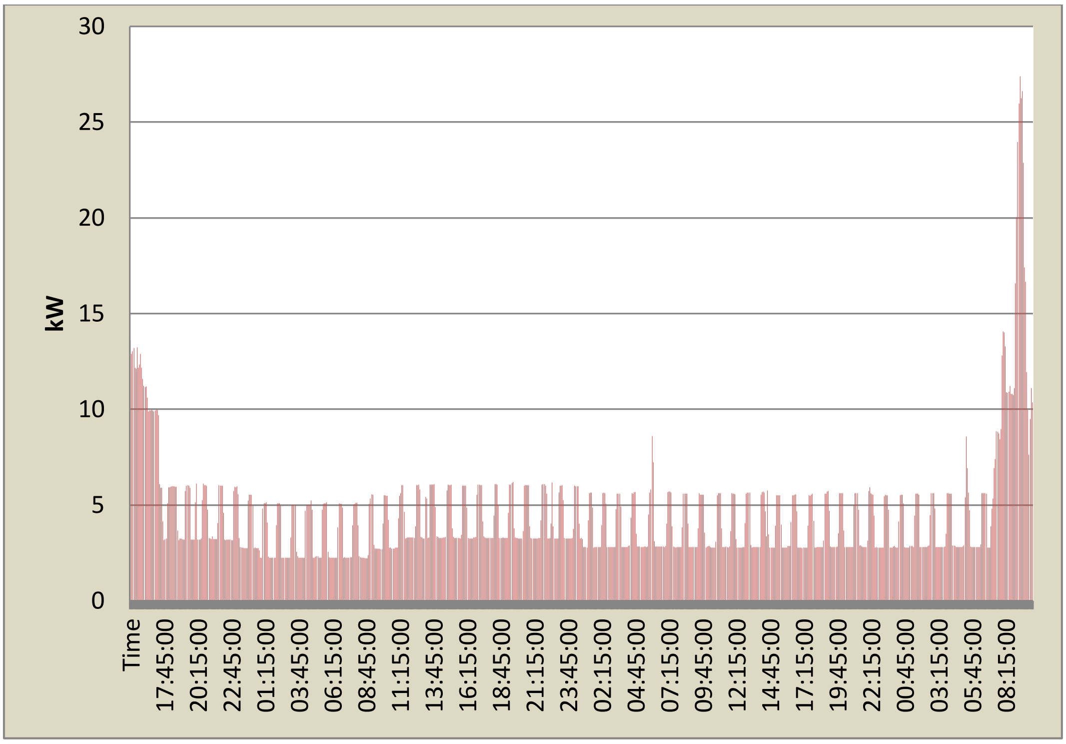


Figure 23: Electrical Energy (kW) Consumed Over a Typical Weekend

Chapter 3: Energy Performance Results

3.1 Using IES<VE>

The software selected for this analysis, IES<VE>, contains a common user interface which provides a number of tools to perform a building energy analysis. The floor plan drawings of the building being analysed are imported as a type *DXF* file format in to the building modeller software, ModelIT, the user then creates the three dimensional representation for the building, including any adjacent buildings that may affect the solar shading and daylighting analyses. All walls, ceilings, floors, windows, rooflights, doors and roofs are created using the detailed results recorded from the building walk-through survey, to ensure the most up-to-date layout for the building.

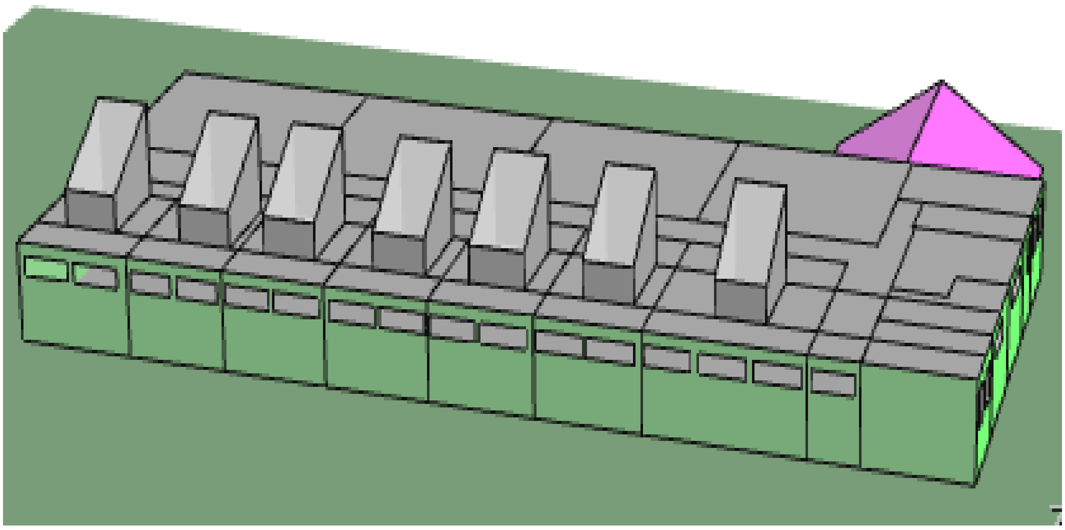


Figure 24: Rooflights Included in Each Room Zone

An important aspect during the development of the drawing from one dimensional to three dimensional is that the rooflights had to be drawn in such a way so that they are part of the room volume and zone beneath each rooflight as can be seen in Fig. 24 above.

Within IES<VE> a building template manager is used to allow the designer to set up a number of templates for the building. The main categories include;

- **Room Attributes** which designate the percentage of Lettable Floor Area compared to Circulation Floor Area inside the building
- **Constructions** of all building envelopes, the window opening types for natural ventilation design
- **Thermal Conditions** including room set-points and types of heating systems
- **Electrical Lighting** illuminance design for each room
- **Radiance Surface Properties** to select the room construction surface reflectance properties for performing a detailed daylighting and glare analysis for the building

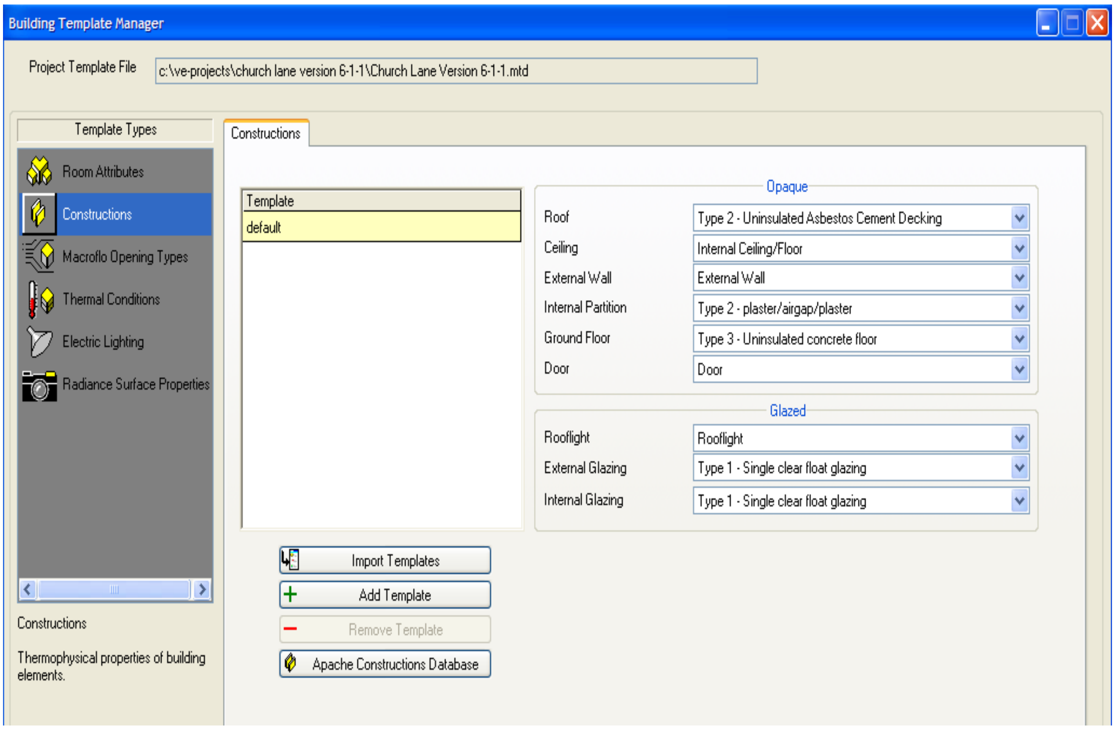


Figure 25: Selected Constructions for Church Lane Building

Within each category the individual opaque construction components such as; the roof, ceiling, external wall, internal partition, ground floor and doors, can be defined using the extensive constructions components database. Glazing components are also selected here and a wide variety of glazing constructions are available for internal, external windows and rooflights, as shown in Fig. 25.

For carrying out the Building Energy Rating, the thermal conditions for each type of National Calculation Methodology (NCM) activity are selected. The NCM is the recognised assessment method defined by the Dept. of Communities and Local Government (DCLG). The actual building's heating profile and simulated set-point conditions are selected including the number of air changes per hour for all rooms. The infiltration rate was estimated to correspond with the current thermal conditions recorded during the occupant satisfaction survey. The value is high in this building, 1 Air Change per Hour (ACH), due to the lack of maintenance of this building compared to a newly constructed further education building where the ACH vary from 0.25 to 0.50 at most. Since there is no air conditioning, i.e. the building uses radiators for heating purposes; the cooling profile has been set to *off continuously*, as can be seen in Fig. 26 below.

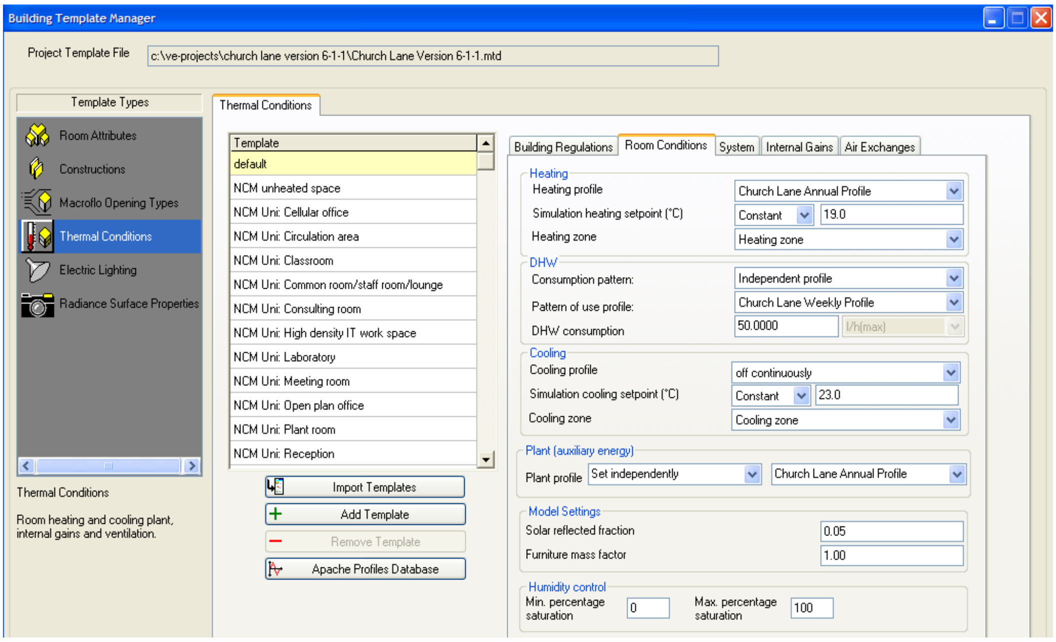


Figure 26: Thermal Conditions and Heating Profile for Church Lane Building

The auxiliary electrical energy required for operating circulation pumps and boiler fuel pumps are set to the Church Lane Annual Profile. This profile is also used for the Heating Profile. The Apache Profiles Database was used to define the Church Lane Annual Profile. The Apache Profiles Database is used to set up how the building's heating system is used daily, weekly and annually.

The daily profile includes a modulating value from 0.00 to 1.00, or as was the case for the Church Lane heating control system, OFF and ON, respectively.

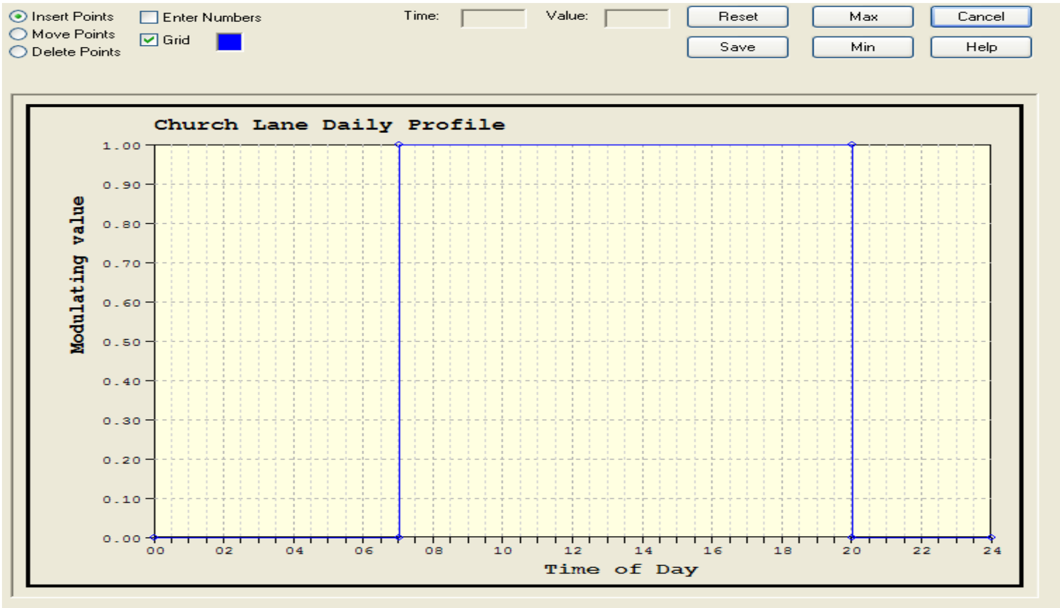


Figure 27: Church Lane Daily Profile

The heating controls are rudimentary in the sense that the boiler is only capable of turning ON and OFF. This control is operated using a central time clock and this time clock is merely a single day 24-hour time clock and the ON and OFF times are at 7:00 and 20:00 hours respectively, see Fig. 27 above. The weekly profile is therefore based on this daily profile including Saturdays, Sundays and Holidays as shown in Fig.28. The existing time clock is only a 24-hr analogue device and does not turn off at the weekends.

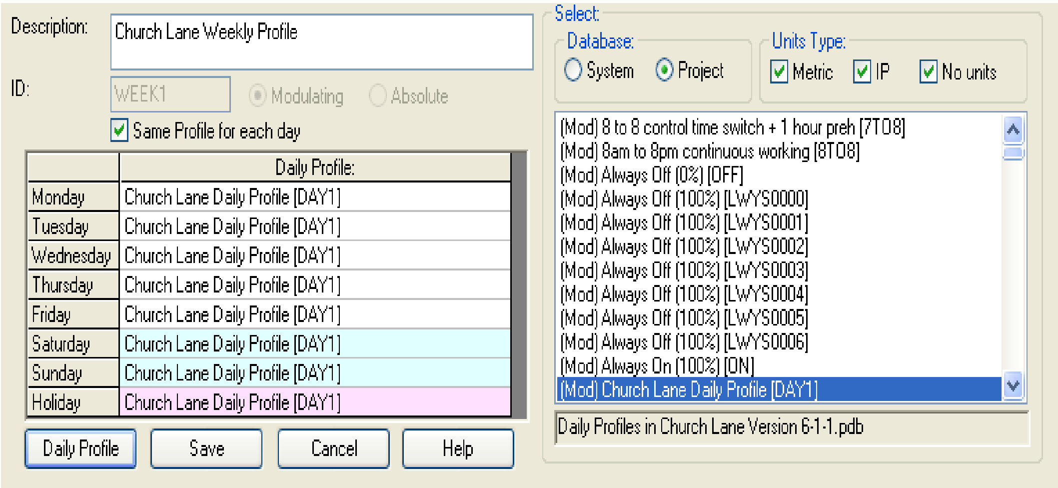


Figure 28: Church Lane Weekly Profile

Even though the building is open during the summer there is very limited activity, the heating for the building is turned off and a very small amount of electrical energy is consumed. Therefore, the Annual Profile for the building is set so that June, July and August are *off continuously [OFF]*, seen here in Fig. 29, in an attempt to compensate for the reduced loads at the weekends and public holidays throughout the scholastic calendar. The electrical energy consumed over a weekend in the summer months was recorded using an energy logger over a weekend and the average load was approximately 3 kW seen previously in Fig. 23.

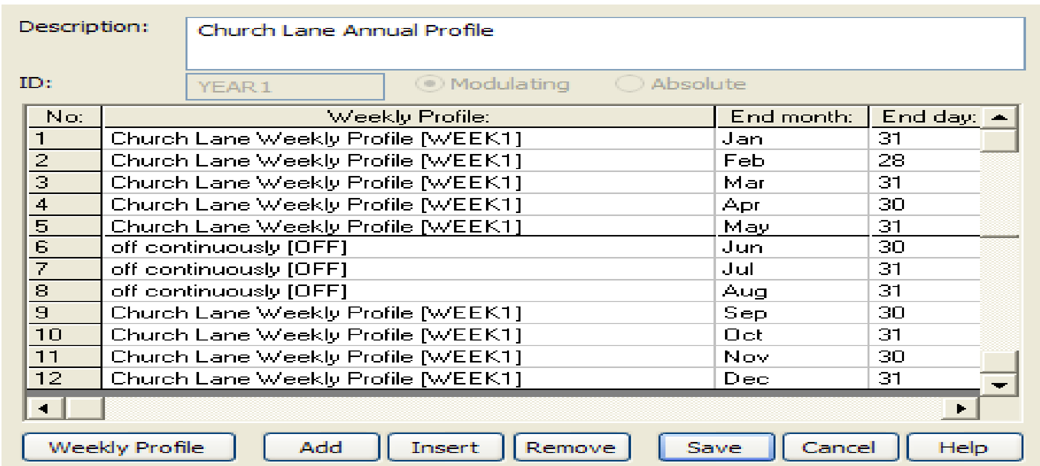


Figure 29: Church Lane Annual Profile

This assumption, at first glance may appear crude, but the annual electrical consumption value provided from the e^3 website and the simulation created using IES<VE> have similar overall electrical energy consumed. The annual average quantities of fuel to generate the thermal energy required for the Church Lane building are also similar to the simulated value. The simulation software had to be tuned to the actual recorded values.

A solar shading analysis of the building using the Suncast software can then be performed. Suncast performs the internal and external insolation values over a twenty four hour period, for each day of the year for the building. Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. This calculation examines the building's thermal gains in terms of area (m^2) or percentage (%) on all external surfaces throughout the year, seen here in Fig. 31, a critical part of the simulation software analysis.

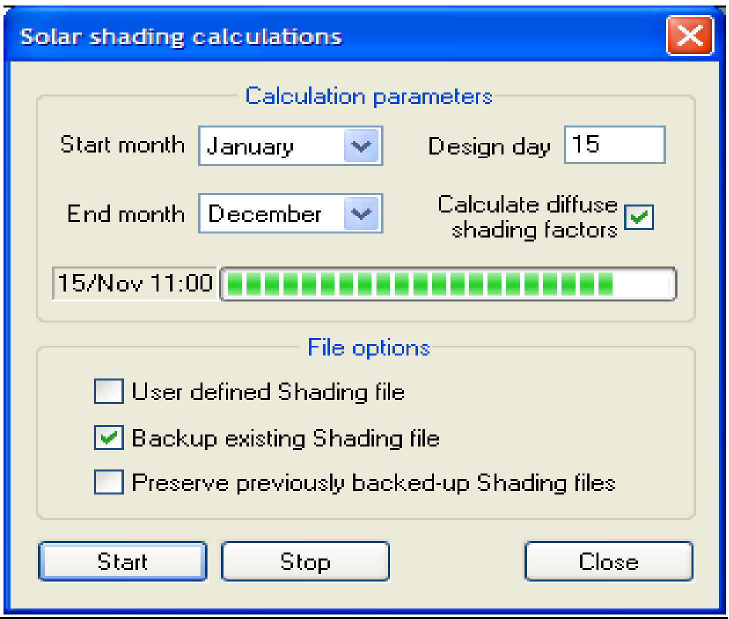
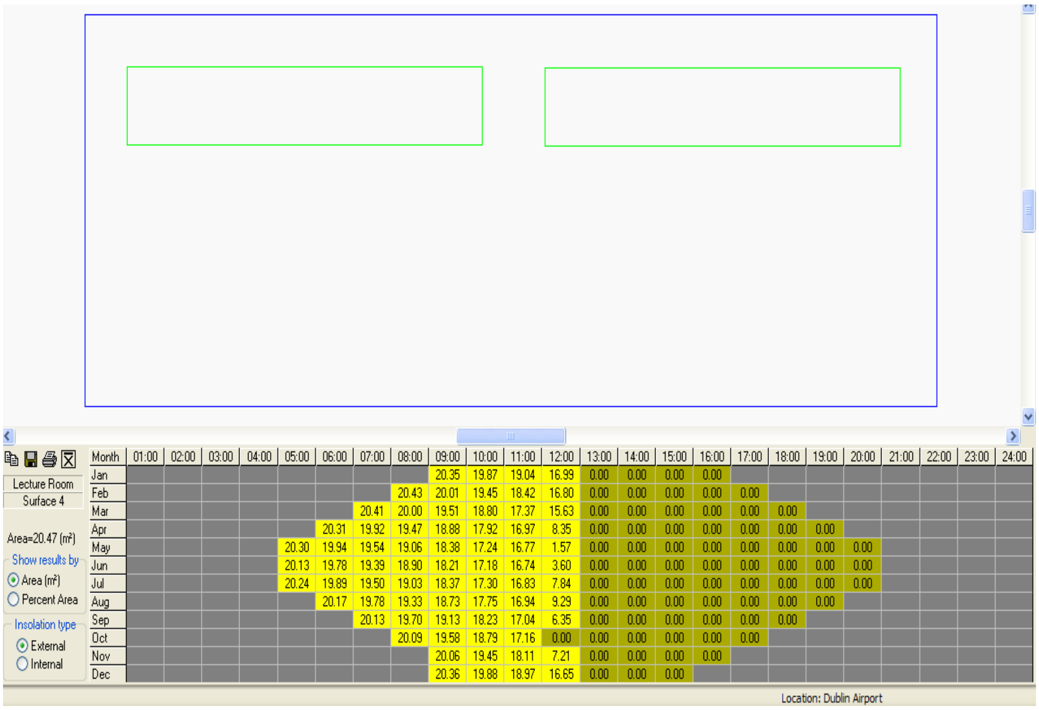


Figure 30: Suncast Solar Shading Calculation Settings



Month	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00
Jan									20.35	19.87	19.04	16.99	0.00	0.00	0.00	0.00								
Feb								20.43	20.01	19.45	18.42	16.80	0.00	0.00	0.00	0.00	0.00							
Mar							20.41	20.00	19.51	18.80	17.37	15.63	0.00	0.00	0.00	0.00	0.00	0.00						
Apr						20.31	19.92	19.47	18.88	17.92	16.97	8.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00					
May					20.30	19.94	19.54	19.06	18.38	17.24	16.77	1.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Jun					20.13	19.78	19.39	18.90	18.21	17.18	16.74	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Jul					20.24	19.89	19.50	19.03	18.37	17.30	16.83	7.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
Aug						20.17	19.78	19.33	18.73	17.75	16.94	9.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00					
Sep							20.13	19.70	19.13	18.23	17.04	6.35	0.00	0.00	0.00	0.00	0.00	0.00						
Oct								20.09	19.58	18.79	17.16	0.00	0.00	0.00	0.00	0.00	0.00							
Nov									20.06	19.45	18.11	7.21	0.00	0.00	0.00	0.00								
Dec									20.36	19.88	18.97	16.65	0.00	0.00	0.00									

Figure 31: External Insolation Example of East Side for Room CL1-002

The Suncast software also affords the user to perform right-to-light calculations during the design stages for a new building to ensure that other buildings and their occupants are not affected by your new design before construction has commenced, as shown in Fig. 32 below.

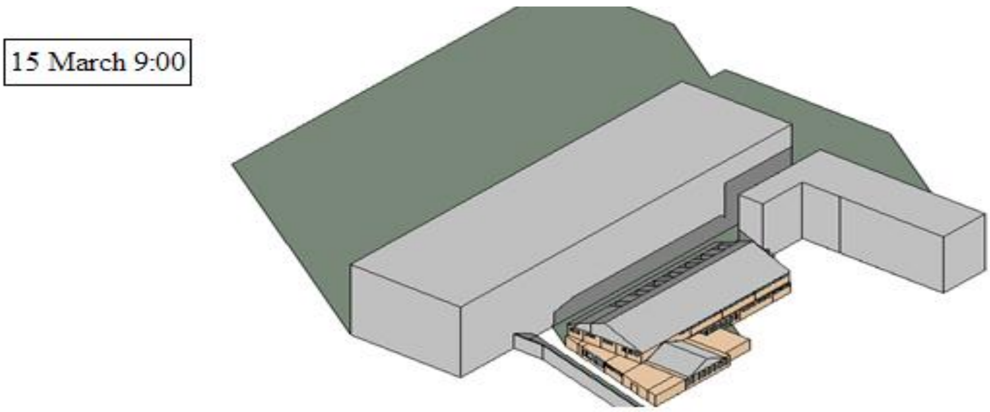


Figure 32: Suncast Image of Church Lane Building and Surrounding Buildings

The Suncast software package must be run before any thermal analysis can commence in the Thermal Calculation and Simulation area – Apache.

3.2 Apache Simulation Settings and Options

The ApacheSim [Dynamic Simulation] option is selected once the Apache package is activated and all the rooms in the building were selected for the thermal analysis of the Church Lane building, as shown in Fig. 33.

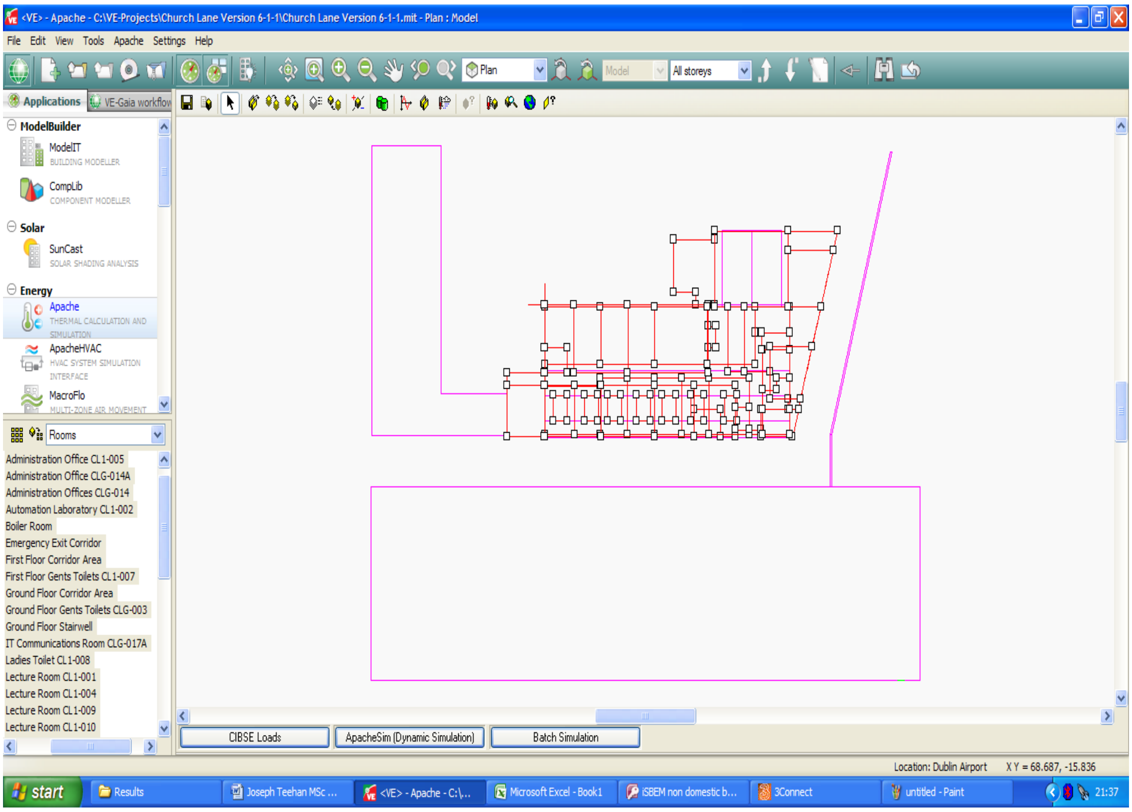


Figure 33: ApacheSim [Dynamic Simulation]

To correctly perform this thermal analysis the Model Links for Suncast and Natural Ventilation were selected. These links provided a wide variety of outputs for the analysis. These outputs include but are not limited to; the room sensible heating load, natural ventilation, comfort index, lighting and equipment gains, conduction and ventilation gains and the outside temperature based on historical meteorological files.

The other links, MacroFlo, Radiance and Auxilary Ventilation are unchecked. MacroFlo allows the user to simulate window opening amounts for natural ventilation calculations, Radiance performs a much more detailed analysis of daylighting, glare and artificial lighting and there is no mechanical ventilation in the building for HVAC purposes since the building is heated using radiators. Therefore these three links would increase the calculation time and complexity unnecessarily and are outside the scope of this dissertation.

The simulation time step, reporting interval and preconditioning period can be varied at the cost of longer processing time but a more in depth analysis over a shorter period than one year can be performed by changing the month and date.

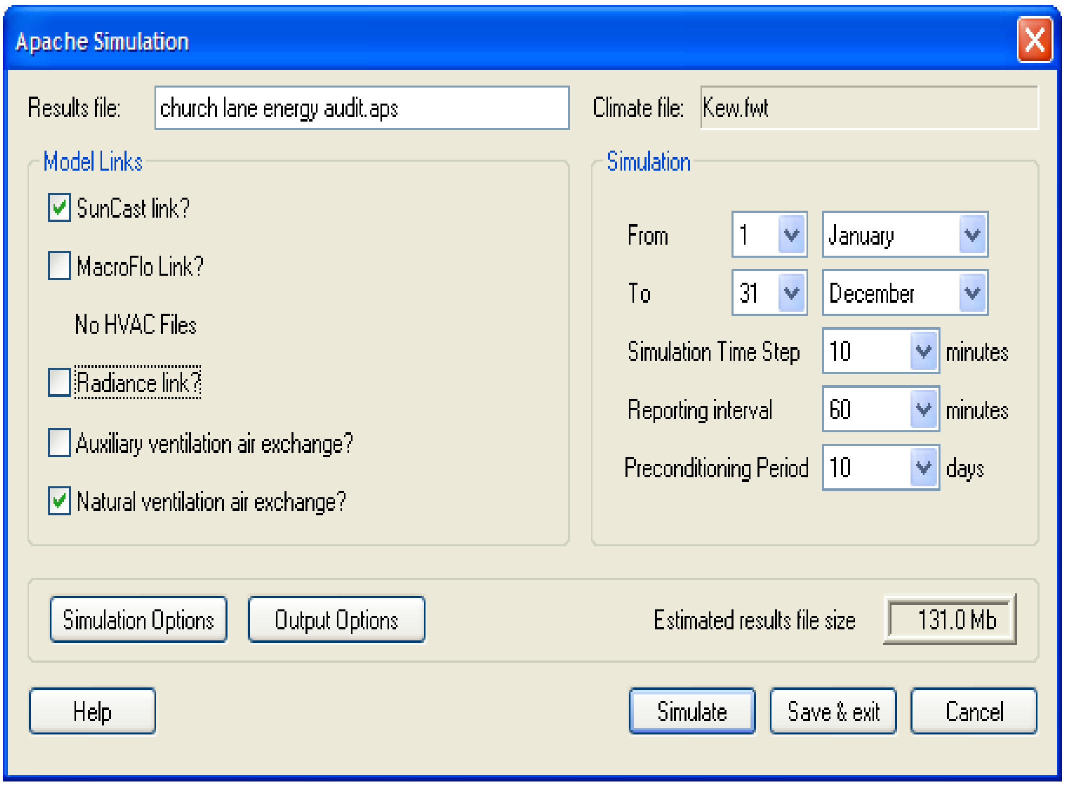


Figure 34: Apache Simulation Settings

The Simulation Options shown in Fig. 35 contain settings to adjust calculation methodologies for;

External Convection, which occurs at the external surfaces of the building, is predominantly wind-driven forced convection. The ApacheSim user has a number of options for modelling convection heat transfer between air masses inside the building and the adjacent building elements. Building surfaces emit thermal radiation by virtue of their absolute temperature. Exterior building surfaces receive long-wave radiation from the sky, the ground and other objects in the environment. They also emit thermal radiation. The emissivity of the air is mainly due to an infra-red absorption band associated with water vapour. If the user selects the anisotropic diffuse solar radiation model from the Simulation Options menu the calculation designates a portion of the diffuse radiation circumsolar, which it treats as if it emanated from the sun position. The initial temperature can be adjusted if required. The NCM lighting control parameters are included in the Part L compliance calculation when using IES<VE>. [61]

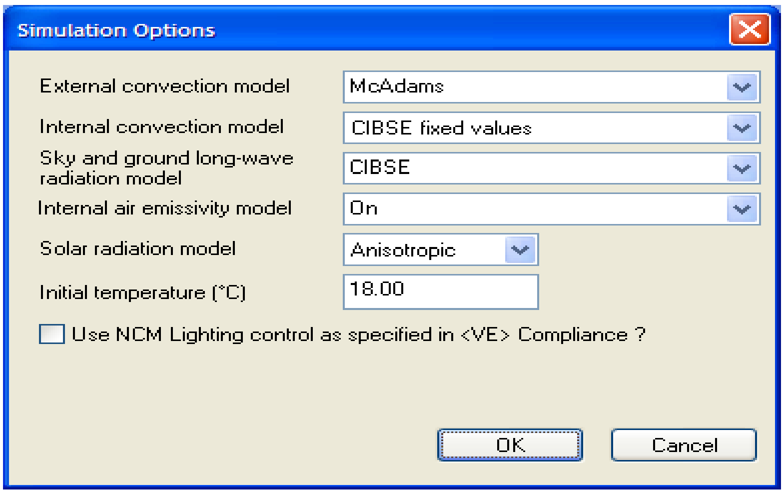


Figure 35: Simulation Options ApacheSim [Dynamic Simulation]

The output options allow the user to deselect specific rooms so that a detailed output for thirty of the forty rooms could be performed, see Fig. 36 below.

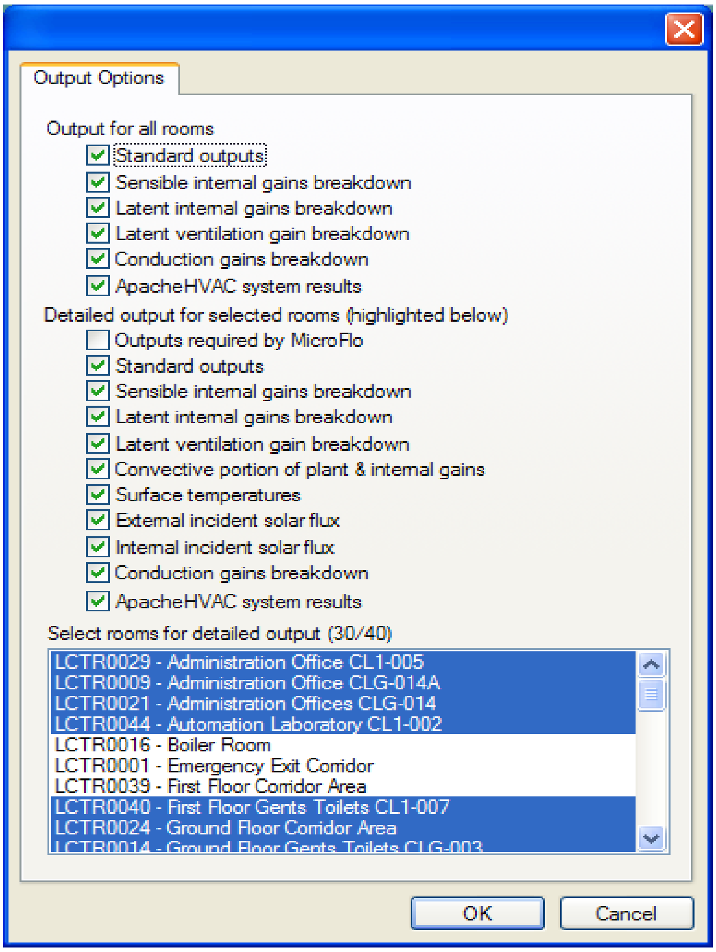


Figure 36: Apache Simulation Detailed Output Options

The rooms which were de-selected for the following reasons:

The circulation corridors are heated indirectly by the adjacent rooms which are using radiators. The boiler room does not require any radiators as the heat losses associated with the boiler and associated pipe work for the heating system maintain a satisfactory temperature in this room. In most other cases in the building there are no radiators inside the smallest rooms.

When the simulate option is selected the software begins processing and the results are viewed in the Vista software package for analysis.

3.3 Energy Performance Rating

IES<VE> contains a software package to perform a compliance check for the Part L building regulations and for the Building Energy Rating (BER) evaluation. By correctly entering the data about the building in the building template manager and selecting the appropriate HVAC type a BER can be generated of the existing building. This calculation was carried out using the *interface* for the Simplified Building Energy Model (iSBEM) package developed by BRE for the DCLG in the United Kingdom.

The Simplified Building Energy Model (SBEM) is a computer program that provides an analysis of a building's energy consumption. SBEM calculates monthly energy use and carbon dioxide emissions of a building given a description of the building geometry, construction, use and HVAC and lighting equipment. SBEM performs all calculations based on the National Calculation Methodology (NCM). This software can also be used for Part L building regulation compliance and BER in the Republic of Ireland provided that version 6.1.1.1 of IES<VE> is used.

The software iSBEM is part of the <VE> Compliance software package and is linked to all other packages, such as Apache and FlucsPro automatically. Therefore once all required calculations are complete the Compliance package can then generate the SBEM output documents and BER certificate.

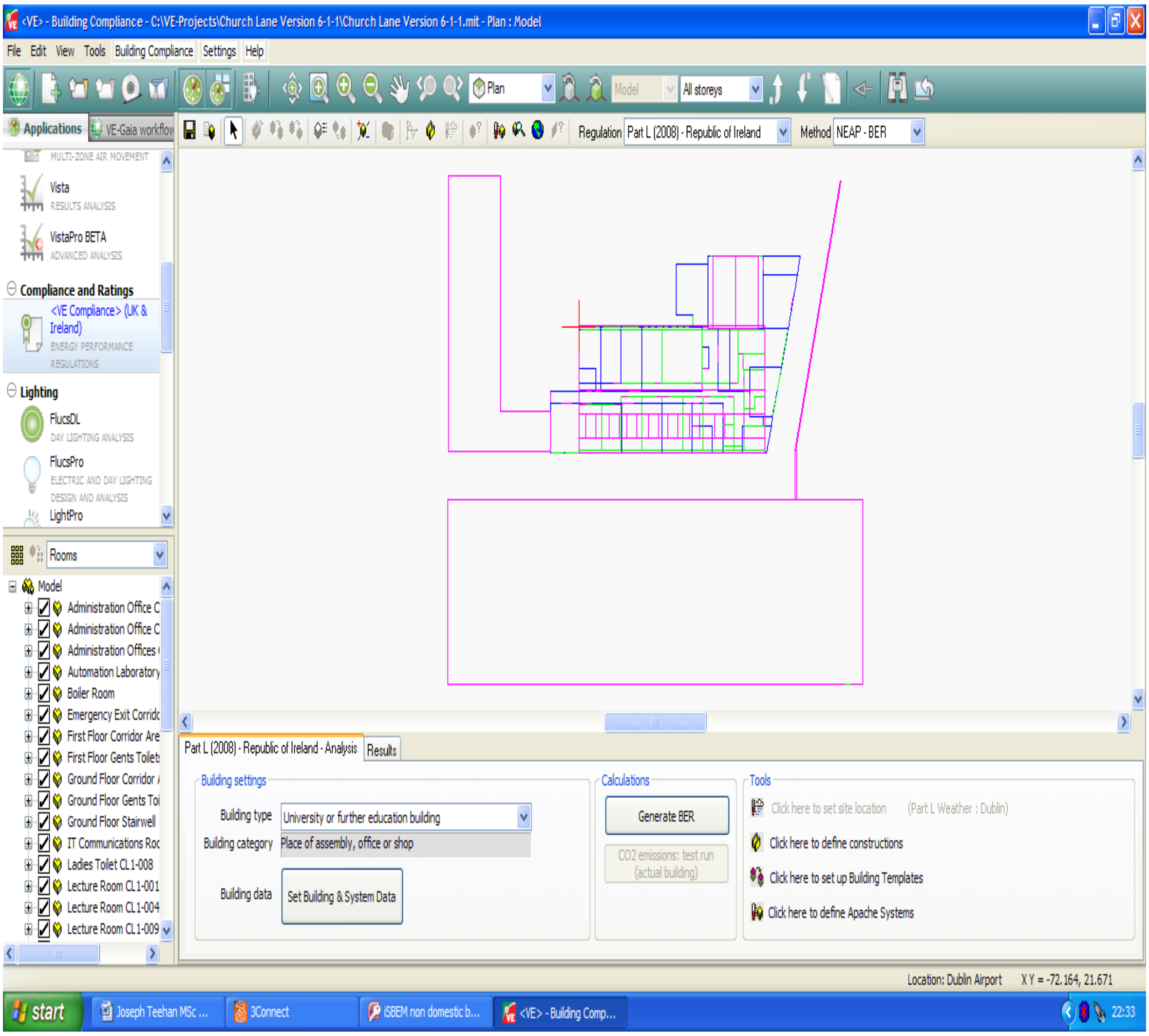
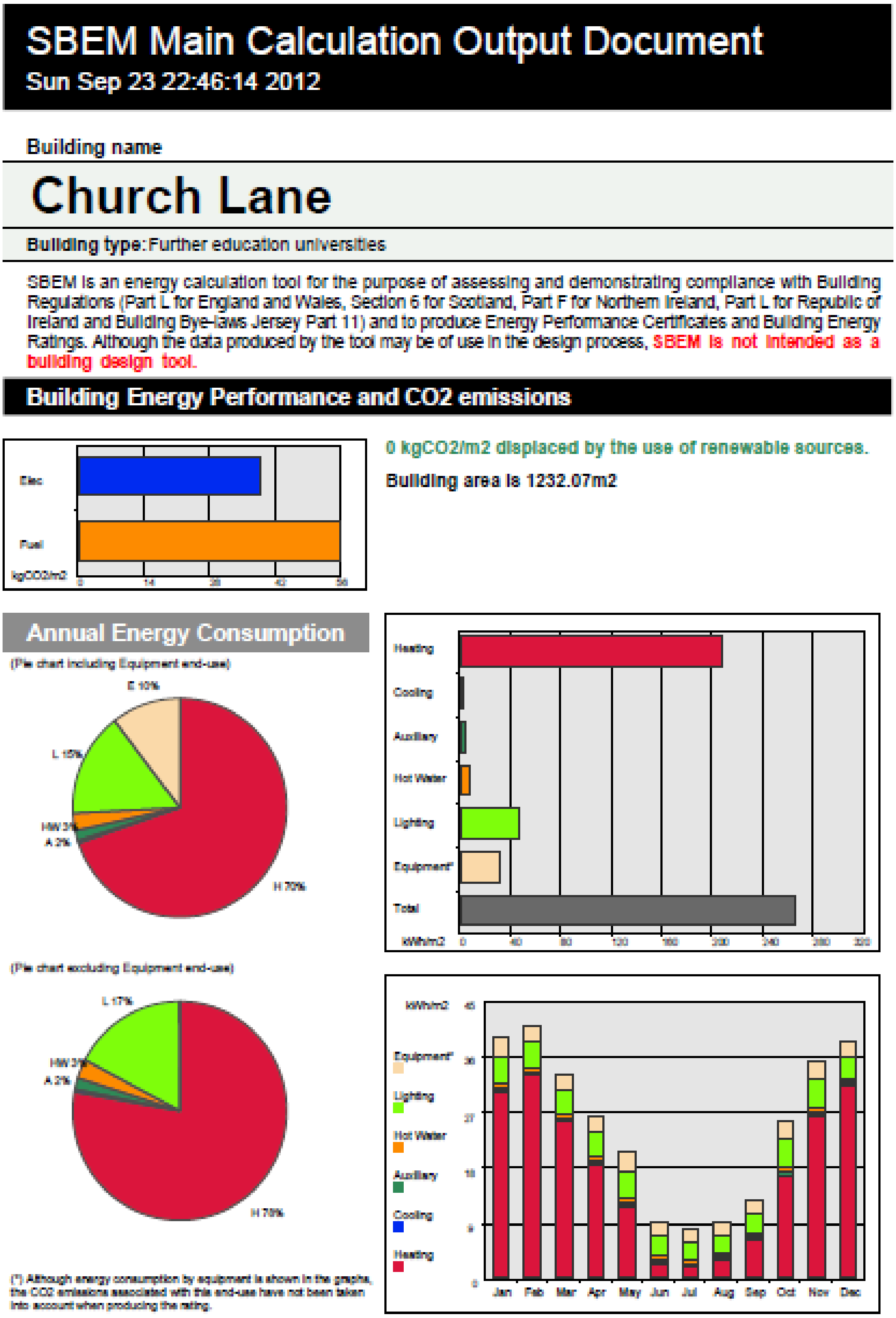


Figure 37: <VE> Compliance Software Package Interface

Once the calculation is complete in SBEM the software then allows the user to view the BER certificate, Advisory Report and the Supplementary Report. The Advisory Report and the Supplementary Report are designed to be provided to the client as part of the Non-Domestic Energy Assessment Procedure (NEAP) along with the BER. The NEAP process is very similar to the energy assessment method, NCM, recognised in the United Kingdom. These two reports highlight areas that may need to be addressed in the building and suggest suitable payback times for specific improvements to the building fabric, heating or lighting systems and promote the installation of renewable energy equipment.


SBEM Main Calculation Output Document
Sun Sep 23 22:46:14 2012

Building name

Church Lane

Building type: Further education universities

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

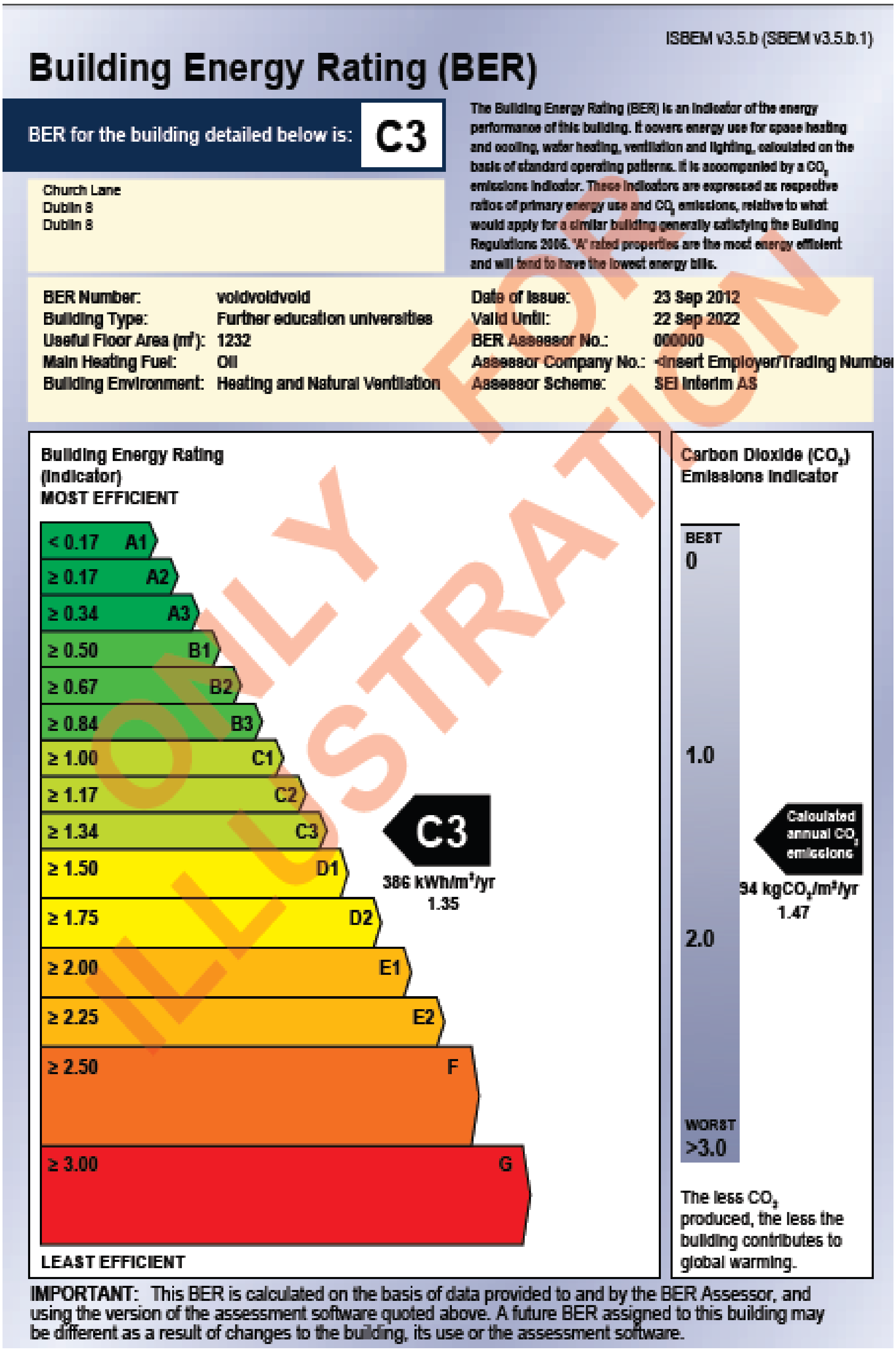
0 kgCO2/m2 displaced by the use of renewable sources.

Building area is 1232.07m2

Annual Energy Consumption

(*) 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.

Figure 38: iSBEM Output Document for Church Lane Building



ISBEM v3.5.b (SBEM v3.5.b.1)

Building Energy Rating (BER)

BER for the building detailed below is: C3

Church Lane
Dublin 8
Dublin 8

The Building Energy Rating (BER) is an indicator of the energy performance of this building. It covers energy use for space heating and cooling, water heating, ventilation and lighting, calculated on the basis of standard operating patterns. It is accompanied by a CO_2 emissions indicator. These indicators are expressed as respective ratios of primary energy use and CO_2 emissions, relative to what would apply for a similar building generally satisfying the Building Regulations 2005. 'A' rated properties are the most energy efficient and will tend to have the lowest energy bills.

BER Number:	voidvoidvoid	Date of Issue:	23 Sep 2012
Building Type:	Further education universities	Valid Until:	22 Sep 2022
Useful Floor Area (m²):	1232	BER Assessor No.:	000000
Main Heating Fuel:	Oil	Assessor Company No.:	<Insert Employer/Trading Number
Building Environment:	Heating and Natural Ventilation	Assessor Scheme:	SEI Interim AS

Building Energy Rating (Indicator)
MOST EFFICIENT
< 0.17 A1
≥ 0.17 A2
≥ 0.34 A3
≥ 0.50 B1
≥ 0.67 B2
≥ 0.84 B3
≥ 1.00 C1
≥ 1.17 C2
≥ 1.34 C3
≥ 1.50 D1
≥ 1.75 D2
≥ 2.00 E1
≥ 2.25 E2
≥ 2.50 F
≥ 3.00 G
LEAST EFFICIENT
C3
386 kWh/m²/yr
1.35

Carbon Dioxide (CO_2) Emissions Indicator
BEST
0
1.0
2.0
WORST
>3.0
Calculated annual CO_2 emissions
94 $kgCO_2/m^2/yr$
1.47
The less CO_2 produced, the less the building contributes to global warming.

IMPORTANT: This BER is calculated on the basis of data provided to and by the BER Assessor, and using the version of the assessment software quoted above. A future BER assigned to this building may be different as a result of changes to the building, its use or the assessment software.

FOR ILLUSTRATION ONLY

Figure 39: iSBEM BER Certificate for Church Lane Building

Chapter 4: Analysis of Results

4.1 Methods Adopted

This analysis compares the recorded and historical data of the building. The results for heating, daylighting and electrical energy consumption are viewed in the Vista software package and displayed in the following analysis accordingly.

This simulation had to be tuned as closely as possible to the current operating condition of the building. The building's construction elements, artificial lighting, boiler and radiators were not in good condition. Therefore the best possible representation of the existing building was created in the simulation. The analysis of both the historical and simulated data will reflect the anomalies of the Church Lane building.

It is critical to this energy audit to determine the number of days the building is closed annually. In the Republic of Ireland there are nine Public Holidays including the Christmas Break of the 25^{th}, 26^{th} December and the 1^{st} of January when the building is closed for approximately two weeks each year.

Therefore, the building is closed for the following number of days;

14 days Christmas Break + 6 Public Holidays + 50 weekends = 120 days

A summary table of potential savings will be presented in the recommendations section of this dissertation, Chapter 5. Calculations performed to represent these savings are carried out throughout the analysis stage of the dissertation.

4.2 Specific Interpretations

Electrical Analysis - Domestic Hot Water

The historical electrical energy consumption data is an invaluable resource. It helped with the initial analysis of the building by highlighting the unusual minimum load over weekends to run the building. After detailed analysis using an electrical energy analyser it was determined that the grid supplied electrical water heater was switching on and off frequently over the weekend when the building was closed completely and there was no hot water demand. The load in the building varied approximately by 3.0 kW each hour, off for one hour on for thirty minutes, as can be seen in Fig. 40.

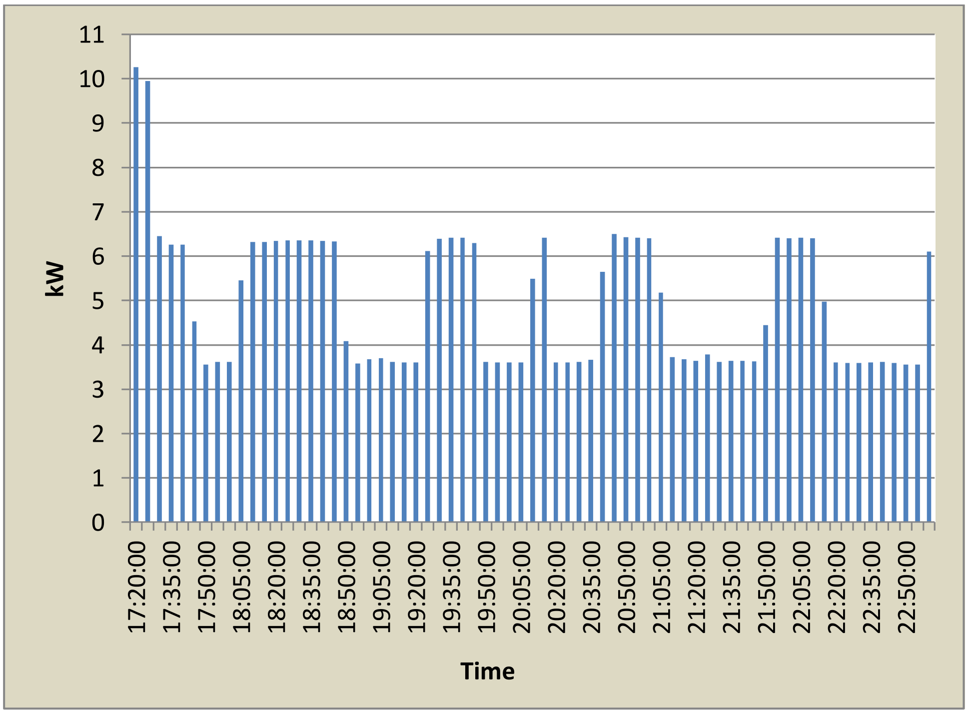


Figure 40: Electrical Energy Consumed after Church Lane Building is Closed

The annual average daily electrical load recorded from the BMS equipment used by the e[3] website is similar to the peak day electrical load calculated in the IES simulation. Therefore based on Fig. 41, the annual kilo watt hours consumed per square metre is a good approximation for the BER evaluation. It should be noted that the annual average daily electrical load recorded by the BMS in 2010/2011, at fifteen minutes intervals, implies that the load is more variable than the simulation.

Analysis of the maximum values recorded by the BMS in 2010/2011 indicated that that a significant electrical load had being switched on. This was due to supplemental electrical heating being introduced to keep the building from shutting down. This occurred in mid-February, when the oil supply for the building was not checked and the tank supply was exhausted. After contacting the DIT Buildings Management Office the staff indicated that the oil supply does need to have automatic monitoring installed.

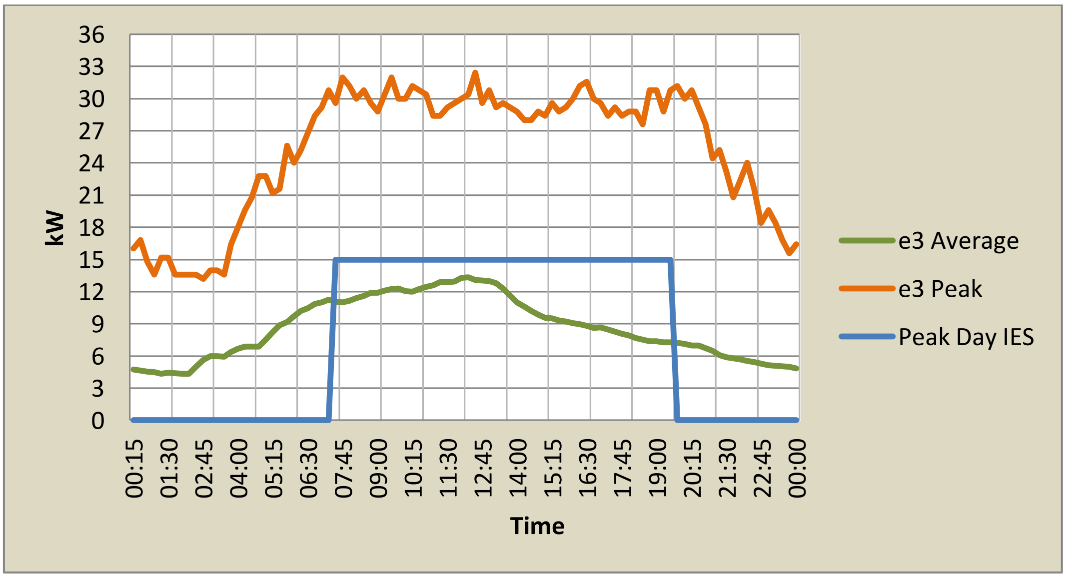


Figure 41: Electrical Energy Data – BMS (2010/2011) v IES (Simulation)

Electrical Analysis – Maximum Import Capacity

The peak energy values recorded in order to compare them against the Maximum Import Capacity (MIC). The electrical energy provider charges commercial and industrial customers a MIC charge based on the size of transmission equipment required to supply the building. This was found to be grossly over-estimated and potential savings could be gained by requesting a billing charge alteration.

The overall electrical power factor for the building and the current per phase were recorded using the HAWK 5000 energy logger. The data provided from this equipment indicated that while the load current is small value during this time, the three phases are frequently unbalanced in terms of current, as shown in Fig. 42. The energy analyzer was used to identify which phase was unbalanced and by switching of individual final circuits the Domestic Water Heater was identified as the load which increased and decreased as shown in Fig. 40.

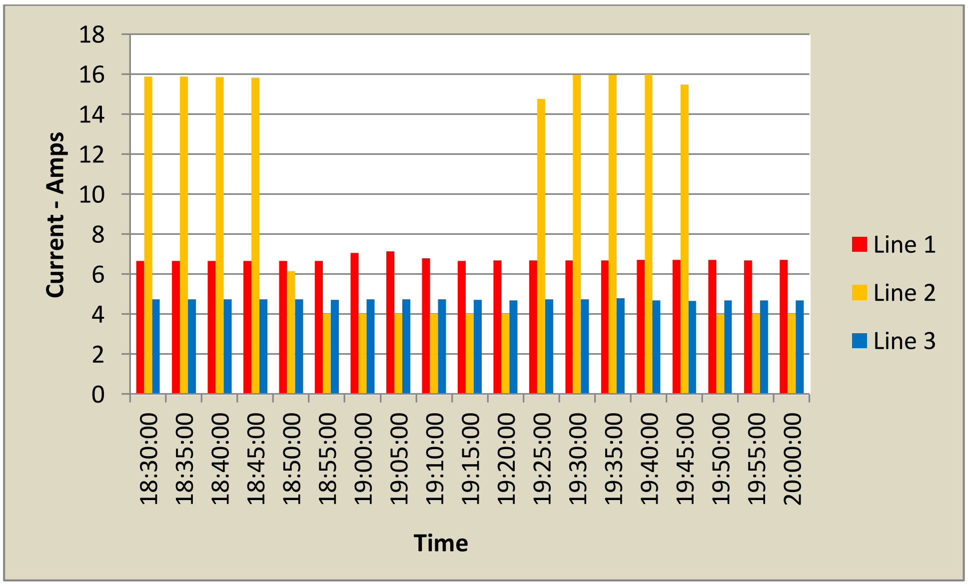


Figure 42: 3-Phase Electrical Current during Winter Maximum Demand Hours

Electrical Analysis – Maximum Demand Penalties

Maximum demand occurs during winter months when peak demand on electrical generation occurs. The National Grid Operator, Eirgrid, charges penalties to commercial and industrial electrical customers from 5pm to 7pm each day if the load for the building produces a power factor of less than 0.95 for longer than one fifteen minute period. This in turn increases the cost of operating the building unnecessarily in terms of electrical energy. The overall power factor for the building remains below the minimum value of 0.95 during the peak hours permitted by the electricity supplier during Winter Maximum Demand Hours, as shown in Fig. 43.

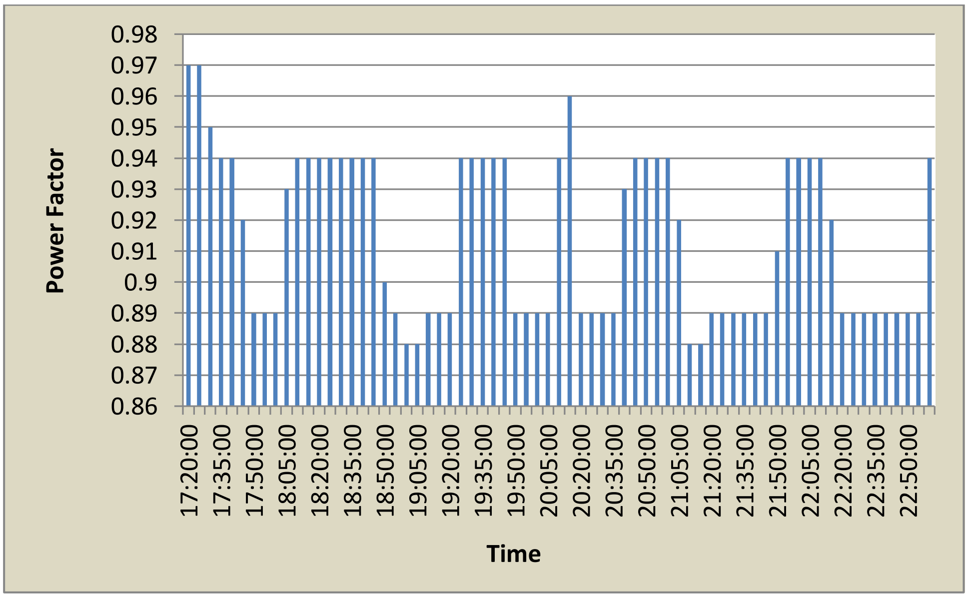


Figure 43: Power Factor during Winter Maximum Demand Hours

The electrical energy simulation available within IES<VE> is not designed to monitor the building's electrical load. The methodology used to calculate the electrical consumption in IES<VE> is based on the size of each room in square metres, the number of people in each room, each room activity and general office equipment used throughout the building.

Electrical Analysis - Daylighting

There is a large rooflight ($5m^2$) installed in seven lecture rooms and adequate fenestration penetration in the external walls in a number of other rooms to merit daylight harvesting controls. The existing lighting controls installed consist of manual switches. All rooms should have occupancy sensors to extinguish the artificial lighting when the room is not occupied after a defined period. Some rooms have adequate natural daylight when the rooms are occupied during the day. There are evening lectures but these are limited to four lecture spaces and laboratories.

> *For a daylit appearance without any electric lighting, the average daylight factor should not be less than 5 percent. For a daylit appearance with the use of electric lighting, the average daylight factor should be not less than 2 percent. For this condition, daylight will be sufficient for part of the year but for others additional electric lighting will be required. In both cases, the surface reflectance and the positions of windows should be high so that inter-reflected lighting in the space is strong and even.*
>
> *In a room where the average daylight factor is less than 2 percent, the general appearance will be of an electrically lit interior. Daylight will be noticeable only on room surfaces immediately adjacent to windows, although the windows may still provide adequate views out for occupants throughout the room.* [62]

Based on further studies of the same region in the UK the affect of daylight and the probability of lights being switched on vary but the consideration is that it varies between 0.1% to a 10% minimum daylight factor [62].

These values contribute to the reasoning and methodology for selecting specific rooms to contain daylight dimming control in the Church Lane building.

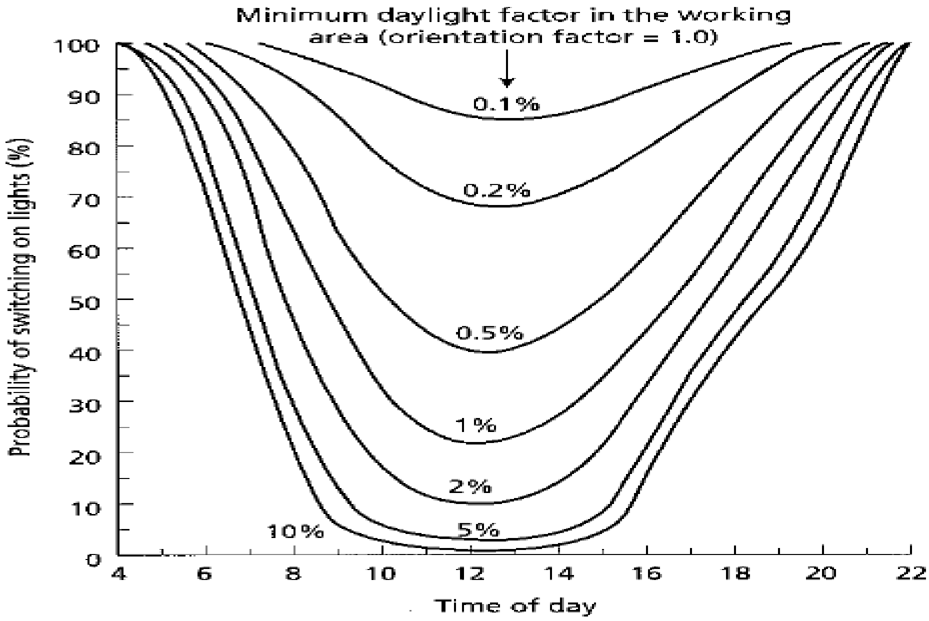


Figure 44: Switch-On Probabilities for One Year (London) [62]

A number of rooms would benefit from daylight linked controls based on Fig. 44 and Fig. 45. From the data generated using the FlucsPro package, 24 of 29 rooms exceed 0.1% minimum daylight factor, based on Fig. 14 in Section 2.4. Therefore there is 90% probability of artificial lighting on during the day. This suggests that a 10% savings in electrical consumption could be achieved by using daylight linked controls. This would require that the building's artificial lighting system would have to be completely upgraded and the luminaires would have to contain electronic dimmable ballasts. A costly upgrade since the building will be sold in the near future.

Electrical Analysis - Artificial Lighting

In case of an example taken in London [62] the effect of high frequency dimming linked with levels of daylight are considerable in terms of energy savings.

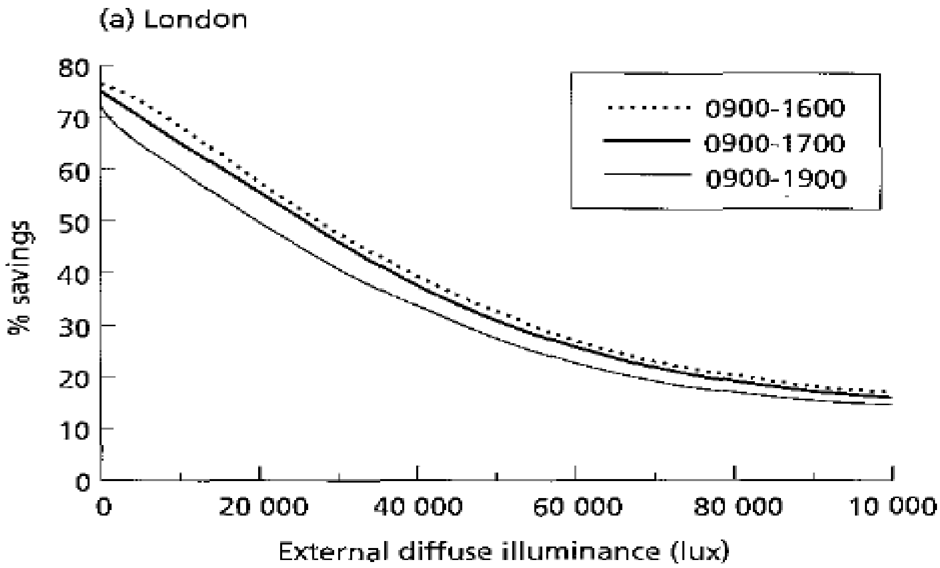


Figure 45: Energy Savings from High Frequency Dimming (London) [62]

The artificial lighting values recorded in the teaching areas suggest that the Illuminance level in four rooms is below the CIBSE Lighting Guide minimum of 300 lux, as shown in Fig. 17 in Section 2.5. Other rooms exceed the minimum requirement considerably. The artificial lighting installed in the Church Lane building is over ten years old and the lighting design is not consistent. Since the DIT is relocating to a new campus there is little interest by the Buildings Management Office to make a capital investment to upgrade the artificial lighting and controls to take advantage of the natural daylighting available.

Thermal Analysis – Room Occupant Satisfaction Survey

In all rooms the occupants appear to content with the artificial lighting levels, but their opinion of the room temperature and air quality is below average expectations, as shown in Fig 19. Using this software the percentage of people dissatisfied was based on the lowest temperature degree days of occupancy available in the weather database files within IES<VE>. The percentage of people dissatisfied within the teaching areas is high and in the case of CLG-015 this room appears to be significantly underperforming, further analysis of this room would be necessary to confirm this anomaly.

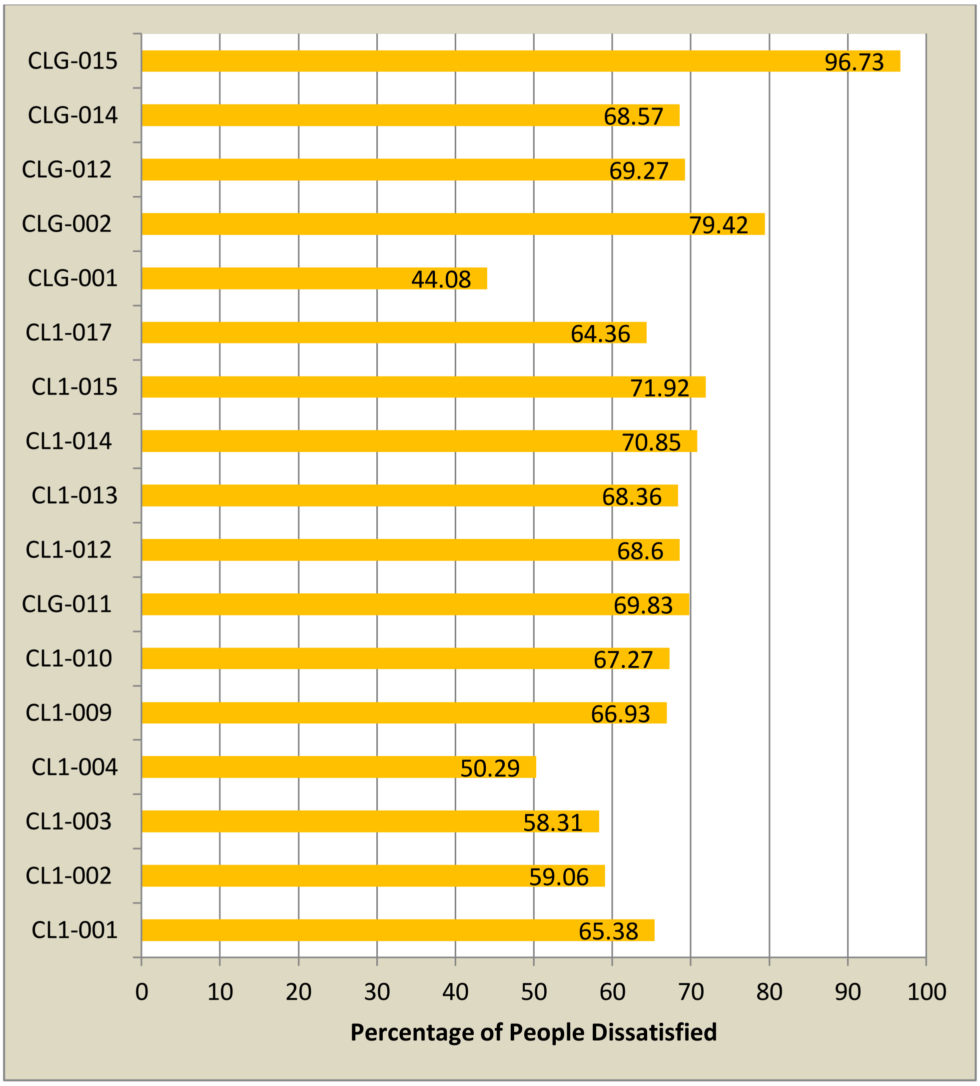


Figure 46: Percentage of People Dissatisfied with Teaching Areas

Whilst the values from the IES<VE> simulation, as shown in Fig. 46, are consistent with the temperature values recorded using the portable measurement equipment, as seen in Fig. 19 in Section 2.6, the overall impression for the building is that the thermal performance of the heating system is not maintaining the minimum 16.5 °C room temperature regulation required of by the Health and Safety Authority of Ireland for education and office spaces. The room occupant satisfaction survey highlighted that the environmental conditions were not satisfactory, as shown in Fig. 20, which also supports the recorded data and the simulated results using IES<VE>. Furthermore, the IES<VE> simulation of the building's space conditioning sensible load along with the dry bulb temperature of the rooms also confirmed that the building fabric and heating system is unable to maintain the thermal comfort levels for the building's occupants, see Fig. 47.

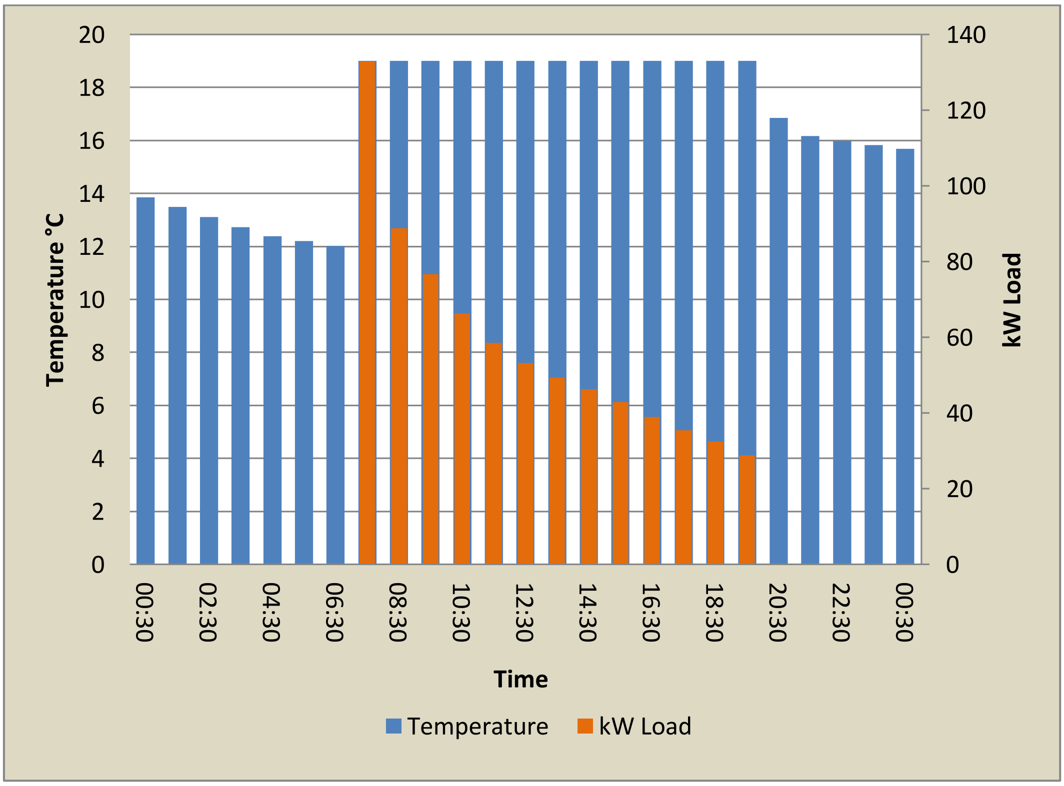
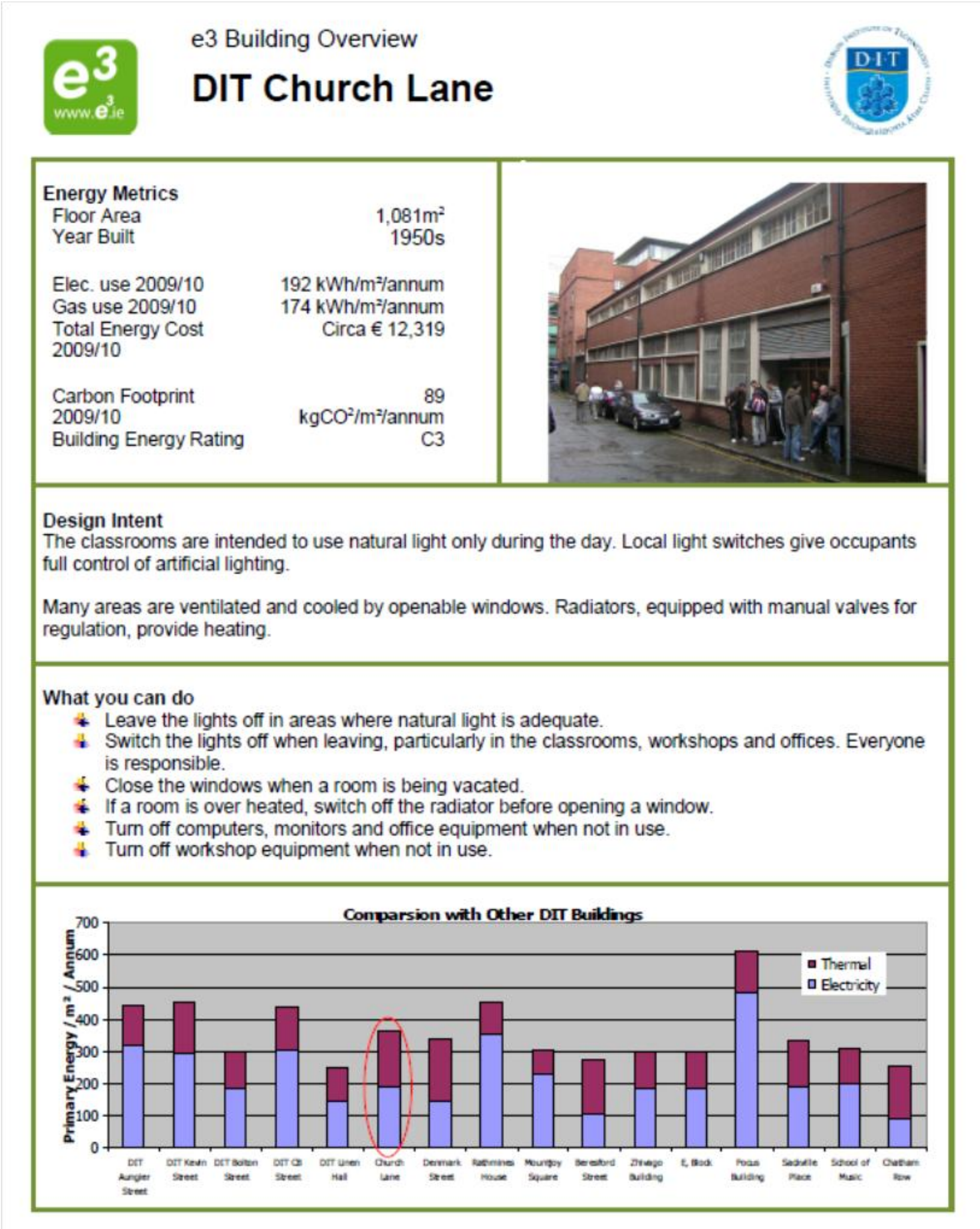


Figure 47: Space Conditioning Sensible Load and Dry Bulb Temperature

Energy Performance Assessment – e³ v SBEM

The building energy performance available from the e³ website provided a valuable comparison between the BER created using IES<VE> and the previously recorded BER of C3 seen here in Fig. 48. The Floor Area in this report subtracts the circulation area in the building, whereas the IES<VE> BER certificate generated is for the Total Floor Area of the Building.



e3 Building Overview

DIT Church Lane

Energy Metrics

Floor Area	1,081m²
Year Built	1950s
Elec. use 2009/10	192 kWh/m²/annum
Gas use 2009/10	174 kWh/m²/annum
Total Energy Cost 2009/10	Circa € 12,319
Carbon Footprint 2009/10	89 kgCO²/m²/annum
Building Energy Rating	C3

Design Intent

The classrooms are intended to use natural light only during the day. Local light switches give occupants full control of artificial lighting.

Many areas are ventilated and cooled by openable windows. Radiators, equipped with manual valves for regulation, provide heating.

What you can do

- Leave the lights off in areas where natural light is adequate.
- Switch the lights off when leaving, particularly in the classrooms, workshops and offices. Everyone is responsible.
- Close the windows when a room is being vacated.
- If a room is over heated, switch off the radiator before opening a window.
- Turn off computers, monitors and office equipment when not in use.
- Turn off workshop equipment when not in use.

Figure 48: e³ Website Report on Church Lane 2009/2010

The results for Electricity and Oil in terms of energy measured in kWh/m^2/annum and the carbon footprint measured in CO_2/m^2/annum measured here are similar to the results recorded in Figs. 38 and 39 in Section 2.3 for oil consumption when converted to kWh.

The IES<VE> BER evaluation yielded values of 386 kWh/m^2/annum and 94 CO_2/m^2/annum. These values were higher than the e^3 report by just over 5%.

Since the original calculation was carried out some time ago, 2004, and the previous survey and results could not be verified, the most recent evaluation is taken to be correct and that the difference between the Useful Floor Area of 1232 m^2 (IES<VE>) and the Total Floor Area of 1081 m^2 (e^3) may have caused this error.

An observation made during this analysis is that the SBEM output document indicates that the heating energy required to heat the building represents 70% of the overall load for the building, this is equivalent to 270 kWh/m^2/annum which is 155% greater than the estimated heat energy required, 174 kWh/m^2/annum using the oil fired boiler in the e^3 report.

This is a considerable discrepancy when previously; the average annual oil consumption over eight years was calculated to be equivalent to 159,726 kWh or 130 kWh/m^2/annum when the annual oil equivalent total was divided by the Useful Floor Area or 148 kWh/m^2/annum when divided by the Total Floor Area. It is clear that the heating system needs a metering system installed to accurately measure the heating oil consumption periodically so a more accurate analysis can be performed.

4.4 Enveloping Interpretations

The average and maximum values of daylighting calculated using IES<VE> highlight the potential even during short periods to switch off the artificial lighting. Over half of the rooms exceed the 5% minimum at some point during the day, as shown in Figs. 15 and 16 in Section 2.4.

After taking note of the heating system boiler rating plate (86–105 kW), for the Church Lane building, the simulation software space conditioning sensible load reaches a peak of 132 kW, as seen in Fig. 47. This indicates that the boiler was undersized or in reality; that the building fabric losses are very high during unseasonably colder days and the boiler cannot overcome these high heat losses.

As was noted in the walk-through survey the condition and age of the glazing is poor. The glass is single glazing with metal frames and in most cases the window does not seal shut correctly or at all. The condition of the windows is not an area that could be incorporated with the simulation software.

Compared to other buildings in the DIT being monitored by the BMS equipment for the e^3 website, the Church Lane building is a below average performer in terms of energy consumption.

Chapter 5: Recommendations and Conclusions

The following recommendations provide a practical approach to improve the energy performance and the thermal and visual comfort conditions for the building's occupants. It is recognised that the building is being sold within the next ten years and any recommendations are aimed at improving the environmental conditions. Such a short term improvement would provide a return on investment for the DIT in terms of their energy costs.

Energy Awareness and Implementation

The buildings management offices should appoint a technical staff officer who is interested in implementing energy savings for the building. This position should be incentivised by providing a performance award in monetary or time off in lieu terms. Without a local energy champion there is much less ownership of the building's energy problems by the occupants and motivation to improve the current poor conditions.

Electrical Load Recommendations

To correctly control the domestic hot water (DHW) system a 24 hr / 365 day digital timer should be installed. The simulation analysis using IES<VE> was unable to represent this load variation thus the empirical data obtained using the energy analyser was essential to identify this electricity consumption anomaly. By examination of the data provided from the energy analyser it was discovered that the DHW system was on for approximately eight hours each day over the weekend. The electrical load for this heater consumed 24 kWh of electrical energy each day the building was closed.

A more detailed investigation is warranted to identify which loads are switching on and off each day. Any other electrical loads which are on unnecessarily could also be controlled by installing a similar type of digital timer, as previously described for the DHW system.

A Maximum Import Capacity reduction application must be submitted to the electrical network supplier for approval. This process must also include a summary of the recorded data and relevant calculations carried out by a chartered electrical engineer. This entails more upfront costs at the outset but the monetary gain will negate this capital investment. With the electricity consumption data readily available from the e^3 website this application would be relatively straightforward and nominal administrative costs are expected.

The installation of Occupancy Sensors offers a realistic quick fix energy saving solution to reduce the lighting energy costs in each room. These sensors could also be linked to the rooflights such that when the room is not occupied the rooflights will automatically open or close based on the outside weather conditions.

The rooflights were installed within the last fifteen years have motorised controls to open and close them, operated using a manual electrical switch. The building's occupants have not being able to fully realise the potential benefit of this type of control. For warmer days the rooflights could be controlled using local thermostatic operated controls to cool the seven lecture rooms and provide much needed fresh air when required in the room.

Power factor correction equipment could be installed but the fact that the DIT will be selling this property would not justify the capital investment for a dynamic power factor correction system.

The results from the room survey indicate that some room's lighting installations are poorly designed. After recording the average surface illuminance in each of the teaching spaces; such data indicates that the building's lighting system should be upgraded.

Based on the data collected in each room and from the daylight analysis performed using the FlucsPro software package in IES<VE> there are a number of opportunities to install daylight dimming equipment.

Building Fabric Recommendations

The building's fabric especially the glazing requires some immediate attention.

There is an opportunity to repair many of the existing window latches so that the windows would close and remain close especially during inclement weather conditions. The window frames could also be fitted with weather stripping to seal the air gaps around the window's metal frames.

Insulation should be improved above the ceilings in all rooms containing acoustic ceiling tiles to reduce heat losses. The rooms containing the high open ceilings are designed as workshop spaces and should remain un-insulated.

An inner sliding window could be installed; the inner window ledge is approximately 200mm in depth. This solution could be trialled in rooms which contain rooflights, there would be no requirement to open the outer vertical windows in the walls after the inner pane of glass was installed.

The optimum energy saving solution would be to replace the glazing with new double or triple glazed windows with a high energy rating. New energy efficient glazing increases the value of the property, this recommendation would have a good return on investment for the DIT and is more attractive to prospective buyers or tenants, should the DIT decide to lease the building, in the interim.

Installing plasterboard with integrated Styrofoam panels on internal walls would be too costly as all external walls rooms have the radiators and pipe work installed along their inner surfaces. However, the introduction of external insulation could be very viable since the exterior does not have too many unusual shapes the installation would be quick and very effective in terms of reduction in heat losses.

Heating System Recommendations

The significant energy user for the Church Lane Building is the thermal requirements for the building supplied using the oil-fired boiler. The maintenance and running costs could be reduced by implementing the following recommendations:

Install a 365 day programmable timer that would only turn on the heating system if the outside temperature reached plus five degrees to prevent pipe work freezing. Turn on the boiler early on academic scheduled mornings after a weekend or public holiday so that the building’s thermal mass is warm before staff and students arrive by 8:00am.

The building is occupied in an unpredictable fashion due to classroom and laboratory scheduling. In cooperation with the timetable convenor the building could be occupied by students more efficiently, thus affording a reduction in temperature for rooms which are closed for the rest of the day or week.

The pipe work in the boiler room is insulated to a very high standard and since the rest of the building’s flow and return pipes heat the building along with the radiators, insulating these would not save energy and may cause rooms to be heated unevenly. Only areas that the pipe work is routed through which do not require heat should be insulated.

Installing thermostatic radiator valves would increase the thermal comfort of each room individually and with a nominal cost for each of these mechanically operated devices this recommendation should be implemented.

A new oil-fired boiler was installed within the last five years and it is approximately 90% efficient. The only feasible recommendation for this boiler is to convert its fuel supply to natural gas. Any other renewable energy heat source such as biomass or wood pellets would be cost prohibitive and take too long to repay the cost of installing a brand new heating system. Natural gas is metered locally and would provide more accurate data in terms of monitoring the building’s thermal requirements.

Installing variable speed drives (VSDs) to control the circulation pumps for the Low Temperature Hot Water heating system would introduce energy savings in terms of the power factor, the building's electrical load and thermal comfort levels would be improved in terms of being able to control the volume of water flowing per floor.

The Church Lane building heating system would benefit with upgrades to the control system, in contrast to the existing crude control system. Weather compensation controls, zone control, room thermostats and motorised radiator valves would increase the thermal comfort of the building and allow the system to be optimised by providing a closed feedback heating system. This type of system would require the installation of a BMS or BEMS. This may be cost prohibitive in the short term.

The building's heating system pipe work is supplying each floor separately from the boiler room. This could be controlled using zone control valves to reduce temperatures on the floors not being used. This recommendation depends on the full cooperation with the timetable convenor.

5.2 Potential Energy Savings

Aside from improving the glazing for the building by correctly sealing the windows and that they are modified or repaired so that they can close correctly the thermal requirements for the building is the main energy user. Including regular maintenance for a oil-fired burner and the rising costs of this type of fuel because it is becoming more and more unpopular as means to heat a building.

As a commercial customer DIT pays €0.94 per litre. With an annual average quantity of 15,212 litres this equates to an annual average of €14,300. If the heating system in the building was more accurately controlled at first with a three hundred and sixty five day programmable timer the number of hours could be reduced. Currently the boiler can be at most operating for 9 months or 36 weeks of the year, 7 days a week, for thirteen hours a day which is 3,276 hours.

Introducing the timer the boiler could be switched off most weekends and public holidays apart from operating to protect against freezing. This would mean that the boiler would not be operating for 30 weekends at 13 hours each day or 390 hours, a 12% reduction in operating time, or now operating for 2,886 hours.

By installing separate zone control for the ground floor and first floor of the building the first floor room temperature could be set back in the evenings. This energy saving value is difficult to quantify but a conservative estimate of; 5pm to 8pm, 3 hours each day for 180 days is a further 540 hours or approximately 30% less than the maximum load required during this time. A reduction in operating time for this strategy of 2,724 hours, i.e. 30% of 540 hours is equal to a reduction of 162 hours.

These two very low cost strategies could reduce the overall operating hours for the boiler by 17%. Based on the current cost of heating oil per litre as stated above of €0.94 this could reduce the cost of the annual oil quantity by approximately €2,400. Considering the cost of installing a suitable programmable timer for this purpose of approximately €200 this is certainly a worthwhile improvement.

Similarly, the DHW is an easy target to install a programmable timer. The DHW is heating water when it is not required for approximately 15 hours a day. The weekend profile observed from the energy analyzer data indicates that the heating element is on for one third of this time. Therefore at 3kW for 5hours each day this would equal 15kWh per day, 365 days or 5,475 kWh. At a commercial rate for electricity at €0.11 this would provide an annual saving s of €602. Again a worthwhile and very lost cost solution.

Other solutions are listed in Table 4 with indicative costs and approximate payback periods for each improvement. It is up to the Buildings Maintenance Office to choose the appropriate steps but have shown eagerness to implement the solutions described in detail above as soon as possible.

Table 4: Church Lane Building Improvements Recommendations

Improvement Opportunity	**CO_2 Impact**	**kWh Impact**	**Cost**	**Payback**
Energy Awareness Initiative	LOW	MEDIUM	LOW	< 1Week
Electrical				
Time Control of DHW	MEDIUM	MEDIUM	LOW	< 6 Months
Time Control of Large Electrical Loads	MEDIUM	MEDIUM	LOW	< 6 Months
Maximum Import Capacity	LOW	LOW	LOW	< 2 Months
Roof Light Controls Linked to Heating	MEDIUM	MEDIUM	MEDIUM	< 6 Months
Occupancy Sensors	LOW	MEDIUM	MEDIUM	< 18 Months
Power Factor Correction	HIGH	MEDIUM	HIGH	< 10 Years
Upgrade of Lighting Installation	HIGH	HIGH	HIGH	< 5 Years
Daylight Linked Controls for Lighting	HIGH	HIGH	HIGH	< 5 Years
Building Fabric				
Window Latches	MEDIUM	MEDIUM	LOW	< 6 Months
Weather Stripping	MEDIUM	MEDIUM	LOW	< 6 Months
Insulation – Loose Above Ceilings	MEDIUM	MEDIUM	LOW	< 2 Years
Inner Window Pane	MEDIUM	MEDIUM	MEDIUM	< 5 Years
Window Replacement	HIGH	MEDIUM	HIGH	< 20 Years
Insulation – External Insulation	HIGH	MEDIUM	HIGH	< 25 Years
Heating				
Boiler Scheduling	HIGH	MEDIUM	LOW	< 6 Months
Timetabling Alignment	HIGH	MEDIUM	LOW	< 6 Months
Thermostatic Radiator Valves	MEDIUM	MEDIUM	MEDIUM	< 2 Years
Natural Gas Conversion	LOW	MEDIUM	MEDIUM	< 6 Months
Install VSDs for Circulation Pumps	HIGH	MEDIUM	MEDIUM	< 18 Months
Zone Control	HIGH	MEDIUM	MEDIUM	< 2 Years
Heating BMS or BEMS	HIGH	HIGH	HIGH	< 4 Years

5.3 Future Investigation, Surveys and Analysis

There are a number of issues highlighted in the dissertation that need to be addressed for the Church Lane building. Some energy efficient improvements are not feasible because the building will be sold or leased in the near future as discussed throughout the dissertation.

However the building occupancy profile appears to be an area for improvement. Based on new time settings after the programmable timers are installed on the boiler and other significant energy users in the building, the analysis should be repeated to compare the current results with the results after the improvements are implemented.

By examining the internal temperature, CO_2 and humidity in each room over a twelve month period the conditions thermal comfort conditions for the occupants could be explored with the view for improvement.

Assess the feasibility of installing variable speed drives on the LTHW circulation pumps. Develop a clearer understanding of the MacroFlo software package in IES<VE> to simulate natural cooling of the building from fresh air by using window actuators. Assess the feasibility of introducing renewable technologies.

5.4 Conclusion

The term 'prevents maintenance' rather than 'preventive maintenance' inspired this student to respond to the current situation for the Church Lane building by making the best attempt to highlight the condition of the building. The building has not been maintained correctly and the condition of the building has deteriorated.

The Buildings Management Office have conceded to this fact and are willing to tackle some of the issues raised within their current limited budget. A fundamental result of this audit was to highlight the deficiencies and identify low cost corrections that the Buildings Management Office can afford to implement over the short term.

There are a number of low cost energy saving solutions that this building could benefit from even though the DIT will move from this location to a new campus in the near future. The thermal and visual comfort of the building's occupants is a priority in the future campus for the DIT.

At times the Buildings Management Office was reluctant to help, the DIT is trying to avoid any significant changes to the building as this would encompass the EPBD requirements that the whole building should be upgraded and the local fire authorities insist on a complete building upgrade in term of fire protection; this scenario they are trying to avoid because the costs are prohibitive compared to the short amount of time the DIT intends to occupy the building.

The building's construction elements, artificial lighting, boiler and radiators were not in good condition. To recreate this using IES<VE> proved a difficult task, since most building simulation software is designed for new or well maintained buildings. For example, there is no scope for the infiltration rate for these windows in the software; therefore the user must make an estimate which may or may not be accurate. By using this type of software to complete an analysis of the energy performance of the building the user is required to spend an enormous amount of time fine tuning the software version of the building to the operating conditions of the actual building. This analysis had taken much longer than expected but with the help of experienced colleagues, the data recorded manually and from the e^3 website; the best approximation of the building was completed to this student's knowledge.

Due to the legislation that has been introduced due to the EPBD, the reduction of energy and carbon emissions is now a priority for all public buildings in Ireland. The Church Lane building has slipped through the '*quality control process*' along the way but it is not too late.

The energy required for a building of this size and type of activity could be reduced by approximately 15-20% depending on the willingness and budget of the Buildings Maintenance Office. By introducing a report with recommendations to this department in DIT they have this as the baseline to improve from. Using the same process after improvements are made will make the task of evaluation relatively straightforward compared to the where the building was 2 years ago.

Using Dynamic Simulation Software is an appropriate methodology to assess accurately new buildings in terms of their energy performance. For existing buildings much more experience is required to match the software to the actual building thermal and electrical loads.

The goals set out in the Introduction, Chapter 1, were achieved. The literature review explored the myriad of standards and legislation governing the energy efficiency of buildings. In some cases the legislation has become too complex to follow. For the stakeholders involved in energy efficiency projects and equipment there are number of products and methods available now compared to 2002 when the EPBD was introduced. The Church Lane building needs to be improve but it also needed to be survey and evaluated to gain a better insight of the building's energy performance. Using IES<VE> software was a steep learning curve with positive outcomes in terms of understanding of buildings, the equipment used and the people that occupy them. I feel that I have satisfactorily completed the various sections of this dissertation.

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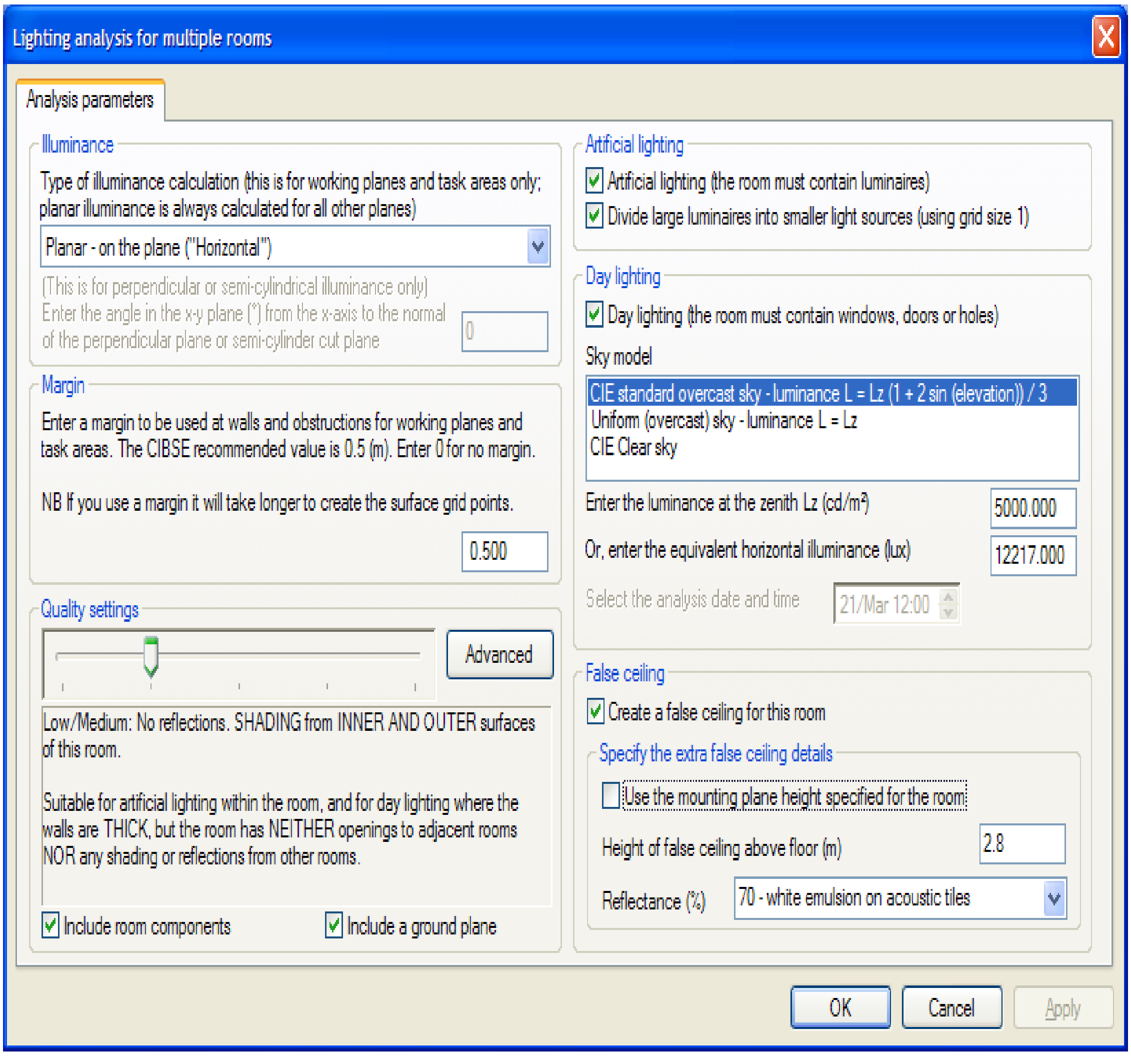
Appendix A:

A.1: Daylighting Analysis

Daylighting Analysis Summary with CIE Standard Overcast Sky

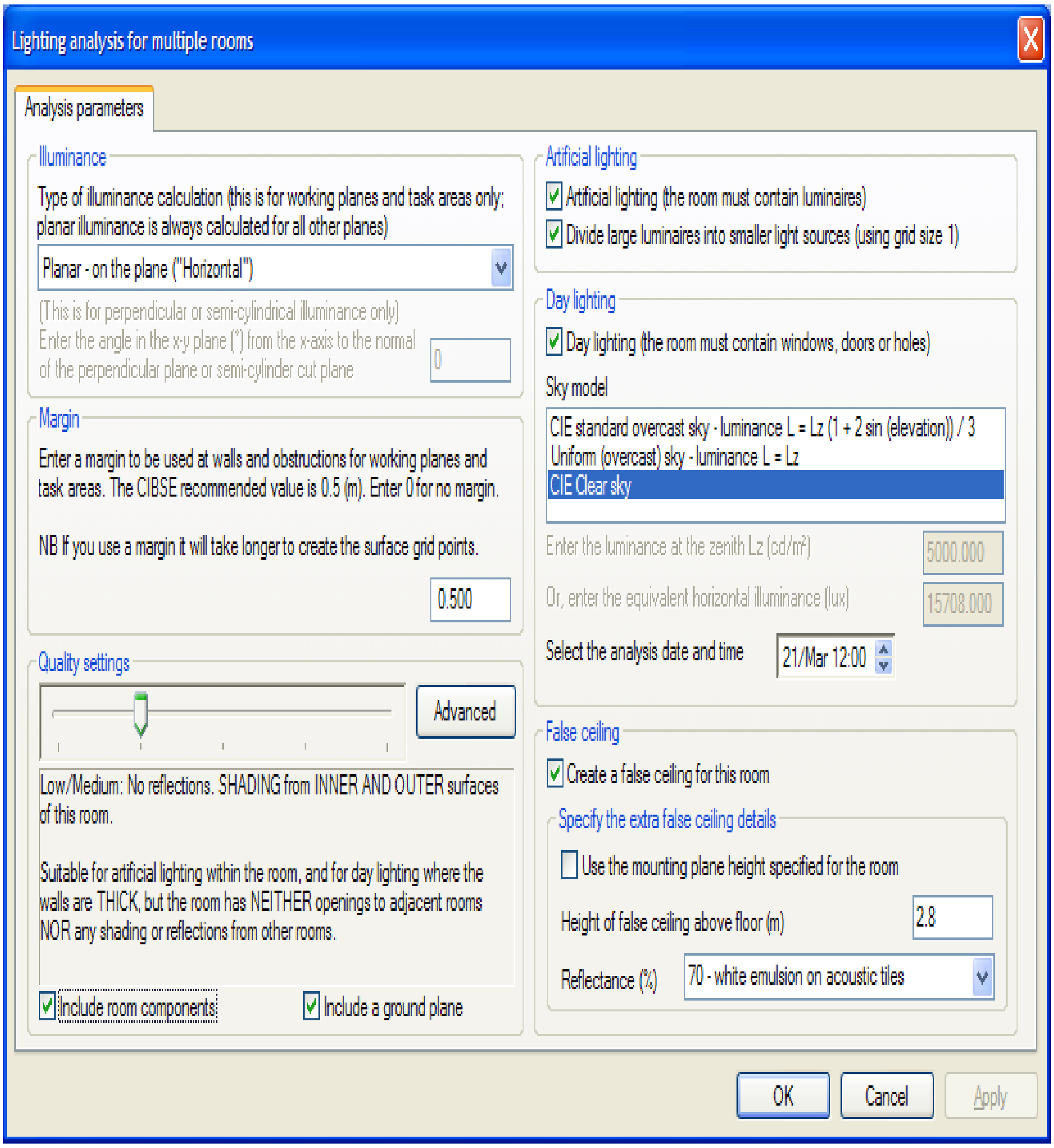


<u>Figure 49: Lighting Analysis for Multiple Rooms - Overcast Sky</u>

Table 5: Church Lane Building Daylight Factor - CIE Overcast Sky

	Percentage Daylight Factor		
Room Name	**Minimum**	**Average**	**Maximum**
CLG-001	0.0 %	0.6 %	4.0 %
CLG-002	0.1 %	1.4 %	11.0 %
CLG-003	0.0 %	0.1 %	2.0 %
CLG-004	0.0 %	1.1 %	8.4 %
CLG-005	0.1 %	1.1 %	4.2 %
CLG-006	0.3 %	1.4 %	2.9 %
CLG-007	0.6 %	5.3 %	19.6 %
CLG-011	0.2 %	1.6 %	4.5 %
CLG-012	0.2 %	1.6 %	4.8 %
CLG-013	0.3 %	2.9 %	10.1 %
CLG-014	0.0 %	1.2 %	14.5 %
CLG-014A	2.7 %	8.5 %	17.6 %
CLG-015	5.6 %	10.7 %	17.0 %
CLG-017	0.5 %	4.3 %	20.9 %
CL1-001	0.3 %	2.5 %	8.6 %
CL1-002	0.2 %	1.4 %	4.6 %
CL1-003	0.2 %	1.4 %	4.6 %
CL1-004	0.0 %	0.4 %	3.2 %
CL1-005	0.3 %	2.1 %	6.6 %
CL1-006	0.2 %	0.8 %	2.4 %
CL1-007	0.1 %	1.2 %	3.4 %
CL1-008	0.3 %	1.4 %	2.8 %
CL1-009	0.1 %	1.2 %	3.7 %
CL1-010	0.1 %	1.1 %	3.5 %
CL1-011	0.1 %	1.1 %	3.6 %
CL1-012	0.2 %	1.4 %	4.6 %
CL1-013	0.1 %	1.1 %	3.4 %
CL1-014	0.2 %	1.3 %	3.5 %
CL1-015	0.2 %	1.6 %	4.5 %

Daylighting Analysis Summary with CIE Clear Sky



<u>Figure 50: Lighting Analysis for Multiple Rooms - Clear Sky</u>

Table 6: Church Lane Building Daylight Factor - CIE Clear Sky

	Percentage Daylight Factor		
Room Name	**Minimum**	**Average**	**Maximum**
CLG-001	0.0 %	1.6 %	7.2 %
CLG-002	0.1 %	1.9 %	11.7 %
CLG-003	0.0 %	0.1 %	2.0 %
CLG-004	0.1 %	1.5 %	10.1 %
CLG-005	0.2 %	1.3 %	4.0 %
CLG-006	0.3 %	1.2 %	2.8 %
CLG-007	0.6 %	5.3 %	19.6 %
CLG-011	0.3 %	1.3 %	3.1 %
CLG-012	0.3 %	1.4 %	3.3 %
CLG-013	0.3 %	2.9 %	10.1 %
CLG-014	0.9 %	5.1 %	16.9 %
CLG-014A	2.7 %	7.2 %	14.3 %
CLG-015	4.4 %	7.8 %	12.3 %
CLG-017	2.0 %	12.7 %	41.9 %
CL1-001	0.5 %	2.4 %	4.9 %
CL1-002	0.2 %	1.4 %	4.6 %
CL1-003	0.3 %	1.6 %	4.6 %
CL1-004	0.0 %	0.4 %	2.8 %
CL1-005	0.3 %	2.1 %	6.6 %
CL1-006	1.0 %	3.0 %	6.1 %
CL1-007	0.3 %	3.3 %	6.4 %
CL1-008	1.2 %	3.2 %	5.5 %
CL1-009	0.2 %	1.0 %	2.5 %
CL1-010	0.2 %	0.8 %	2.3 %
CL1-011	0.2 %	0.8 %	2.3 %
CL1-012	0.2 %	1.1 %	3.0 %
CL1-013	0.2 %	0.8 %	2.2 %
CL1-014	0.3 %	1.0 %	2.3 %
CL1-015	0.3 %	1.2 %	2.9 %

A.2: Building Actual Lighting and Temperature Values

Table 7: Church Lane Temperature Values 2010-2011

DATE	TIME	ROOM	TEMP 1	TEMP 2	TEMP 3	AVG TEMP
27/09/10	10:00:00	CL1-001	19.0	20.0	20.0	19.7
27/10/10	10:00:00	CL1-001	19.0	20.0	21.0	20.0
27/11/10	10:00:00	CL1-001	17.0	18.0	19.0	18.0
			Average			19.2
04/10/10	12:00:00	CL1-002	17.0	17.0	17.0	17.0
18/10/10	17:00:00	CL1-002	16.0	16.0	16.0	16.0
01/11/10	12:00:00	CL1-002	15.0	15.0	15.0	15.0
15/11/10	18:00:00	CL1-002	11.0	11.0	11.0	11.0
			Average			14.8
27/09/10	13:30:00	CL1-003	18.0	18.0	18.0	18.0
27/09/10	13:30:00	CL1-003	18.0	19.0	19.0	18.7
04/10/10	16:45:00	CL1-003	16.0	16.0	16.0	16.0
04/10/10	08:45:00	CL1-003	15.0	15.0	15.0	15.0
04/10/10	16:45:00	CL1-003	19.0	19.0	20.0	19.3
11/10/10	08:45:00	CL1-003	15.0	15.0	16.0	15.3
22/11/10	13:00:00	CL1-003	15.0	16.0	16.0	15.7
24/11/10	18:00:00	CL1-003	16.0	16.0	17.0	16.3
29/11/10	10:00:00	CL1-003	11.0	11.0	11.0	11.0
29/11/10	10:00:00	CL1-003	11.0	11.0	11.0	11.0
			Average			15.6
27/09/10	13:15:00	CL1-004	19.0	20.0	20.0	19.7
04/10/10	17:00:00	CL1-004	21.0	21.0	21.0	21.0
09/10/10	16:45:00	CL1-004	20.0	21.0	21.0	20.7
16/10/10	09:45:00	CL1-004	16.0	17.0	17.0	16.7
19/10/10	09:30:00	CL1-004	15.0	15.0	16.0	15.3
26/10/10	14:00:00	CL1-004	21.0	20.0	21.0	20.7
			Average			19.0
27/09/10	08:30:00	CL1-009	13.0	13.0	13.0	13.0
27/09/10	11:00:00	CL1-009	15.0	15.0	15.0	15.0
27/09/10	13:00:00	CL1-009	16.0	18.0	19.0	17.7
27/09/10	17:00:00	CL1-009	14.0	14.0	15.0	14.3
04/10/10	08:30:00	CL1-009	12.0	12.0	12.0	12.0
04/10/10	11:00:00	CL1-009	13.0	13.0	13.0	13.0
04/10/10	13:00:00	CL1-009	13.0	13.0	14.0	13.3
04/10/10	17:00:00	CL1-009	12.0	13.0	13.0	12.7
15/11/10	08:30:00	CL1-009	10.0	10.0	10.0	10.0
15/11/10	11:00:00	CL1-009	11.0	12.0	12.0	11.7
15/11/10	13:00:00	CL1-009	12.0	13.0	14.0	13.0
15/11/10	17:00:00	CL1-009	12.0	12.0	12.0	12.0
			Average			13.1

DATE	TIME	ROOM	TEMP 1	TEMP 2	TEMP 3	AVG TEMP
04/10/10	08:45:00	CL1-010	16.0	16.0	17.0	16.3
04/10/10	12:00:00	CL1-010	15.0	16.0	17.0	16.0
04/10/10	14:00:00	CL1-010	14.0	16.0	18.0	16.0
04/10/10	17:00:00	CL1-010	15.0	17.0	18.0	16.7
01/11/10	08:45:00	CL1-010	17.0	18.0	18.0	17.7
01/11/10	12:00:00	CL1-010	16.0	18.0	18.0	17.3
01/11/10	14:00:00	CL1-010	15.0	17.0	18.0	16.7
01/11/10	17:00:00	CL1-010	15.0	15.0	17.0	15.7
			Average			16.5
04/10/10	08:45:00	CL1-011	15.0	16.0	17.0	16.0
04/10/10	12:00:00	CL1-011	15.0	15.0	17.0	15.7
04/10/10	14:00:00	CL1-011	15.0	16.0	18.0	16.3
04/10/10	17:00:00	CL1-011	14.0	16.0	17.0	15.7
01/11/10	08:45:00	CL1-011	13.0	13.0	14.0	13.3
01/11/10	12:00:00	CL1-011	15.0	15.0	15.0	15.0
01/11/10	14:00:00	CL1-011	15.0	16.0	18.0	16.3
01/11/10	17:00:00	CL1-011	14.0	15.0	15.0	14.7
			Average			15.4
27/09/10	13:30:00	CL1-012	11.0	11.0	11.0	11.0
04/10/10	13:30:00	CL1-012	19.0	19.0	20.0	19.3
08/11/10	10:45:00	CL1-012	17.0	17.0	17.0	17.0
22/11/10	13:30:00	CL1-012	14.0	14.0	14.0	14.0
			Average			15.3
27/09/10	13:30:00	CL1-013	11.0	11.0	11.0	11.0
04/10/10	13:30:00	CL1-013	19.0	19.0	20.0	19.3
08/11/10	10:45:00	CL1-013	17.0	17.0	17.0	17.0
22/11/10	13:30:00	CL1-013	14.0	14.0	14.0	14.0
			Average			15.3
27/09/10	13:00:00	CL1-014	17.0	17.0	17.0	17.0
04/10/10	16:45:00	CL1-014	20.0	20.0	21.0	20.3
15/10/10	09:00:00	CL1-014	16.0	17.0	17.0	16.7
01/11/10	13:00:00	CL1-014	14.0	14.0	15.0	14.3
08/11/10	16:45:00	CL1-014	13.0	13.0	13.0	13.0
15/11/10	09:00:00	CL1-014	18.0	19.0	19.0	18.7
			Average			16.7
27/09/10	13:00:00	CL1-015	17.0	16.0	17.0	16.7
04/10/10	16:45:00	CL1-015	19.0	19.0	20.0	19.3
15/10/10	09:00:00	CL1-015	16.0	17.0	17.0	16.7
01/11/10	13:00:00	CL1-015	14.0	14.0	15.0	14.3
08/11/10	16:45:00	CL1-015	13.0	13.0	14.0	13.3
15/11/10	09:00:00	CL1-015	17.0	18.0	18.0	17.7
			Average			16.3

DATE	TIME	ROOM	TEMP 1	TEMP 2	TEMP 3	AVG TEMP
11/10/10	12:00:00	CL1-017	18.0	17.0	17.0	17.3
12/10/10	17:00:00	CL1-017	16.0	15.0	15.0	15.3
08/11/10	12:00:00	CL1-017	17.0	19.0	16.0	17.3
09/11/10	17:00:00	CL1-017	15.0	17.0	14.0	15.3
			Average			16.3
07/02/11	09:00:00	CLG-001	13.0	14.0	15.0	14.0
07/02/11	11:00:00	CLG-001	16.0	17.0	18.0	17.0
07/02/11	15:00:00	CLG-001	16.0	17.0	18.0	17.0
07/02/11	18:00:00	CLG-001	16.0	17.0	19.0	17.3
07/02/11	09:00:00	CLG-001	13.0	14.0	15.0	14.0
07/02/11	11:00:00	CLG-001	16.0	17.0	18.0	17.0
07/02/11	15:00:00	CLG-001	16.0	17.0	18.0	17.0
07/02/11	18:00:00	CLG-001	16.0	17.0	19.0	17.3
07/02/11	09:00:00	CLG-001	13.0	14.0	15.0	14.0
07/02/11	11:00:00	CLG-001	16.0	17.0	18.0	17.0
07/02/11	15:00:00	CLG-001	16.0	17.0	18.0	17.0
07/02/11	18:00:00	CLG-001	16.0	17.0	19.0	17.3
21/03/11	12:30:00	CLG-001	15.0	15.0	16.0	15.3
23/03/11	15:00:00	CLG-001	16.0	16.0	17.0	16.3
04/04/11	18:00:00	CLG-001	16.0	18.0	19.0	17.7
			Average			16.4
14/02/11	14:45:00	CLG-002	16.0	15.0	15.0	15.3
04/03/11	13:00:00	CLG-002	16.0	16.5	17.0	16.5
10/03/11	08:45:00	CLG-002	16.0	16.0	16.0	16.0
14/03/11	10:30:00	CLG-002	15.0	14.5	14.0	14.5
			Average			15.6
21/03/11	12:00:00	CLG-012	15.0	15.0	16.0	15.3
21/03/11	12:00:00	CLG-012	17.0	18.0	19.0	18.0
28/03/11	15:00:00	CLG-012	15.0	16.0	17.0	16.0
04/04/11	18:00:00	CLG-012	15.0	16.0	17.0	16.0
			Average			16.3
10/02/11	09:00:00	CLG-014	16.0	18.0	19.0	17.7
10/02/11	14:00:00	CLG-014	18.0	19.0	20.0	19.0
10/02/11	17:00:00	CLG-014	17.0	18.0	19.0	18.0
17/02/11	09:00:00	CLG-014	15.0	18.0	17.0	16.7
17/02/11	14:00:00	CLG-014	16.5	18.0	20.0	18.2
17/02/11	17:00:00	CLG-014	16.0	18.0	19.0	17.7
			Average			17.9
07/02/11	12:00:00	CLG-015	17.0	17.0	18.0	17.3
08/02/11	12:00:00	CLG-015	16.0	16.0	17.0	16.3
09/02/11	12:00:00	CLG-015	17.0	17.0	18.0	17.3
10/02/11	12:00:00	CLG-015	17.0	17.0	18.0	17.3
			Average			17.1

Table 8: Church Lane Lighting Levels - Lights On – 2010/2011

DATE	TIME	ROOM	LUX 1	LUX 2	LUX 3	LUX 4	AVG LUX ON
27/09/10	10:00:00	CL1-001	303.0	330.0	396.0	354.0	345.8
27/09/10	14:00:00	CL1-001	333.0	375.0	434.0	382.0	381.0
27/09/10	17:00:00	CL1-001	337.0	371.0	422.0	371.0	375.3
27/10/10	10:00:00	CL1-001	299.0	324.0	370.0	336.0	332.3
27/10/10	14:00:00	CL1-001	327.0	321.0	418.0	366.0	358.0
27/10/10	17:00:00	CL1-001	321.0	343.0	401.0	341.0	351.5
27/11/10	10:00:00	CL1-001	303.0	330.0	396.0	354.0	345.8
27/11/10	14:00:00	CL1-001	333.0	375.0	434.0	382.0	381.0
27/11/10	17:00:00	CL1-001	301.0	316.0	372.0	319.0	327.0
14/02/11	09:00:00	CL1-001	220.0	355.0	345.0		306.7
14/02/11	11:00:00	CL1-001	255.0	390.0	365.0		336.7
14/02/11	15:00:00	CL1-001	250.0	385.0	290.0		308.3
14/02/11	18:00:00	CL1-001	250.0	365.0	280.0		298.3
14/02/11	09:00:00	CL1-001	325.0	405.0	325.0		351.7
14/02/11	11:00:00	CL1-001	355.0	445.0	375.0		391.7
14/02/11	15:00:00	CL1-001	295.0	435.0	340.0		356.7
14/02/11	18:00:00	CL1-001	295.0	425.0	320.0		346.7
14/02/11	09:00:00	CL1-001	325.0	290.0	260.0		291.7
14/02/11	11:00:00	CL1-001	375.0	315.0	295.0		328.3
14/02/11	15:00:00	CL1-001	340.0	295.0	280.0		305.0
14/02/11	18:00:00	CL1-001	320.0	325.0	265.0		303.3
21/02/11	09:00:00	CL1-001	230.0	370.0	350.0		316.7
21/02/11	11:00:00	CL1-001	265.0	395.0	370.0		343.3
21/02/11	15:00:00	CL1-001	255.0	380.0	290.0		308.3
21/02/11	18:00:00	CL1-001	245.0	365.0	280.0		296.7
21/02/11	09:00:00	CL1-001	320.0	410.0	330.0		353.3
21/02/11	11:00:00	CL1-001	360.0	435.0	370.0		388.3
21/02/11	15:00:00	CL1-001	295.0	425.0	330.0		350.0
21/02/11	18:00:00	CL1-001	295.0	420.0	310.0		341.7
						Average	333.9
04/10/10	12:00:00	CL1-002	480.0	431.0	611.0	627.0	537.3
04/10/10	12:00:00	CL1-002	326.0	370.0	453.0	454.0	400.8
18/10/10	17:00:00	CL1-002	459.0	443.0	457.0	561.0	480.0
18/10/10	17:00:00	CL1-002	330.0	321.0	447.0	459.0	389.3
01/11/10	12:00:00	CL1-002	485.0	426.0	592.0	604.0	526.8
01/11/10	12:00:00	CL1-002	362.0	353.0	461.0	473.0	412.3
15/11/10	18:00:00	CL1-002	451.0	439.0	506.0	514.0	477.5
15/11/10	18:00:00	CL1-002	356.0	341.0	463.0	469.0	407.3
						Average	453.9

DATE	TIME	ROOM	LUX 1	LUX 2	LUX 3	LUX 4	AVG LUX ON
27/09/10	13:30:00	CL1-003	950.0	820.0	290.0	820.0	720.0
27/09/10	13:30:00	CL1-003	950.0	820.0	290.0	820.0	720.0
04/10/10	16:45:00	CL1-003	405.0	472.0	322.0	926.0	531.3
04/10/10	08:45:00	CL1-003	660.0	645.0	530.0	1257.0	773.0
04/10/10	16:45:00	CL1-003	405.0	472.0	322.0	926.0	531.3
11/10/10	08:45:00	CL1-003	660.0	645.0	530.0	1257.0	773.0
22/11/10	13:00:00	CL1-003	314.0	495.0	358.0	870.0	509.3
24/11/10	18:00:00	CL1-003	303.0	408.0	288.0	934.0	483.3
29/11/10	10:00:00	CL1-003	291.0	392.0	474.0	617.0	443.5
29/11/10	10:00:00	CL1-003	291.0	392.0	474.0	665.0	455.5
						Average	594.0
27/09/10	13:15:00	CL1-004	480.0	402.0	826.0	510.0	554.5
04/10/10	17:00:00	CL1-004	432.0	395.0	624.0	582.0	508.3
09/10/10	16:45:00	CL1-004	389.0	378.0	509.0	342.0	404.5
16/10/10	09:45:00	CL1-004	396.0	354.0	562.0	431.0	435.8
19/10/10	09:30:00	CL1-004	409.0	387.0	536.0	365.0	424.3
26/10/10	14:00:00	CL1-004	421.0	399.0	662.0	409.0	472.8
						Average	466.7
27/09/10	08:30:00	CL1-009	210.0	200.0	320.0	310.0	260.0
27/09/10	11:00:00	CL1-009	201.0	126.0	430.0	360.0	279.3
27/09/10	13:00:00	CL1-009	192.0	75.0	472.0	360.0	274.8
27/09/10	17:00:00	CL1-009	200.0	150.0	440.0	370.0	290.0
04/10/10	08:30:00	CL1-009	180.0	100.0	260.0	410.0	237.5
04/10/10	11:00:00	CL1-009	210.0	160.0	300.0	420.0	272.5
04/10/10	13:00:00	CL1-009	220.0	186.0	330.0	440.0	294.0
04/10/10	17:00:00	CL1-009	200.0	163.0	290.0	340.0	248.3
15/11/10	08:30:00	CL1-009	160.0	50.0	190.0	205.0	151.3
15/11/10	11:00:00	CL1-009	205.0	170.0	260.0	400.0	258.8
15/11/10	13:00:00	CL1-009	220.0	200.0	290.0	410.0	280.0
15/11/10	17:00:00	CL1-009	120.0	75.0	110.0	115.0	105.0
						Average	245.9
04/10/10	08:45:00	CL1-010	339.0	403.0	582.0	410.0	433.5
04/10/10	12:00:00	CL1-010	347.0	396.0	613.0	420.0	444.0
04/10/10	14:00:00	CL1-010	326.0	371.0	587.0	438.0	430.5
04/10/10	17:00:00	CL1-010	278.0	338.0	559.0	380.0	388.8
01/11/10	08:45:00	CL1-010	353.0	438.0	682.0	485.0	489.5
01/11/10	12:00:00	CL1-010	364.0	412.0	655.0	485.0	479.0
01/11/10	14:00:00	CL1-010	336.0	389.0	598.0	463.0	446.5
01/11/10	17:00:00	CL1-010	296.0	352.0	554.0	400.0	400.5
						Average	439.0

DATE	TIME	ROOM	LUX 1	LUX 2	LUX 3	LUX 4	AVG LUX ON
04/10/10	08:45:00	CL1-011	210.0	210.0	326.0	319.0	266.3
04/10/10	12:00:00	CL1-011	201.0	200.0	379.0	357.0	284.3
04/10/10	14:00:00	CL1-011	214.0	208.0	358.0	339.0	279.8
04/10/10	17:00:00	CL1-011	200.0	178.0	347.0	302.0	256.8
01/11/10	08:45:00	CL1-011	201.0	204.0	312.0	302.0	254.8
01/11/10	12:00:00	CL1-011	219.0	223.0	376.0	337.0	288.8
01/11/10	14:00:00	CL1-011	202.0	202.0	352.0	326.0	270.5
01/11/10	17:00:00	CL1-011	189.0	168.0	322.0	208.0	221.8
						Average	265.3
27/09/10	13:30:00	CL1-012	395.0	360.0	554.0	595.0	476.0
04/10/10	13:30:00	CL1-012	295.0	355.0	320.0	420.0	347.5
08/11/10	10:45:00	CL1-012	300.0	308.0	425.0	422.0	363.8
22/11/10	13:30:00	CL1-012	125.0	183.0	270.0	245.0	205.8
						Average	348.3
27/09/10	13:30:00	CL1-013	375.0	355.0	430.0	455.0	403.8
04/10/10	13:30:00	CL1-013	270.0	240.0	400.0	350.0	315.0
08/11/10	10:45:00	CL1-013	258.0	215.0	350.0	290.0	278.3
22/11/10	13:30:00	CL1-013	163.0	146.0	316.0	291.0	229.0
						Average	306.5
27/09/10	13:00:00	CL1-014	496.0	560.0	470.0	595.0	530.3
04/10/10	16:45:00	CL1-014	300.0	370.0	400.0	421.0	372.8
15/10/10	09:00:00	CL1-014	285.0	350.0	360.0	380.0	343.8
01/11/10	13:00:00	CL1-014	190.0	200.0	250.0	361.0	250.3
08/11/10	16:45:00	CL1-014	215.0	160.0	338.0	345.0	264.5
15/11/10	09:00:00	CL1-014	243.0	162.0	332.0	262.0	249.8
						Average	335.2
27/09/10	13:00:00	CL1-015	590.0	546.0	620.0	495.0	562.8
04/10/10	16:45:00	CL1-015	290.0	273.0	448.0	380.0	347.8
15/10/10	09:00:00	CL1-015	290.0	352.0	356.0	380.0	344.5
01/11/10	13:00:00	CL1-015	189.0	229.0	242.0	362.0	255.5
08/11/10	16:45:00	CL1-015	172.0	165.0	332.0	368.0	259.3
15/11/10	09:00:00	CL1-015	238.0	164.0	328.0	255.0	246.3
						Average	336.0
11/10/10	12:00:00	CL1-017	134.0	137.0	131.0	116.0	129.5
12/10/10	17:00:00	CL1-017	159.0	113.0	104.0	106.0	120.5
08/11/10	12:00:00	CL1-017	103.0	193.0	127.0	83.0	126.5
09/11/10	17:00:00	CL1-017	64.0	185.0	108.0	132.0	122.3
						Average	124.7

DATE	TIME	ROOM	LUX 1	LUX 2	LUX 3	LUX 4	AVG LUX ON
07/02/11	11:00:00	CLG-001	245.0	335.0	290.0		290.0
07/02/11	15:00:00	CLG-001	235.0	280.0	280.0		265.0
07/02/11	18:00:00	CLG-001	230.0	280.0	295.0		268.3
07/02/11	09:00:00	CLG-001	340.0	395.0	280.0		338.3
07/02/11	11:00:00	CLG-001	375.0	420.0	315.0		370.0
07/02/11	15:00:00	CLG-001	365.0	410.0	310.0		361.7
07/02/11	18:00:00	CLG-001	350.0	405.0	300.0		351.7
07/02/11	09:00:00	CLG-001	320.0	315.0	240.0		291.7
07/02/11	11:00:00	CLG-001	350.0	350.0	275.0		325.0
07/02/11	15:00:00	CLG-001	270.0	310.0	260.0		280.0
07/02/11	18:00:00	CLG-001	265.0	290.0	240.0		265.0
21/03/11	12:30:00	CLG-001	300.0	480.0	570.0	460.0	452.5
23/03/11	15:00:00	CLG-001	190.0	240.0	310.0	320.0	265.0
04/04/11	18:00:00	CLG-001	160.0	230.0	260.0	310.0	240.0
						Average	308.1
14/02/11	14:45:00	CLG-002	418.0	273.0	225.0	298.0	303.5
04/03/11	13:00:00	CLG-002	340.0	415.0	330.0	460.0	386.3
10/03/11	08:45:00	CLG-002	450.0	370.0	265.0	480.0	391.3
14/03/11	10:30:00	CLG-002	325.0	326.0	245.0	390.0	321.5
						Average	350.6
21/03/11	12:00:00	CLG-012	230.0	320.0	500.0		350.0
21/03/11	12:00:00	CLG-012	590.0	480.0	633.0		567.7
28/03/11	15:00:00	CLG-012	126.0	198.0	246.0		190.0
28/03/11	15:00:00	CLG-012	315.0	324.0	286.0		308.3
04/04/11	18:00:00	CLG-012	123.0	176.0	234.0		177.7
04/04/11	18:00:00	CLG-012	269.0	312.0	345.0		308.7
						Average	317.1
10/02/11	09:00:00	CLG-014	230.0	143.0	132.0	277.0	195.5
10/02/11	14:00:00	CLG-014	213.0	146.0	232.0	158.0	187.3
10/02/11	17:00:00	CLG-014	230.0	186.0	185.0	182.0	195.8
17/02/11	09:00:00	CLG-014	224.0	140.0	285.0	139.0	197.0
17/02/11	14:00:00	CLG-014	218.0	154.0	245.0	169.0	196.5
17/02/11	17:00:00	CLG-014	239.0	192.0	189.0	188.0	202.0
						Average	195.7
07/02/11	12:00:00	CLG-015	230.0	235.0	263.0	115.0	210.8
08/02/11	12:00:00	CLG-015	228.0	115.0	234.0	260.0	209.3
09/02/11	12:00:00	CLG-015	227.0	114.0	234.0	259.0	208.5
10/02/11	12:00:00	CLG-015	230.0	114.0	234.0	260.0	209.5
						Average	209.5

A.3: Room Occupant Satisfaction Survey

Table 9: Church Lane Occupant Survey 2010/2011

	SATISFACTION SURVEY		
ROOM	**LIGHTING**	**TEMPERATURE**	**AIR QUALITY**
CL1-001	3.0	3.0	4.0
CL1-001	3.0	3.0	4.0
CL1-001	3.0	3.0	3.0
CL1-001	3.0	3.0	3.0
CL1-001	5.0	2.0	3.0
CL1-001	4.0	2.0	2.0
CL1-001	4.0	2.0	2.0
CL1-001	4.0	1.0	2.0
CL1-003	4.0	2.0	4.0
CL1-003	4.0	1.0	3.0
CL1-003	3.0	3.0	3.0
CL1-003	3.0	2.0	3.0
CL1-003	4.0	5.0	3.0
CL1-003	4.0	5.0	3.0
CL1-003	4.0	4.0	2.0
CL1-003	4.0	4.0	2.0
CL1-003	4.0	4.0	3.0
CL1-003	4.0	5.0	3.0
CL1-003	4.0	2.0	4.0
CL1-003	4.0	1.0	3.0
CL1-003	3.0	3.0	3.0
CL1-003	3.0	2.0	3.0
CL1-003	4.0	2.0	2.0
CL1-004	2.0	4.0	1.0
CL1-004	2.0	3.0	1.0
CL1-004	3.0	1.0	1.0
CL1-004	1.0	3.0	2.0
CL1-004	1.0	3.0	1.0
CL1-004	3.0	4.0	1.0
CL1-004	4.0	3.0	2.0
CL1-004	4.0	2.0	2.0
CL1-004	3.0	2.0	1.0
CL1-004	4.0	3.0	1.0
CL1-004	2.0	2.0	2.0
CL1-004	2.0	2.0	1.0
CL1-004	1.0	1.0	1.0
CL1-004	1.0	1.0	1.0
CL1-004	2.0	1.0	2.0
CL1-004	3.0	2.0	2.0
CL1-004	3.0	3.0	3.0
CL1-004	2.0	3.0	2.0
CL1-004	4.0	4.0	1.0
CL1-004	3.0	4.0	3.0

ROOM	LIGHTING	TEMPERATURE	AIR QUALITY
CL1-009	3.0	3.0	2.0
CL1-009	2.0	3.0	2.0
CL1-009	3.0	1.0	2.0
CL1-009	4.0	2.0	2.0
CL1-009	3.0	2.0	3.0
CL1-010	3.0	3.0	2.0
CL1-010	3.0	3.0	2.0
CL1-011	3.0	2.0	1.0
CL1-011	4.0	3.0	3.0
CL1-012	3.0	3.0	2.0
CL1-012	3.0	1.0	2.0
CL1-012	2.0	4.0	3.0
CL1-012	3.0	2.0	4.0
CL1-012	3.0	4.0	4.0
CL1-012	3.0	3.0	3.0
CL1-012	2.0	2.0	3.0
CL1-012	5.0	3.0	4.0
CL1-012	3.0	2.0	3.0
CL1-013	5.0	2.0	3.0
CL1-013	5.0	3.0	3.0
CL1-013	4.0	3.0	5.0
CL1-013	4.0	1.0	3.0
CL1-013	4.0	3.0	4.0
CL1-013	2.0	4.0	3.0
CL1-013	2.0	3.0	2.0
CL1-013	3.0	3.0	3.0
CL1-013	2.0	3.0	3.0
CL1-013	2.0	2.0	2.0
CL1-014/15	1.0	3.0	3.0
CL1-014/15	2.0	3.0	3.0
CL1-014/15	2.0	3.0	4.0
CL1-014/15	3.0	3.0	4.0
CL1-014/15	3.0	3.0	4.0
CL1-014/15	3.0	1.0	4.0
CL1-014/15	4.0	4.0	2.0
CL1-014/15	4.0	4.0	2.0
CL1-014/15	4.0	4.0	2.0
CL1-014/15	4.0	2.0	2.0
CL1-014/15	4.0	2.0	2.0
CL1-014/15	4.0	2.0	1.0
CL1-014/15	4.0	2.0	1.0
CLG-001	1.0	1.0	2.0
CLG-001	1.0	1.0	2.0
CLG-001	1.0	1.0	2.0
CLG-001	2.0	1.0	2.0
CLG-001	2.0	1.0	2.0
CLG-001	2.0	2.0	2.0
CLG-001	2.0	2.0	2.0
CLG-001	2.0	2.0	2.0

ROOM	LIGHTING	TEMPERATURE	AIR QUALITY
CLG-001	2.0	2.0	2.0
CLG-001	2.0	2.0	3.0
CLG-001	2.0	2.0	3.0
CLG-001	2.0	2.0	3.0
CLG-001	2.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	3.0
CLG-001	3.0	2.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	3.0	4.0
CLG-001	3.0	4.0	4.0
CLG-001	3.0	4.0	4.0
CLG-001	3.0	4.0	5.0
CLG-001	4.0	4.0	5.0
CLG-001	4.0	4.0	5.0
CLG-001	4.0	4.0	5.0
CLG-001	4.0	5.0	5.0
CLG-001	5.0	5.0	5.0
CLG-001	2.0	1.0	1.0
CLG-001	2.0	1.0	1.0
CLG-001	2.0	1.0	2.0
CLG-001	2.0	2.0	3.0
CLG-001	2.0	2.0	3.0
CLG-001	2.0	2.0	3.0
CLG-001	3.0	3.0	3.0

ROOM	LIGHTING	TEMPERATURE	AIR QUALITY
CLG-001	3.0	3.0	3.0
CLG-001	3.0	3.0	3.0
CLG-001	3.0	3.0	3.0
CLG-001	4.0	3.0	3.0
CLG-001	4.0	3.0	4.0
CLG-001	4.0	3.0	4.0
CLG-001	4.0	4.0	4.0
CLG-001	4.0	4.0	4.0
CLG-001	5.0	4.0	4.0
CLG-002	2.0	2.0	2.0
CLG-002	2.0	2.0	2.0
CLG-002	4.0	2.0	3.0
CLG-002	3.0	3.0	4.0
CLG-002	3.0	3.0	2.0
CLG-002	4.0	4.0	3.0
CLG-002	2.0	3.0	4.0
CLG-002	2.0	3.0	2.0
CLG-002	3.0	5.0	4.0
CLG-002	4.0	3.0	4.0
CLG-002	2.0	3.0	3.0
CLG-002	4.0	2.0	3.0
CLG-002	4.0	3.0	2.0
CLG-002	4.0	4.0	2.0
CLG-002	3.0	3.0	3.0
CLG-002	4.0	4.0	4.0
CLG-002	3.0	4.0	3.0
CLG-002	3.0	2.0	3.0
CLG-002	3.0	3.0	3.0
CLG-002	3.0	4.0	4.0
CLG-002	4.0	3.0	4.0
CLG-002	3.0	2.0	3.0
CLG-002	4.0	4.0	3.0
CLG-002	3.0	4.0	5.0
CLG-012	2.0	1.0	1.0
CLG-012	2.0	1.0	1.0
CLG-012	2.0	1.0	2.0
CLG-012	2.0	2.0	3.0
CLG-012	2.0	2.0	3.0
CLG-012	2.0	2.0	3.0
CLG-012	3.0	3.0	3.0
CLG-012	3.0	3.0	3.0
CLG-012	3.0	3.0	3.0
CLG-012	3.0	3.0	3.0
CLG-012	4.0	3.0	3.0
CLG-012	4.0	3.0	4.0
CLG-012	4.0	3.0	4.0
CLG-012	4.0	4.0	4.0
CLG-012	4.0	4.0	4.0
CLG-012	5.0	4.0	4.0

ROOM	LIGHTING	TEMPERATURE	AIR QUALITY
CLG-014	4.0	3.0	2.0
CLG-014	4.0	3.0	2.0
CLG-014	4.0	3.0	3.0
CLG-014	5.0	3.0	3.0
CLG-015	4.0	2.0	3.0
CLG-015	2.0	1.0	4.0
CLG-015	3.0	2.0	3.0
CLG-015	2.0	3.0	4.0
CLG-015	3.0	4.0	4.0
CLG-015	2.0	3.0	3.0
CLG-015	4.0	3.0	3.0
CLG-015	2.0	4.0	4.0
AVERAGE	3.1	2.7	2.9
Total No. Respondents	202	202	202

Appendix B:

B.1: Room Dimensions

Table 10: Church Lane Room Dimensions

Room Name	Floor Area (m²)	Volume (m³)
Administration Office CL1-005	15.6	46.8
Administration Office CLG-014A	12.5	37.4
Administration Offices CLG-014	23.5	70.6
Automation Laboratory CL1-002	53.6	160.8
Boiler Room	38.3	114.8
Emergency Exit Corridor	8.4	25.2
First Floor Corridor Area	75.2	225.5
First Floor Gents Toilets CL1-007	16.5	49.4
Ground Floor Corridor Area	92.3	277.0
Ground Floor Gents Toilets CLG-003	41.4	124.2
Ground Floor Stairwell	16.5	49.4
IT Communications Room CLG-017A	2.0	5.9
Ladies Toilet CL1-008	11.8	35.5
Lecture Room CL1-001	54.9	164.8
Lecture Room CL1-004	46.9	140.7
Lecture Room CL1-009	45.3	130.0
Lecture Room CL1-010	32.1	90.4
Lecture Room CL1-011	32.7	91.6
Lecture Room CL1-012	32.4	91.0
Lecture Room CL1-013	32.4	91.0
Lecturers' Mail Room	3.0	9.0
Lecturers' Offices CL1-015	31.1	87.0
Lecturers' Offices CLG-001	61.1	183.2
Lecturers' Offices CLG-0013	35.4	106.2
Machines Laboratory CLG-011	49.8	149.4
Electrical Distribution CLG-006A	9.6	28.7
Measurements Laboratory CLG-005	63.2	189.6
Meeting Room CL1-014	27.7	76.7
Phase 4 Practical Workshop CLG-002	95.0	285.1
Phase 6 Practical Workshop CLG-004	93.2	279.7
PLC Laboratory CLG-012	47.4	142.2
Porter Office CLG-015	5.5	16.4
Renewable Laboratory CL1-003	52.3	156.8
Staff Toilet CL1-006	8.4	25.2
Stairwell	12.3	36.9
Technical Services Offices CLG-006	24.4	73.2
Technical Services Stores CLG-001A	18.2	54.7
Technical Services Stores CLG-002A	15.4	46.2
Technical Services Stores CLG-017	32.6	97.9
Technical Services Workshop	33.6	100.8

B.2: Ground and First Floor Layout Plans

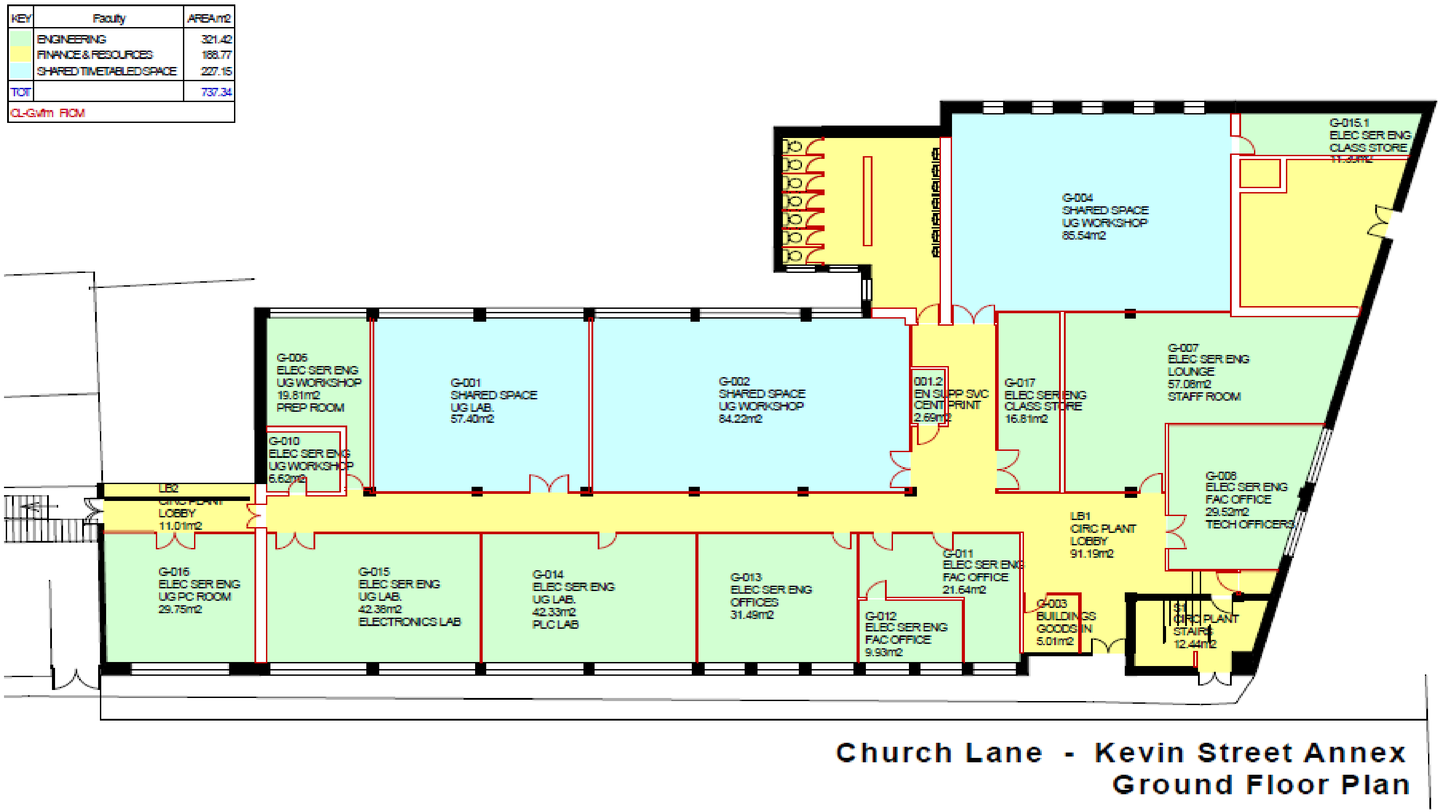


Figure 51: Church Lane Building - Ground Floor Plan

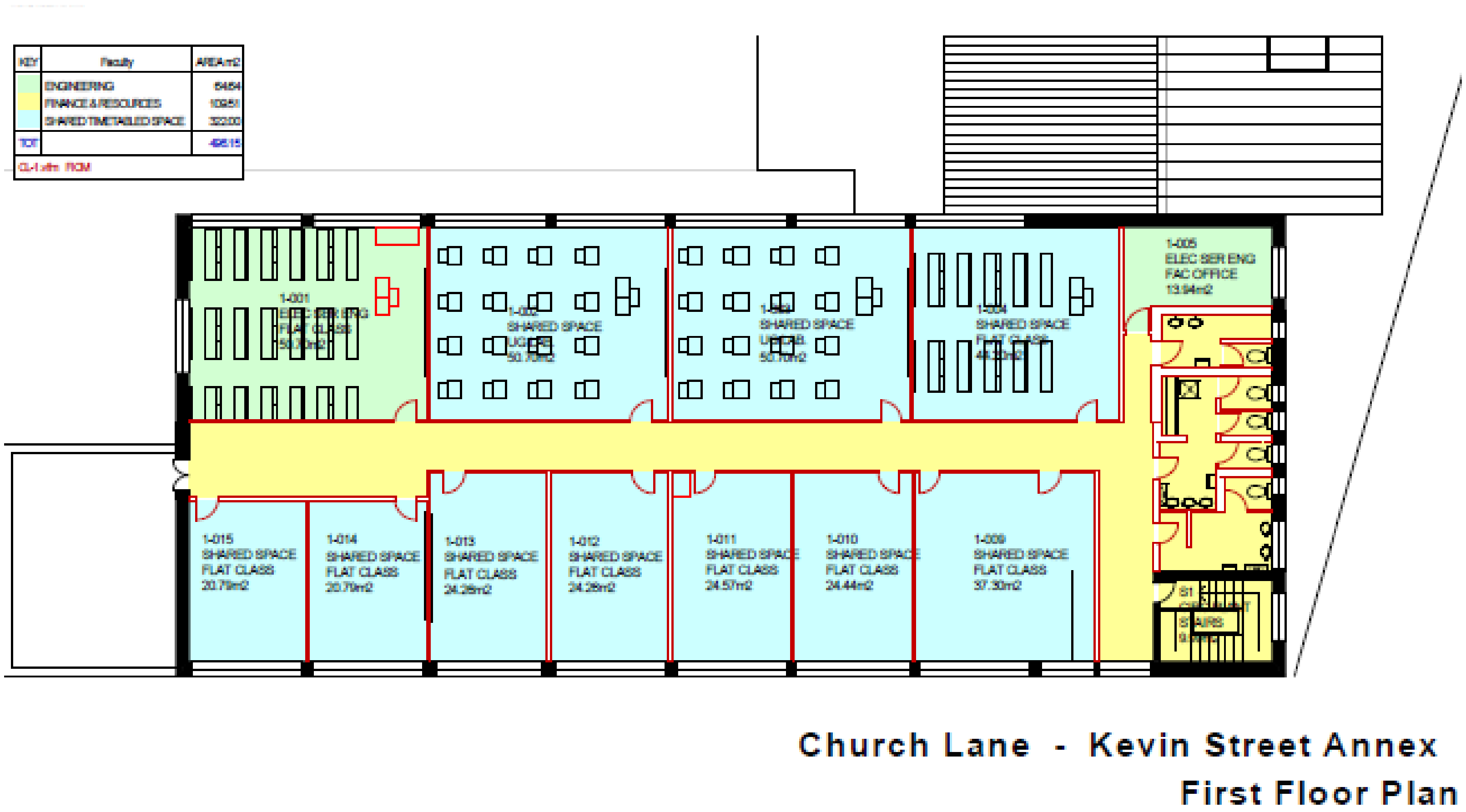


Figure 52: Church Lane Building - First Floor Plan

B.3: Measurement Equipment Data Sheets

Bosch DLR130K **Laser Measurement Device**
Range 0.5 to 40 metres
Accuracy +/- 1.5 mm

Data Sheet Link:

http://www.boschtools.com/Products/MeasuringAndLayout/Pages/BoschProductDetail.aspx?pid=DLR130K#specs

Lutron LX-101 Lux Meter		
Range	Resolution	Accuracy
2,000 Lux	1 Lux	± (5 % + 2 d)
20,000 Lux	10 Lux	± (5 % + 2 d)
50,000 Lux	100 Lux	± (5 % + 2 d)

Data Sheet Link:

http://www.mantech.co.za/Datasheets/Products/LX101_LUT.pdf

Rapid 328 DMM with PT100 Temperature Sensor			
Range	Resolution	Accuracy	
°C	1°C	–20°C to 0°C	5.0% + 4
		0°C to 400°C	1.0% + 3
		400°C to 1000°C	2.0%

Data Sheet Link: http://www.rapidonline.com/Tools-Equipment/328-Digital-LCD-multimeter-31051#techSpecs

HAWK 5000 Energy Logger
Range 0.4 to 1000 A
Resolution 0.1A
Range 0 to 280 V
Resolution 0.5 V
Range 45 to 64 Hz
Resolution 0.01 Hz

Data Sheet Link: http://www.sotaew.co.uk/hawk_commander.htm

Appendix C: Management of Project

C.1: Comparison of Proposed Schedule v Actual Progress

In hindsight, the original project schedule was ambitious in its goals and milestones; this forced the alteration of the schedule for a number of reasons which are mainly outlined below:

- Birth of my first child in September 2011 and some minor personal health problems
- Concurrently studying for a Bachelor of Electrical and Communications Engineering since September 2011 at DIT
- Developed and introduced a new Building Automation module for the Level 7 (NFQ) ordinary degree students in Electrical Services Engineering over the last two years
- Coordinated the construction and development of a new laboratory for the Building Automation module in connection with my lecturing duties
- Increased lecture contact hours and administrative duties due to budget cuts

In summary, life issues forced this student to compress and expand the time allowed to prepare this dissertation with undesirable consequences. This situation made the process of submitting individual stages to the dissertation supervisor sporadic and poorly organized; the delivery of each stage was not aligned to the original project schedule.

However, the MSc programme was a five year distance learning course which I have satisfactorily completed in the overall timeline to the best of my knowledge. The dissertation completion time originally planned was not realistic and I was fortunate to have extra time at the end of the taught modules to allow for the delays encountered.

This dissertation provided a challenge that I had underestimated and now I feel much more enriched from this experience, in terms of planning, prioritizing, structuring and implementing a project of this type, along with performing my duties as a lecturer.

To begin with, my first thoughts regarding the dissertation itself, title and objectives were not entirely focused. This lack of focus led me down some blind pathways which of course are easy to see now. Some aspirations and/or objectives were not achievable in the time available or became unrealistic once the decision had been made to allocate resources for relocation to a new campus, as had been announced by the Irish Government in May 2012.

When I began the process of collating data I realised the enormity of the challenge I had taken on, especially in the time I had left before submission. I had began using IES<VE> in April 2010 in a self taught manner, received some training and then was distracted from completing this part of the analysis satisfactorily due to the reasons described earlier. Notwithstanding these obstacles I had managed to use IES<VE> confidently after extensive testing of simple models and accessed the online training guides which are readily available from the help menus in IES<VE>.

Using this software required that the dimensions were verified for the building. In verifying this I had recognized that some changes to the building layout had occurred and needed to be updated. Otherwise, the thermal analysis of the building would have been erroneous. Understanding the operational hours for the building became difficult especially in the summer period when students were not attending lectures. The type of mechanical services installed required consultation with the maintenance staff employed by the DIT to verify the operating conditions of the heating system.

The precise composition of the building materials and elements was unknown since the building had been completed over sixty years prior to this analysis. My own past experience of construction methods for this time period in conjunction with a thorough walk-through survey of the building provided baseline assumptions which were regarded by local advisors for my dissertation as satisfactory and as accurate as possible.

Following this process I began to collate, present and comment on the data acquired. As summary of this work is detailed below:

- Building Dimensions Verified using Digital Measurement Device
- Building Thermal Transmittance Values
- Mechanical Services Verified
- Collated Electrical Energy Consumption Data from e^3 Web Resource
- Portable Electrical Energy Analyzer Data Collected
- Room Temperature Recorded Manually over a Period

- Illuminance Levels Recorded Manually over an Extended Period
- Satisfaction Survey Executed
- Entered Building Data in Simulation Software
- IES<VE> Analysis Performed
- Comparison of Actual Building Performance versus IES<VE> Simulation

The most significant discovery was that the thermal energy generated from the boiler was insufficient to maintain the thermal comfort for the building's occupants. This was mainly due to the poor condition of the glazing and a poor installation of existing insulation above suspended ceilings. Practical recommendations were explored and discussed in terms of indicative costs.

Most stages of the project were completed but not necessarily very well done. I feel that the final draft a true reflection on my ability to complete a project correctly, be as it may in a slightly unorthodox fashion. The goals I eventually set out to achieve were reached. An extensive amount of knowledge and experience of managing a project of this type has been gained from this journey. The results using DSM software compare well with the actual building and the recommendations for improvements are now in the planning stages to be implemented. I look forward to recording the results after each improvement is completed to highlight the gains achieved from each stage of works.

C.2: Original and Final Gantt chart

Project Proposal Gantt chart	Starting	Ending	Duration	Month No.											
				1	2	3	4	5	6	7	8	9	10	11	12
Project Title Selection	18/11/10	25/11/10	1 week												
Background Reading	25/11/10	31/01/11	8 weeks												
Initial Room Surveys	25/11/10	22/12/10	4 weeks												
Energy Analyzer Recording	01/12/10	22/12/10	3 weeks												
Room Drawings	25/11/10	07/12/11	2 weeks												
IES<VE>	25/11/10	07/06/11	26 weeks												
DayLighting Analysis	25/11/10	07/03/11	14 weeks												
Thermal Analysis	25/03/11	07/05/11	6 weeks												
Energy Performance	25/04/11	07/06/11	6 weeks												
Post Project Constraints	01/06/11	07/06/11	1 week												
Collation of Recorded Results	25/04/11	22/06/11	8 weeks												
Final Draft Write Up	25/05/11	25/08/11	12 weeks												
Delivery of Dissertation	10/08/11	23/09/11	6 weeks												

Final Thesis Gantt chart	Starting	Ending	Duration	*Month No.*											
				1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
				2010/2011											
Project Title Selection	18/11/10	25/11/10	1 week												
Background Reading	25/11/10	31/01/11	8 weeks												
Initial Room Surveys	25/11/10	22/12/10	4 weeks												
No Activity				*2012*											
Energy Analyzer Recording	25/03/12	07/06/12	10 weeks												
Room Drawings	25/05/12	07/06/12	2 weeks												
IES<VE>	25/04/12	07/06/12	6 weeks												
DayLighting Analysis	25/04/12	07/06/12	2 weeks												
Thermal Analysis	25/04/12	07/06/12	4 weeks												
Energy Performance	25/04/12	07/06/12	6 weeks												
Post Project Constraints	01/06/12	07/06/12	1 week												
Collation of Recorded Results	25/04/12	22/06/12	8 weeks												
Final Draft Write Up	20/08/12	25/09/12	5 weeks												
Delivery of Dissertation	25/09/12	30/09/12	5 days												

C.3: Original Project Proposal

Introduction:

This proposal is entitled Energy Audit and the Feasibility of a Building Energy Management System (BEMS) for an Existing Educational Building. The building energy performance needs to be improved. At present, the thermal comfort of the building is poor and the lighting in each room is in some cases too high and in others not uniform. The heating system is of very basic control, On/Off, and does not meet the heating needs during the coldest periods of the year.

This proposal outlines the author's justification for selecting this topic, the intended methodology to be used and an overall time plan to manage the project is included.

Background:

This student's previous experience in the Building Services Engineering field has been limited to the installation and commissioning of the electrical components that compliment building services equipment in commercial buildings. Since beginning the MSc in Building Services Engineering in 2007 the author has been exposed to buildings mechanical components, the theory and methods of implementation that comprise a modern commercial building.

The Church Lane Building was built in the 1960s to accommodate a woodworking business. In the 1980s, the Church Lane building was purchased and adapted by the Dublin Institute of Technology to deliver Electrical Apprenticeship, Electrical Services Engineering and Energy Management programmes.

The Church Lane Building has, at present, a poor energy performance. At present, there are persistent complaints from staff and students about the performance of the building. This building will soon benefit from building works to improve its energy performance.

Appropriate implementation of building upgrades are intended to enhance the energy performance, thermal comfort and lighting levels. These improvements must reduce energy consumption and improve the working environment.

Correct selection of the most suitable type of BEMS for this building and its occupants is critical for the occupants, management and the energy performance of the building in the future.

Aims and Broad objectives:

The first aim of this project is to produce a comprehensive energy performance analysis of the Church Lane building and recommend improvements that enhance the performance of this building. It is intended that the project will enhance the author's understanding of the building energy performance tools used in industry.

The second aim is to perform a feasibility study of BEMS which would be appropriate for this building and its occupants. Performing this study will also develop a greater understanding of the BEMS equipment used to control the environment that they are installed in. This author recognises that the control of the building must be left to the building facilities management but that the information about the building's performance should be made available to all to create energy awareness.

A literature review shall be performed to support the background knowledge and theory in these areas.

Methods to be adopted:

The Church Lane building is occupied from mid-September to mid-June, the academic year. This survey is being performed over this period. It is intended that this survey will provide the evidence required to adopt appropriate measures in the future by the building's facilities management team.

This building survey shall include:

- Detailed description and drawings of the building.
- Analysis of the existing hydronic heating system.
- Analysis of the thermal performance of the building.
- Measurement of artificial and natural light values.
- Analysis of the electrical energy consumption.

This dissertation will also include an analysis of existing BEMS available in the marketplace. Selection of appropriate BEMS technology shall be determined based on the following criteria:

- Ability to record the building energy performance; room temperature and lighting level so that future comparison and analysis can be performed.
- Monitor and record the Electrical Energy consumption of the building.
- Measure the consumption of fossil fuel to heat the building.
- Historic data shall be stored to afford the department and the building facilities management team information on the performance of the building.

One aim of this dissertation is to produce a comprehensive energy survey of the building. The existing building performance shall be compared using two building simulation software solutions IES and SBEM.

An occupant survey, including routine data acquisition of temperature and lighting levels using portable measurement devices over the academic year is already ongoing and shall continue until the end of the academic year.

A detailed list of recommendations for improving the energy performance of the building shall be created including the life cost analysis of each recommendation.

A literature review will be included in the project and the Harvard referencing system will be used throughout.

The literature review will include:

- Energy performance survey methodologies.
- Outline of BEMS technologies.
- Current papers and articles on both subjects.
- Relevant national and European legislation.

A life-cost analysis will performed on Method A and B to justify the proposed installations.

Time-plan with specific dates for submission of future forms:

A Gantt chart outlining the estimated time to completion with critical submission dates is attached.

Deliverables or Specific Outcomes:

The specific outcomes of the project include:

- Identification of trends in energy consumption.
- Presentation of analysed data in a concise manner.
- Comparison of energy performance software and BEMS.
- Enhancing the author's understanding of these subjects.