Department of Mechanical Engineering

Developing a Methodology to Identify Discrepancies in Comparisons Between Predicted and Actual Energy Use in Non Domestic Buildings:

Lews Castle College Case Study

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Signed: Andy Ho Yan Cheng **Date: 10th September 2010**

Abstract

The purpose of this thesis is to analyse predicted and measured energy usage for non-domestic buildings. A case study of Lews Castle College campus in Stornoway, was used to carry out the analysis for this thesis. The procedure used to carry out this analysis was then used as a basis to develop a methodology to identify the discrepancies between measured and predicted energy use in non-domestic buildings. Energy bills and Energy Performance Certificate data were used to compare against each other for the whole campus to ascertain the discrepancies between predicted and actual energy use. It was found that the energy use was currently over predicted compared to the energy bill history for the college.

Several techniques, which were mostly qualitative, were used to identify the discrepancies that were occurring in the building campus. This included;

- A sensitivity study of the Energy Performance Certificate modelling tool (SBEM) with new values obtained compared to actual energy usage.
- A Post Occupancy Evaluation (POE)
- Thermal imaging surveys and air pressure testing of the campus
- An analysis of the Building Energy Management System (BEMS) of the campus

The new predicted usage still showed an over projection in heat loads, albeit only 22% higher compared to a 63% over projection in the previous prediction. However, the new predicted electricity conformed more to expectations, after investigations around the campus suggested an over use in electricity should be occurring.

Through the analysis of the campus, recommendations for improving the campus were made from the results. The recommendations included replacing current light bulbs to LED lighting and installing mechanical blinds on the glass/fibreglass roofs, amongst others, as a cost effective method of improving energy efficiency. One of the main recommendations was to properly integrate the BEMS of the campus.

The procedure used in the case study of the College campus buildings was used as a basis to compile a methodology that could be used on non-domestic buildings in the UK for this topic. Future potential developments of this methodology are also discussed in this report.

Acknowledgements

In writing this thesis I would like to show my gratitude to a number of people.

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Nomenclature

A – Area

BEMS – Building Energy Management System

CO_2 – Carbon Dioxide

CRC – Carbon Reduction Commitment

c – Specific Heat Capacity

DEC – Display Energy Certificate

EPC – Energy Performance Certificate

HDD – Heating Degree Days

HVAC – Heating, Ventilation and Air Conditioning

kW – Kilowatt

kWh – Kilowatt Hour

LED – Light Emitting Diode

MWh – Megawatt hour

P – Pressure

Pa – Pascal

POE – Post Occupancy Evaluation

Q – Volume flow rate

$\dot{Q}_A$ *– Heat flow per unit area*

R-value – Thermal Resistance

SBEM – Simplified Building Energy Model

STEM – Short Term Energy Model

T – Temperature

TER – Target Emissions Rate

UK – United Kingdom

U-value – Overall Heat Transfer Coefficient

V – Voltage

W – Power

ε – Emissivity

ρ - Density

τ – Transmittance

K_m – Effective Thermal Capacity

K – Kelvin

°C – Degrees Celsius

1. Introduction

Non-domestic buildings accounts for around 18% of the total UK CO_2 emissions (UK-GBC 2010). With the UK government targeting an 80% reduction in carbon emissions by 2050 (Summers & Carrington 2006), this is a sector that clearly has to be looked at to meet this aim. The Carbon Reduction Commitment (CRC) is an example of a scheme that the UK Government has brought through to encourage energy efficiency in non-domestic buildings. It is therefore important to look at ways of improving efficiencies of non-domestic buildings.

An area that has to be looked at is the reasons why most buildings do not perform well compared to predicted levels in terms of energy use. When it comes to matching building actual energy use to that expected from the theoretical calculations or the designers expectations, it is very seldom achieved (Bill Bordass 2004). This area clearly has to be looked at as no matter how green the credentials of a building are - if it is not performing like it is supposed to, there is something fundamentally wrong. If the designers of an upgrade to an existing building wishes to improve efficiency, then the discrepancy between predicted and measured energy use must be identified and addressed prior to carrying out improvements. This has been seen in analysis carried out in so called green buildings which show poor performance in comparison to benchmarks (Bill Bordass 2004). This is a startling fact and highlights this is an area of concern that can occur even with newly constructed low carbon buildings.

It is very difficult to match the final construction of a building to the proposed design of it. Even with the best laid designs, most of the time, reliance is put on workers dealing with the construction to stick to the proposals and build it to a good standard. Poor workmanship will lead to issues with air tightness in the building. In addition to this, in order to save on expenses, corners may be cut during the building phase.

2. Aim

Greenspace Research has been looking into making the Lews Castle College campus in Stornoway, where the group is based, as sustainable as possible in line with the company's ethics. The first stage of this process is to analyse the building and look into how it currently performs in line with predicted energy use. This will lead to making improvements to the campus buildings allowing the college to be more energy efficient. The final stage would be to make use of the local resources, through renewable energy systems, to generate low carbon energy to supply the campus onsite.

The aim of the project is to look at the discrepancies between measured and predicted energy use in the Lews Castle College campus in Stornoway, Scotland. Based on the results of this analysis, it is hoped to carry out a survey of the campus buildings and identify the areas of improvement. Investigations to identify the discrepancies were performed by analysing the Energy Performance Certificate data of the various buildings on campus and comparing them to the energy bill history of the College. An investigation of the Building Energy Management System was carried out as well as a Post Occupancy Evaluation which helped determine where the discrepancies may be originating. Further to this, air pressure testing and thermal imaging surveys were completed throughout the campus to check the quality of workmanship, as well as air leakages, around the building. In carrying out this case study, the main aim that was hoped to be achieved was to establish a methodology on this topic that could be used on other non domestic buildings in Scotland and areas with similar climates. This methodology can be applied to non-domestic buildings that are not performing to expectations and used to identify what is causing the discrepancies so that these aspects can be rectified. Following the findings in this case study, recommendations were made on what measures can be introduced and aspects that can be improved upon that have the biggest impact on energy efficiency in the campus.

3. Building Background

The Lews Castle College campus is situated on elevated land of the Lews Castle grounds to the West of Stornoway, Scotland. The College is part of the University of Highlands and Islands (UHI) network. Stornoway is situated in the Outer Hebrides, in the North West of Scotland. It has a mild UK temperate climate, but is typically wetter, colder and windier. The College has 3361 Heating Degree Days (HDD) for a base temperature of 18°C. Climate and HDD profiles of the area are found in the Appendix A of this report.

The campus is split up into three main building sectors and is illustrated in Figure 1. The Rural Development building (F Block), which predominately houses the Greenspace Research group and also some teaching kitchens, is situated in the North East of the Campus and is shown in green in Figure 1. The Engineering Building (E Block) is situated to the West of this building and is shown in yellow in Figure 1. The Engineering Building mostly comprises of workshops to teach practical skills such as joinery, car mechanics and welding. This building also has several classrooms in which technical skills are taught to the College students. Adjoining the Engineering building to the South is the Facilities Building (A, B, C and D Blocks), shown in Figure 1 in orange and blue, which also houses the administrative staff at the College, as well as the library and refectory of the college. It also houses classrooms and computer clusters to aid student learning. Plans of the three buildings can be found in the Appendix B of this thesis.

The whole campus has a gross total floor area of approximately 10130m^2. The heat in the campus is provided by four oil boilers, two 850kW and two 325kW rated. The two larger boilers serve the Facilities Building in the campus, while the two smaller boilers service the Rural Development and Engineering Building. These boilers are on a duty-standby configuration, where the demand loads are shared between each pair of boilers, and use around 100,000 litres of heating oil a year. The campus is mainly heated through a central heating system, with water as the heating control agent. The whole campus is grid connected and electricity usage is metered through one meter that serves the whole campus. Ventilation is provided with Air Handling Units in the Facilities building and the Rural Development Building. The Engineering Building is naturally ventilated; however, there are some extraction systems in the laboratories and workshops.

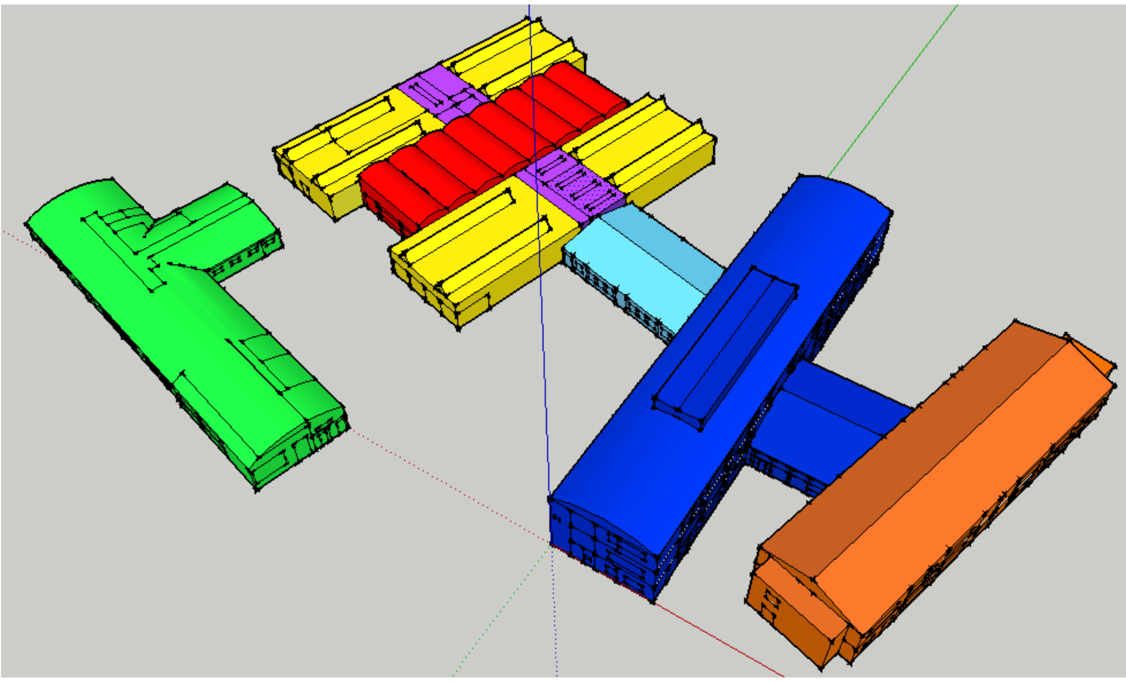

Figure 1: Google Sketchup model of Lews Castle College Campus

4. Scope of the Project

As mentioned previously, this project concentrates on looking at several important aspects of the campus to identify areas heat losses in a building and methods to compare predicted and actual energy use. In this section, influences that can affect energy efficiency in a building will be discussed upon. This section will also touch upon the methods of analysing discrepancies between actual and predicted energy usage, as well as previous work on the area.

4.1 Aspects that Affects Building Energy Performance

This section introduces the possible aspects in a building's make up that can affect energy use.

4.1.1 Building Materials

Materials used in a building's construction have a vital significance on the buildings energy performance. The R-value is known as the thermal resistance of a material is calculated using Equation 1, where C is the conductance, k is the conductivity and x is the thickness of the material.

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

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

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

4.1.2 Heat Gains

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

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

4.1.3 Heat Losses

Heat losses can occur through a number of areas in a building. There are three methods of heat transfer that can affect energy performance in a building. These are:

- Conduction
- Convection
- and Radiation

Convection is the heat transfer in air by the motion of heated air from a warmer to cooler surface (M. Egan 1975). One of the areas that contribute to heat losses is through air leakage. Poor workmanship can create gaps where draughts can occur through window frames, gaps in doors, cracks and joins in walls causing convective heat loss in a heated building space. A draught is defined as an uncontrolled air movement. It can not only cause warm air to escape but can also affect comfort levels inside a building.

Heat losses can also occur through external conduction, especially when the weather is cold outside. Conduction is the heat transfer through solid materials from warmer to cooler particles (M. Egan 1975). This is most apparent with buildings with high amounts of single pane glazing. Conductive heat losses occur when the inside surface of one pane experiences cold temperatures, which cools the surface of the other side of the pane. The likes of installing double glazing, or even better triple glazing, can improve the amount of heat loss dramatically (Babcock & Irving 2004).

The final type of heat loss that can occur is radiative heat losses. The term radiation describes the heat transfer by electromagnetic waves from a warm to a cool surface. An example of radiant heat is the heat that comes from a light bulb that is switched on. The thermal performance of a buildings structure can be affected by radiant heat losses. This is particularly the case on a cold day and a building can radiate heat to the atmosphere. Installing reflective linings, such as aluminium foil, in air spaces can reduce the radiant heat transfer.

4.1.4 Heating System Efficiencies

When looking at heat losses a large proportion can occur from inadequate management of the heating system. This not only means making sure pipes and hot water cylinders are properly insulated, but also the set up of the heating system of the building.

Flow and return flow rate cycles from the pipe carrying heated water to the radiators and hot water cylinders are an aspect that can affect efficiency. Ideally, there should be 10-12K degrees difference between flow and return flows to gain high boiler heat exchanger efficiency. This is so that heat is transferred to the building space from radiators properly, and the system is not using unnecessary energy pumping and heating water. Therefore, it is important, if possible, to optimise the flow rate in of the pipes to make heating more efficient in a building.

Dry cycling is a phenomenon that can also affect efficiencies in the heating system. Dry cycling occurs when the thermostat initiates the boiler for a short period and not allowing the boiler to fire up correctly. This is usually caused when the boiler is close to its set-point temperature (BSEE 2010). A thermal gradient is produced from the boiler to the surrounding atmosphere. This results in standing losses coming from the boiler resulting in heat losses to the surrounding air. Dry cycling may be avoided by increasing the hysteresis of the boiler operation.

4.1.5 Ventilation and Air Conditioning Systems

Ventilation is also an important aspect in a building as it reduces the risk of build up of condensation and pollutants in a building space by controlling the air quality. The air conditioning system also conditions the air so that it is not too dry or humid. This could also affect thermal performance of the building as well as occupancy comfort which could manifest itself as 'sick building syndrome' (Au Yeung et al. 1991). Without ventilation, a building increases its chances of suffering mould and dampness. Mould spores can affect sensitive atopic individuals and can lead to asthma rhinitis, conjunctivitis and eczema (Trotman & Building Research Establishment. 2004). There has to be a good balance in terms of the ventilation flow rates into a building. A lack of ventilation will cause problems with air quality as noted above and too much could lead to adverse effects on energy efficiency of the building. This is due to the system pulling in large amounts of outside air, especially if it is cold, into the building space cooling a heated space. This would then lead to the building space requiring additional heating loads on the system. Pre-heating the outside air, with a heat recovery system, or reusing an amount of re-circulated air from the building space can reduce this effect.

Required ventilation rates to maintain energy efficiency in HVAC systems in non domestic buildings can be found in Section 6 of the Scottish Building Regulations (Non Domestic).

This next section introduces the aspects that can be looked at as part of developing the methodology to meet the aim of this thesis. It also details previous work that has been carried out on the subject.

4.2 Building Energy Management Systems

First introduced in the 1960s with no computer control, Building Energy Management Systems (BEMS) have been used to effectively control the building plant services and energy efficiency in buildings. BEMS are also sometimes called Building Management Systems (BMS), Energy Management Systems (EMS), and Building Automation Systems (BAS) but all have the same function (Levermore 1992). With the advancement of computer systems and micro-electronics, BEMS are now an important feature, in some form, in the majority of commercial, industrial and public buildings. Microprocessors in computers have allowed BEMS to carry out multiple calculations simultaneously from data that is gathered from outstations. Technological and production advancements have also allowed BEMS to become more affordable making it even more popular.

BEMS are used primarily to monitor and control the Heating, Ventilation and Air-Conditioning (HVAC) system in a building. It can also be used to control the operating times of the system. However, the BEMS can also be used to monitor and control lighting, lifts and security/fire systems. Advancements in computer and internet technology, such as broadband, have made it even simpler to control BEMS.

"More than 40% of the UK's primary energy demand is related to buildings for heating, cooling, ventilation, lighting and powering electrical appliances"

(University of Southampton 2010)

The major advantage of having BEMS is a decrease in running costs, and as a result energy use and emissions, in a building. Another advantage of installing a BEMS is that the buildings plants can be easily monitored and controlled through communication, allowing optimisation of the building plants. Through it, it saves on staff costs and it sometimes becomes an important aspect in the commissioning of a building. There are, however, some disadvantages of installing a BEMS. Although with a BEMS the primary functions could be easily learnt, to make it very effective and energy efficient, a large proportion of the functions need to be understood. This could mean taking a considerable amount of time to learn these functions or enrolling employees on expensive training courses (Levermore 1992).

4.3 Post Occupancy Evaluation

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

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

'The process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time'

(Preiser 1988)

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

The Probe (Post-Occupancy Review of Buildings and their Engineering) was a successful project that looked into building efficiency as well as occupant comfort (Cohen et al. 2001). This research project looked into 16 different buildings, used for varying purposes, to gauge the success and potential of this method.

4.4 Current Theoretical Analysis Techniques

4.4.1 Energy Performance Certificates

Energy Performance Certificates (EPCs) are documents which detail a buildings energy use, energy ratings and efficiencies. EPCs display the carbon emissions of a building, in terms of CO_2/m^2, and assigns a rating accordingly between the ratings of A-G, with A being the best and G the worst rating. It also shows the energy usage of the building in terms of kWh/m^2. The certificates show recommendations that could be made to improve efficiency and show benchmark ratings for the building type. The certificate displays the Target Emissions Rate (TER) which is a benchmark CO_2 emissions value that the building should meet. This is derived from the Notional Building simulation that is also run through the SBEM program that keeps the same building dimensions, heating, occupancy, lighting and ventilation values. However, the building is assumed to be constructed within the listed 2002 Building Regulations. The EPC also displays the carbon emission figure that could be achieved if the recommendations from the EPC are put into place.

EPCs now have to be carried out for new non-domestic buildings where the conditions are monitored and existing buildings which have a floor area larger than 500 m^2. This is due to the implementation of the Energy Buildings Performance Directive in April 2008 (RICS 2007). This directive also stipulated that certificates are required for all public buildings with a floor area larger than 1000 m^2 in Northern Ireland, England and Wales. These public buildings have to have Display Energy Certificates (DECs) which shows the energy use of the building to the public. DECs differ from EPCs as the DECs are calculated using actual energy use for the building for the past three years. Operational ratings are given to the buildings, similar to the EPCs, from the actual energy consumption. Currently, similar buildings in Scotland do not require a DEC as it is deemed a visible EPC is sufficient.

4.4.2 SBEM Simulation Program

Energy Performance Certificates in the UK usually have the energy use performance calculated using the Simplified Building Energy Method (SBEM) modelling tool. This tool is also used to satisfy the various building regulations in the UK and was developed specifically for non-domestic buildings.

For the SBEM modelling, the building has to be split up into building 'zones' and the envelopes of these zones defined, with air permeability and dimensions. These zones are modelled using the iSBEM tool which is an interface for the SBEM program. Each zone will have the building makeup detailed, with area of the floor, windows and doors, ceiling and wall sizes determined. The material and U-values of these objects will also have to be logged. In addition, details of the HVAC system, hot water system, lighting systems, thermal bridges and orientation of the building has to be recorded into the program (SBEM Manual 2010). The building type has to be designated in terms of its use from a list of 29 in the SBEM program. The building then needs space types designated to the internal spaces. This is done by assigning a space type from a list of 64 provided in the SBEM database. The designated building space activity type will have fixed assumptions that will be used for the building simulation, such as maintained room temperatures and occupancy values. The year round hourly weather data, which is closest to the building location, is chosen in order to determine external conditions for the simulation. This is chosen from a database that lists 14 locations. All the databases in the SBEM program are locked to allow fair and reliable comparisons to similar buildings to the simulated model.

Once the details of the building are entered into the program, the EPC of the building can be produced. The SBEM program allows the user to run a simulation to meet regional building regulations within the UK. This means the EPC can be carried out to meet Scottish, English, Welsh or Northern Irish Building Regulations.

It is also possible to include any renewable systems that are incorporated into the building, such as photovoltaic systems and wind turbines, in the SBEM modelling.

4.4.3 Other EPC tools

The analysis for the EPCs can also be carried out using Greenspace Live developed software, SBEM and Google Sketchup. A model of the building can be created using the Sketchup software, including space allocation as well as nominating all surfaces and opening types. This model is then exported as a XML file to be loaded into the internet-based gEnergyEPC software developed by Greenspace Live, which has been validated by CLG (Department for

Communities and Local Government). In this program, it is possible to input the relevant building properties, such as HVAC systems and building U-values. An EPC is then generated through CLG's SBEM engine, which the gEnergyEPC software is interfaced with. The EPC can be generated to meet Section 6 of the Scottish Building Regulations, Part L of England and Wales building Regulations as well as Part F of the Northern Ireland Building Regulations as in the SBEM tool. However, even though the EPCs can be produced in this software, and models have been made for the three campus buildings, the software is still continuously being developed as a product that can be rolled out in the near future.

4.5 Techniques for Quantifying Heat and Energy Loss

4.5.1 Thermography Surveys

Thermal imaging, or thermography, surveys are one of the popular methods to ascertain where the heat losses are occurring in a building. Contrary to popular belief, thermal imaging cameras do not measure the temperature of an object, but rather measure the radiation that is emitted from the surface of the object. Using this method, it is possible to see the heat leakages in a building that cannot be seen by the naked eye. Thermal imaging of a building envelope will give a qualitative analysis of heat losses that could be caused by various means, such as insulation and pipe work defects, air leakages and moisture in the building. The results of the thermal imaging will, in turn, allow the proprietor to make possible improvements to the building.

Fundamentals of thermal imaging

From the fundamentals of physics it is know that all matter emits electromagnetic radiation of an intensity and wavelength that is associated to the temperature of the matter in question. Emittance is defined as the ratio of actual radiation to the theoretical radiation of a black body, calculated through the Planck function, of the object (Claes 2001). This is the basis that allows thermal images to be captured. Typically, thermal imaging equipment can take 1 to 15 microns in the infra red spectrum. The most popular cameras usually deal in the latter part of this range, between 6-14 microns, but there are cameras that take in shorter wavelengths, between 1-6 microns, where thermal images of very high temperatures are needed.

As well as the camera receiving the radiation emitted from the surface of the object, it also collects the radiation from the surroundings reflected from the object surface. On top of this, both these measured radiation contributions are attenuated by the atmosphere in the measurement path by some factor (Claes 2001).

It is assumed that the received radiation power (W) from a blackbody source T_{source} from a short distance produces an output signal in a camera V_{source} that is proportional to the power input. This can be written as:

$$V_{source} = C.W(T_{source})$$ **Equation 3**

Where C is a constant.

The camera, once calibrated, collects three different power terms which can be deduced:

The first is the Emission from the object which is given as $\varepsilon\tau.W(T_{obj})$.

Where ε is the emissivity of the object, T_{obj} is the temperature of the object and τ the transmittance of the atmosphere.

The second is the reflected emission from ambient sources, given as,

$(1 - \varepsilon)\tau.W(T_{amb})$.
Where $(1 - \varepsilon)$ is the reflectance of the object and T_{amb} is the temperature of ambient sources.

The third and final term is the emission from the atmosphere:

$(1 - \tau).W(T_{atm})$

Where $(1 - \tau)$ is the emittance of the atmosphere and T_{atm} is the temperature of the atmosphere.

Figure 2 illustrates where the three above equations originate in the thermal imaging process.

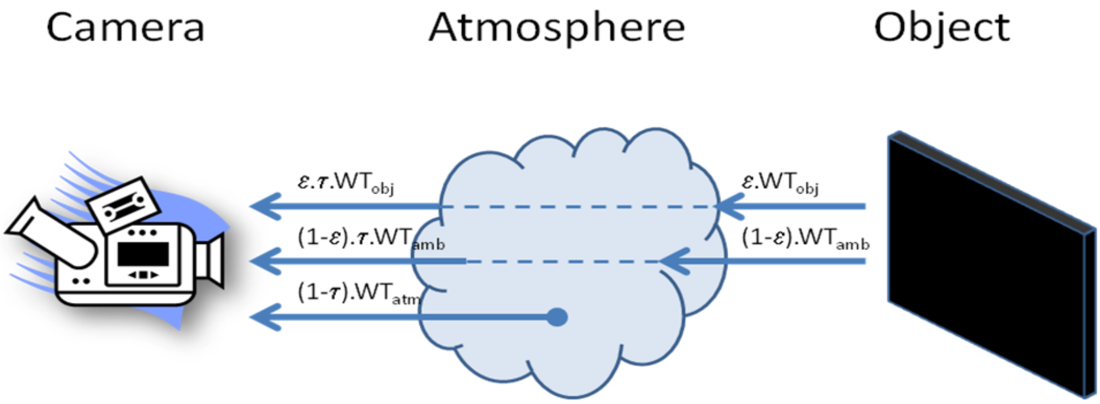

Figure 2: Illustration of thermal imaging capture process. Based on a figure in Claes (2001).

From the three equations outline above the total radiative power can be written as;

$$W_{tot} = \varepsilon.\tau.W(T_{obj}) + (1-\varepsilon).\tau.W(T_{amb}) + (1-\tau).W(T_{atm}) \quad \textbf{Equation 4}$$

Which, when multiplying each term with the constant C from eq. 3 and rearranging gives;

$$V_{obj} = \frac{1}{\varepsilon.\tau}.V_{tot} - \frac{1-\varepsilon}{\varepsilon}.V_{amb} - \frac{1-\tau}{\varepsilon.\tau}.V_{atm} \quad \textbf{Equation 5}$$

The various voltage terms are explained in Table 1. The calculation method is fundamental to thermal imaging cameras and may be different for different objects where more parameters have to be taken into account. An example of this would be when dealing with windows between an object. Here the reflectance, transmittance and emittance of the window, as well as the object have to be taken into account. On top of this, two ambient sources and atmosphere terms, one before and after the window, have to be included. The process of calculation still follows the same principles as outlined above for this case, albeit more complex (Claes 2001).

Voltage Term	Description
V_{obj}	This is the output voltage that is calculated by the camera for a blackbody object. This voltage can be directly converted to the objects temperature.
V_{tot}	This is the total camera output voltage for the given case
V_{atm}	This is the theoretical camera output voltage for ambient sources
V_{amb}	Theoretical camera output voltage of the atmosphere

Table 1: Description of voltage terms in thermal image capture

There are British Standards (BS EN 13187 1999) outlining a methodology for detecting thermal irregularities using infrared technology.

There have been several thermal imaging surveys carried out in further education buildings in the UK and Scotland (Strachan & Cockroft 2010).

4.5.2 Air Pressure Testing

Air pressure testing is an experimental technique to identify the air permeability of a building envelope. This technique can help identify possible air leakages in a building envelope that affects heat losses as well as discomfort for the building occupants. Air leakages are uncontrolled flows of air through gaps and cracks of the building fabrics (Government of Ireland 2008). These leakages are more often than not hard to detect by visual inspection, as they are often hidden by internal decoration or external cladding. Regulations in England and Wales (Part L Building Regulations) and in Scotland (Section 6 Scottish Building Regulations) limit heat gains and heat losses, and this includes those through air leakages. Air pressure testing, used in conjunction with thermal imaging surveys, can be a very powerful tool to identify losses from a building envelope.

The basis of air pressure testing is to create a pressure differential and measure the air permeability of the building envelope for a given volume flow rate. This could be done by placing portable fans, of various sizes depending on the test area, on doors, vents or windows. The pressure difference forces the air out of any leakage sources in the building. The air leakages are then measured as the volume flow rate per hour of air supplied per square metre ($m^3h^{-1}m^{-2}$) for a given pressure difference, for example 50 Pa. Figure 3 illustrates how the air pressure testing is performed.

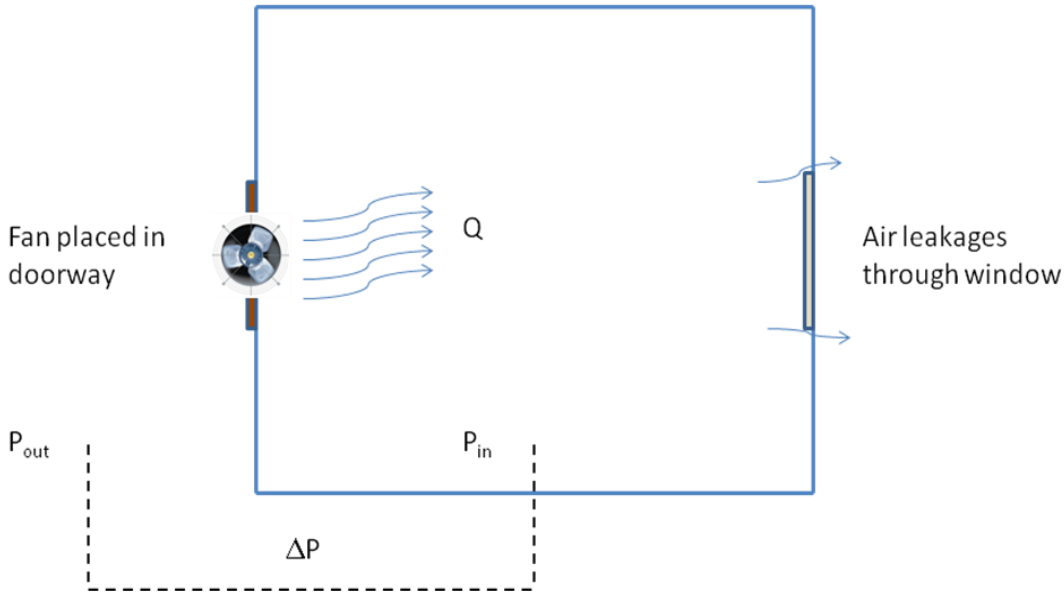

Figure 3: Diagrammatic explanation of air pressure testing.

Again, there are methodologies available for air pressure testing by both British Building Standards (BS EN 13829 2001) and by the Air Tightness Testing and Measurement Association (ATTMA 2006).

4.6 Previous Work on Topic

There have been several studies into looking at the discrepancies between theoretical and actual energy use. These studies have included validation for building simulations, such as ESP-r (produced in the University of Strathclyde), and seeing where the discrepancies come from. The likes of MacDonald (2002) looked into assumptions of heat load gains from occupants and equipment that cause uncertainties in modelling.

Egan (2009) looked at identifying discrepancies between simulated and measured energy use in three different large office buildings, with varying building heights, based in Canberra, Australia. Egan mainly observed the link between occupancy levels and building management to identify these discrepancies.

In the first of the case studies carried out, it was seen that there was more energy being used in the building than in the predictions from modelling program simulations (obtained from EnergyPlus). This discrepancy was seen to be mainly caused by the HVAC system, which had been turned on to activate heating overnight, as the occupants complained to building maintenance staff that the building was too cold in the mornings. This was altered without the knowledge of the building owner which shows the consequences due to mismanagement of building HVAC systems. It was also seen in this case, that the power and lighting use of the occupants were higher than that simulated in the modelling. This was identified to be caused by overuse of lighting, such as leaving lights on overnight, and appliance use whereby some occupants used more than one monitor to carry out their work on computers.

The second of the cases, again, found under projections of electrical and gas usage from the modelling program compared to actual energy use. It was found with this case study, that there were issues quantifying the energy use of a medium sized cafeteria in the building in the simulation tool. The third case study yet again saw problems with underestimation in energy use from the modelling tool. However, with this case it was found to be caused by the inability to model control strategies implemented in the BEMS of the building. There was also seen to be similarities with the first case in that lighting and power was underestimated due to misuse by the occupants.

Bordass (2004) saw that many non-domestic buildings waste large amounts of energy. He concentrated his work analysing the reasons why there are usually differences in the predicted and measured energy use of buildings. Bordass (2004) split the causes for these discrepancies into four different phases of a buildings construction and use. Causes, such as poor assumptions of building zones, occupancy levels and optimum control, were cited for the initial estimation phase of a building. The next phase that was looked at was the initial design phase. Here, it was found that sources for energy discrepancies occurred through areas such as changes in client requirements and alterations in heating and building control during this design phase. The third phase involved the causes that arose during the construction of the building. These could be from cost savings due to going over budget which could alter building materials to poor build quality. The final phase that was analysed was when the building had been completed. The discrepancies for this phase were seen to transpire from such aspects like different occupancy levels than intended, poor usage of BEMS, and limitations in multi-tenanted buildings, whereby tenants have different responsibilities and are reluctant to invest and exacerbate wasteful energy use.

There have been some studies that show that even buildings built with the environment in mind, can have large differences between predicted estimates and actual measured energy use. Curwell et al. (1999) showed this by carrying out a comparison of actual and predicted operational CO_2 emissions for an environmental award winning head office building in the UK. The estimations for emissions were done through several various modelling tools, such as BREEM, ECON 19 and design estimates. The results of the comparisons can be seen in graphical form in Figure 4. Although this study was carried out a decade ago, and there have been a lot of studies and advancements in building simulation, there is still relevance in the study in the present day.

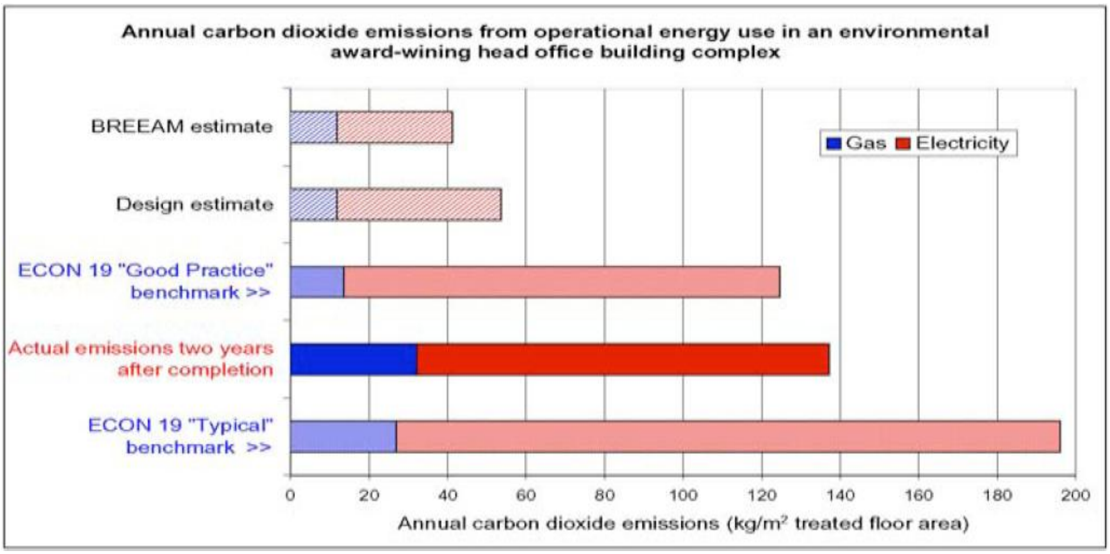

Figure 4: Graph illustrating the comparisons between various predictions and actual measured energy use in an environmental award winning office building. Taken from (Bill Bordass 2004)

Donald (2010) carried out a study on the issues that influence BEMS and how effectively they can be run. In this dissertation, four case studies were carried out on the BEMS of various large public buildings that had been in operation for around 18 months. The case studies were carried out on a leisure centre, an office building with high IT usage and two schools (one primary and one secondary). All the case studies showed different problems and mismanagement of BEMS as well as the aspects that the BEMS controls. It was seen that both schools had problems with occupant behaviour. The school's occupants altered the thermostat when the room was too cold, often set to an unreasonably high temperature in an attempt to heat the room faster. When the room got too hot, the occupants would proceed to open windows to cool the room down. Through the analysis, there were also issues that occurred from the sensors, which in turn, affected BEMS performance. As an example, in the leisure centre, it was found that the external temperature sensor was placed near an exhaust duct which obviously affected the temperature recorded by a number of degrees. The automated skylight, which was actuated upon a designated outside temperature reading, in the swimming pool hall would then open resulting in heat loss which had to be replaced by generated heat. Other case studies had issues with lighting control and CO_2 sensors.

Table 2 summarises the aspects found in reviewing literature that can cause mismatches between predicted and energy use.

Causes of Discrepancies Found in Previous Studies	Literature
Poor management of BEMS	(Donald 2010)
Inadequate positioning of sensors that affects BEMS	(Donald 2010)
Occupancy behaviour	(A. M. Egan 2009)
Building not matching design or plans	(Bill Bordass 2004)
Poor quality workmanship	(Bill Bordass 2004)
Errors in simulation tools	(MacDonald 2002)
Issues with modelling building spaces accurately	(A. M. Egan 2009)

Table 2: Summary of issues that caused discrepancies in predicted and actual energy use from previous studies

The TM22 energy survey procedure, produced by the Chartered Institute of Building Service Engineers (CIBSE), can be used on most completed non-domestic buildings of all ages, whether just build or existing, and types. The procedure was produced from the PROBE study that was previously mentioned in this thesis. This is a simple tool that allows an energy assessor to ascertain how well a building is performing compared to benchmark cases. It is also a useful investigation tool to see how beneficial building upgrades have been in terms of energy use. The procedure uses actual energy usage to calculate CO_2 outputs as well as energy usage per m^2, as with EPCs. The procedure allows alterations to the analysis so that it gives accurate representations of specific buildings. This procedure will be even more relevant at the present in to obtain values for DECs that are stipulated to be displayed for non-domestic buildings, greater than $1000m^2$, England and Wales

A recent energy survey, using the CIBSE TM22 procedure (J Field & Chartered Institution of Building Services Engineers. 2006) has been carried out, by PowerEfficiency, on the Marriott Hotel in Marble Arch, London, which was published in a recent CIBSE Jourrnal (John Field & Balaskas 2010). The work carried out here was to analyse the current energy usage and make recommendations to improve energy efficiency for energy certificates. For this survey, PowerEfficiency used the procedure to see how the building was performing under certain benchmarks. It was seen through this analysis that the hotel used 8% less than the theoretical good practise benchmark in this procedure. It was seen through reading this literature that the TM22 is a good tool to observe how a building is performing in relation to typical and good practise benchmarks.

The Short Term Energy Model, or STEM, methodology was developed by the Solar Energy Research Institute (SERI, now NREL). This methodology was created for thermal analysis in residential buildings and was based on the Primary and Secondary Terms Analysis

Renormalization, or PSTAR, method (Subbarao et al. 1988). The PSTAR method uses a mathematical procedure to observe the thermal characteristics of a residential building. This was an early method to see if predicted energy flows were the same as actual energy flows. The methodology was developed to be able to obtain data in a short time frame using one-time measurements. The PSTAR originates with an energy balance equation for thermal characteristics, using reasonable assumptions of heat flows, in the building. Data was collected around the building and the energy balance equation calculated again with the data. The steps of the PSTAR method were to first identify all the heat flows in the building. This is determined through three categories: measured (electrical heat input), primary (for example, loss coefficient X external-internal temperature difference) and secondary (such as flow due to sky temperature depression). With these values identified, the audit description is required to be obtained to calculate the flows. A test protocol is then needed to be determined to extract the renormalisation parameters and the test data obtained from it. The heat flows for the test period was then calculated and renormalisation parameters obtained from the linear least squared method. The renormalized energy balance equation is then used for the intended application. A case study was carried out on a domestic building using this methodology by SERI (Subbarao et al. 1988)

This STEM methodology was attempted to be validated through testing carried out on two near identical mobile modular office buildings, one with a standard frame modular office and the other an office with Structural Insulating Panels (SIP) installed (Judkoff et al. 2000). The STEM methodology was carried out on both buildings under outdoor conditions. Here, tests were performed to predict long term heating and cooling loads. A series of tests were carried out on the two buildings in an indoor environment under steady state conditions to ascertain the thermal performance of the two buildings. These tests took the shape of air pressure testing, tracer gas tests, thermal imaging surveys, calorimeter tests and STEM testing. The main objective was to analyse the thermal performance of the two mobile offices. However, there was a secondary purpose to validate the STEM testing. It was concluded from the study that the STEM methodology predicted thermal performed very well in relation to the experimental test procedure results that were gathered. Tests saw that there was only a 5% difference in values obtained from calorimeter tests.

5. Case Study Procedure

5.1 Building Simulation Modelling

The Energy Performance Certificates (EPCs) for the three campus buildings in Lews Castle College were produced using the SBEM program in July 2009. These certificates were carried out to meet Section 6 of the Scottish Building Regulations. More detailed simulation files were also obtained for the three campus buildings which gave a monthly breakdown of the energy use into areas such as heating, lighting and electrical appliances. All three of the EPCs of the campus buildings can be seen in the Appendix C of this report.

It was decided it was good practice to investigate the SBEM modelling tool when trying to identify the discrepancies between predicted and measured energy use. This is due to the possibility that the simulation may be the cause of significant discrepancies. A sensitivity study was carried out to ascertain how changing different inputs in the program can affect the EPC output values. The purpose of this is to deduce if the modelling inputs skew the result in a way that it creates discrepancies. Alterations were carried out on infiltration rate values, U-values and K_m (Effective Thermal Capacity) of the building materials and building orientation. The K_m values were calculated using Equation 6, where ρ is the density, c the specific heat capacity, d the thickness and A the area of the materials. The K_m values were calculated for all the main constructions, such as walls floors and windows, in the buildings. It is calculated by the summation of all the building elements in direct thermal contact with the internal air of the zone under construction (SBEM Manual 2010). The U-values were obtained from summer student placements from Greenspace Research that were undertaking a study in U-values of the campus buildings (Vögler et al 2010). In addition to this, the activities assigned to each of the building zones in the SBEM was verified to see if they were correct to what the space was used for.

$$K_m = \sum_j \sum_i \rho_{ij} c_{ij} d_{ij} A_{ij}$$ **Equation 6**

For each of the three buildings, various single changes were made with each input assessment to deduce what difference in results was produced from the original EPC values. New EPCs were obtained for each of the three campus buildings with all the relevant input changes from the sensitivity study put into place. The new EPC values were then compared with the original values to ascertain how much impact the outlined parameters have on the output values.

5.2 BEMS

The campus is managed by a TREND 963 Building Energy Management System serviced and monitored by RE Dew. The BEMS has control over the whole campus. The system has five different outstations around the campus. There are three outstations controlled by an IQ241 and the remaining two outstations controlled by an IQ250 which control the HVAC systems in the buildings. An analysis was carried out on the BEMS to ascertain if it is performing properly, as well as to deduce how much control it actually has over the HVAC system in the campus buildings. In addition to this, a physical inspection of the HVAC system was completed. This was performed to see if the systems are actually controlled by the BEMS. Additionally, the investigation was carried out to establish if the systems are being maintained and operating properly. The ventilation of the campus buildings were provided by eight ventilation units with heating coils to pre-heat the air. An Air Handling Unit is also situated above the C block of the Facilities Building. Heating in the campus buildings is provided mainly by radiator panels mounted on walls. The only exception is with the Engineering Building and the library in the Facilities building, which had ceiling radiator panels installed in them.

An investigation of the positioning and data of sensors was also carried out to see if there are anomalies between them that can affect the performance of the BEMS. Data from outside temperature sensors and pipe temperature sensors in the heating system were analysed.

Schematics of the system in the campus can be seen in the Appendix E of this thesis.

5.3 Post Occupancy Evaluation

A Post Occupancy Evaluation was carried out on the three campus buildings. This consisted of several stages of assessment. The first was to go around each of the buildings and visually inspect them to identify any issues that can affect energy performance. This requires some investigation to ascertain the thermal comfort of the occupants of the buildings. When carrying out the visual investigation, aspects such as electric fans and heaters in use in offices should give clues that the building is not performing to expectations.

For the next stage, an occupancy questionnaire was produced as part of the POE study to see how the occupants behave, and if the environment in the workplace is comfortable in terms of temperature, lighting and air quality amongst others. The questionnaire used in this study was based on a template for a POE developed by the University of Westminster (University of Westminster 2006). This questionnaire was used as a template as it was created for higher education buildings. There are many questionnaires that could be used for templates for different buildings which are widely available. A variety of participants were targeted for each of the three campus buildings. Ideally, there should be a good mix of male and female participants as well as participants with different job backgrounds, such as students, lecturers and maintenance or office workers. This is to gain results that are not distorted towards one set of contributors. As the questionnaires were being completed, the chance was taken to interview the occupants and see if there was anything of concern that should be noted. The questionnaire used in this study can be found in the Appendix F of this report.

5.4 Thermal Image Survey

Thermal imaging surveys were carried out throughout the campus. A FLIR B620 camera was used to carry out the surveys. The camera is easy to use and has the options to take a thermal image, a digital image or both for each shot of an object.

An internal thermal imaging survey was carried out in the campus. In order to see more clearly where the losses were coming from, convective heaters were used in the rooms to identify areas of heat loss. This was to create a temperature difference, between internal and external temperatures, so that it is possible to clearly identify if there are any leakages in the rooms. In several rooms, the blower door was used in conjunction with the heaters. The Model 4 Minneapolis Blower Door testing kit, produced by The Energy Conservatory, was used for some of the experiments. This was used, again, to gain more clarity when determining air leakages in a room by creating a pressure difference between building spaces. Thermal imaging surveys were carried out on most of the main rooms in the campus buildings to investigate the quality of workmanship.

A thermal imaging survey was also carried out on the three buildings externally. This was to see the possible heat loss leakages to the outside of the building envelopes, as well as being used as an investigative tool to see if the HVAC system was operating properly. The thermal imaging camera was used around the three campus buildings, with images being taken of areas that showed a large temperature difference in relation to the surrounding surfaces. The external thermal imaging survey was carried out at various periods of time during the summer. A thermal imaging survey was carried out when the buildings were open and occupied. Besides this, a survey was carried out during the summer bank holiday weekend to ascertain if the building performed any differently. All the thermal imaging surveys were performed during the early morning on overcast days. This was to try and gain the best temperature differential during the summer period to gain the best results.

It has to be noted that these tests were carried out during the summer months which is not the best period to do so. Ideally, the tests would have been carried out when the internal temperature is significantly higher than the outside temperature, usually consistent in the winter months, in order to create a substantial temperature differential between internal and external temperatures of the building. This would allow much clearer images to distinguish the areas where thermal losses occur. It should also be noted that, when taking the thermal images, it is imperative to take the images from an angle away from the object or surface of interest. This is to reduce the heat reflection from the camera user which could affect the output image with errors.

The images carried out externally on the campus buildings were then compared to thermal images that Greenspace Research had obtained in the winter months to see if similar results were being gathered. An analysis of the winter images was also carried out to see if any thermal losses can be observed.

5.5 Air Pressure Testing

Air pressure testing was attempted for all three buildings on campus. The Model 4 Minneapolis Blower Door testing kit, produced by The Energy Conservatory, was used for the air pressure testing. This was carried out to establish the infiltration rates of the buildings. However, it was seen that the fan used was designed for use in domestic buildings and did not have the required fan volume flow rate capacity to carry out testing for large non domestic buildings. The air pressure testing was carried out on large individual rooms that have external doors within its envelope.

Before the air pressure testing was carried out, a procedure to seal the building had to be carried out. It was important that all the internal doors were wedged open and combustion appliances switched off. External doors were closed and, if only part of the building was being tested, internal doors in the test boundary were closed and sealed. Mechanical ventilation systems were switched off, with inlet and outlet grills sealed. On top of this, any flues were also sealed.

A day where there was low wind speed, less than 3m/s, was chosen to carry out the testing. This was so that the weather would not affect the infiltration rates in the experiment. As the experiment was carried out in the summer, the temperature difference internally and externally was not less than 10K (CIBSE 2000).

The blower door was used in conjunction with the DG-700 pressure gauge to measure the pressure difference inside and outside the building being measured. In addition, the kit was linked up to the Automated Performance Testing System which allows the fan speed of the blower door to be controlled automatically or manually.

To set up the experiment, firstly, the blower door had to be installed in the doorway. This was done by firstly setting up the adjustable aluminium door frame to the door in question. This aluminium door frame incorporates a nylon panel around it, so that it creates an airtight seal around the door. The pressurisation fan is then placed in an opening at the bottom of the attached nylon panel of the door frame. The pressure gauge and speed controller is then linked to the pressurisation fan. Figure 5 illustrates how the equipment was set up for the experiment.

Figure 5: Set up of the air pressure testing kit on the classroom E005 in Engineering Building

With the experiment set up, the testing could begin. First of all the baseline building pressure was measured. This was important factor to measure as it takes into account any existing pressures in the building either from stack, wind or other driving forces. To measure the baseline pressure of the building, the fan is first fully covered. The readings from the gauge will then display a reading, which is the baseline value, and this was recorded.

The TECTITE program, developed for the air pressure kit, was used to carry out an automated depressurisation test to get the pressure differential, internally and externally of the building space, to 70Pa. The TECTITE program then automatically steps down the fan flow rate to obtain increments of 5Pa pressure difference, until it reaches 25Pa. A hundred readings of building leakage were sampled for each step down and plotted in a graph in the program.

The air pressure testing kit was then kept on at 50Pa and used in conjunction with convective heaters and the thermal imaging camera to identify the areas of leakages in the room.

6. Current Building Energy Performance

6.1 Predicted Energy Usage

As mentioned previously, EPCs have already been established for all three of the buildings on campus, the Engineering, Facilities and the Rural Development Building. A summary of the EPCs can be found in the Table 3.

Building	EPC rating	Benchmark	CO_2 (kg/m^2 per year)	Energy Usage (kWh/m^2 per year)
Engineering	G	F+	126	448
Rural Development	D+	C+	46	156
Administration	D	D+	53	173
For whole Campus	F		87.23	248.73

Table 3: Current predicted energy use from EPCs of the three buildings

From the SBEM analysis carried out for the EPC of the buildings, it was seen that the largest energy consumption was from heating. Heating accounts for around 60% of the campus' overall energy consumption from the SBEM analysis of the three buildings. This ratio was verified to be true when looking into the energy bills of the college which showed around 60% every year was spent on heating oil. There was no cooling load predicted from SBEM.

It was also seen in the SBEM analysis that lighting contributes significantly to the electricity usage in the energy consumption. In the Engineering building SBEM output document, it was seen to contribute nearly a quarter of the total energy consumption. Other aspects that also contributed notably to the energy consumption were from equipment and hot water demand. Figure 6 shows the annual energy consumption in the Rural Development Building which gives a fair indication of how the campus is performing.

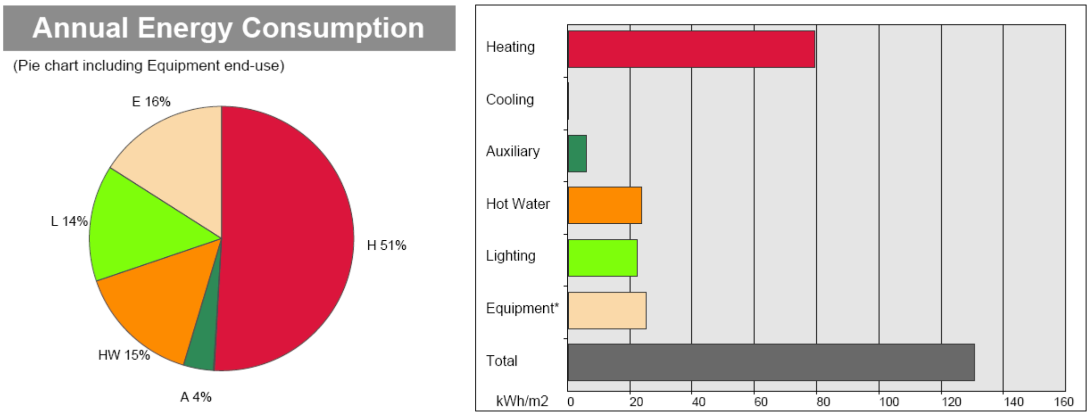

Figure 6: Annual energy consumption obtained from SBEM for the Rural Building

The SBEM analysis of the three campus buildings showed that all three did not meet the heating source efficiency and the U-values outlined in Section 6 of the Scottish Building Regulations.

6.2 Actual Usage

From the energy bills from the College, it was possible to deduce how the building was performing in relation to the EPCs. The results from the analysis of the College energy bills, averaged over 5 years of data, can be found in Table 4. These energy bills are of actual usage of the College campus. The electrical bills showed that actual meter readings were used and heating oil was bought as was needed. The heating loads were calculated from the litres of heating oil bought in every month from the last five years. The heating energy usage, in kWh, was then obtained using the amount of oil bought by using a conversion factor of 11.7 (Carbon Trust 2005) for every litre of oil bought. Of course, the heating energy bill data is not ideal, but it does give reasonable yearly assumption of heating loads in the college. It was seen that the College used 356.22kWh/HDD.

Electricity Usage (kWh)	Oil Usage (kWh)	Total Energy Usage (kWh/m2)	CO2 emissions ($kgCO_2/m^2$) (Carbon Trust 2005)	Energy Rating (Under EPC guidelines)
780720	1197272	195.84	71.33	F

Table 4: Actual yearly average energy usage of all campus buildings

It can be seen that, if the campus has the same characteristics outlined in all three of the buildings EPCs, the campus is operating below the predicted energy usage and emissions from the average SBEM analysis.

6.3 Discussion

From the initial analysis of the predicted and actual energy usage, the results were not as expected. It was seen that the actual energy usage was around 27% lower than the EPC predicted energy usage averaged over the whole campus. This suggests that there are some discrepancies that occur from the modelling, when obtaining the EPC, and has to be investigated.

The major issue when dealing with the comparisons of actual and predicted energy use of the campus is that there is no way of quantifying how much each individual building uses from the energy bills. For electricity usage, the issue is that all the energy goes through one meter. Furthermore, the heating data, gathered from monthly heating oil purchased over the 5 year period, meant it was virtually impossible of quantifying monthly usage. Data from the BEMS was not sufficient enough to calculate the proportion of energy use in each of the buildings.

As well as deducing actual energy usage, the bills showed how the buildings were used throughout the year. The electricity bills especially gave an indication of this. Figure 7 shows the averaged monthly electricity usage over five years. It can be seen that the electrical usage drops dramatically through July and August. This is due to the college not running any classes during this period for the summer break. However, research and support staff still operates in the buildings during this time. It was seen that the predicted electrical usage showed similar usages in the winter months, but a good match over the summer months. The comparisons gave an insight on potential pitfalls of the modelling software and procedure. As mentioned previously, there is a distinct trough in the measured energy usage in July where there is lower occupancy in the college. This is shown to be not as prominent in the simulated case. This is an area that has to be looked at and rectified in the modelling program.

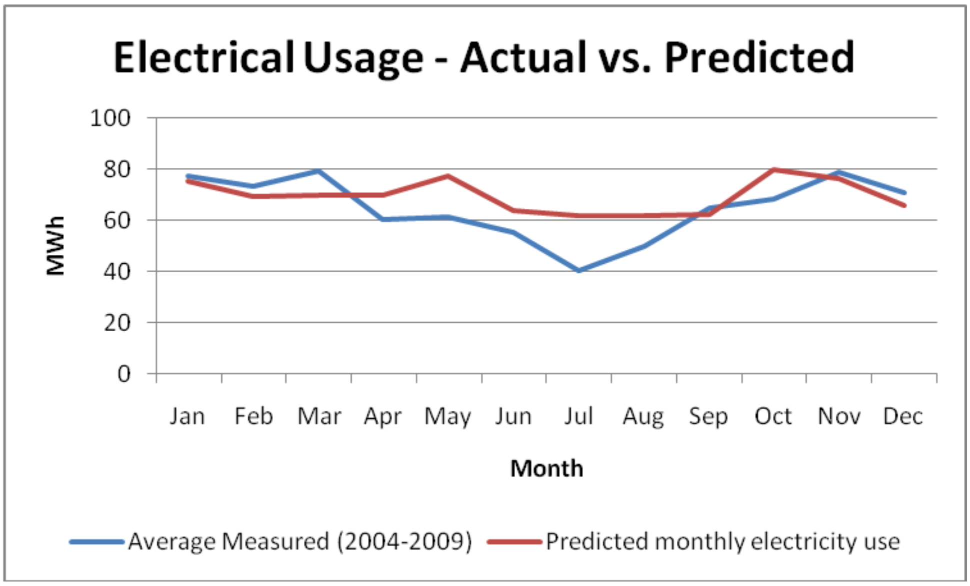

Figure 7: Comparison of actual and predicted electrical usage

A yearly comparison was also carried out of the energy uses for heating oil and electrical usage. It can be seen that the predicted heating oil usage is approximately 63% more than actual heating usage. The prediction shows that there is 547.69kWh/HDD which is 191.47kWh/HDD more than the actual usage. This is quite significant over prediction and is the primary reason why the EPC data is higher than measured energy use. It can be seen that there is only a small over prediction in the electrical usage.

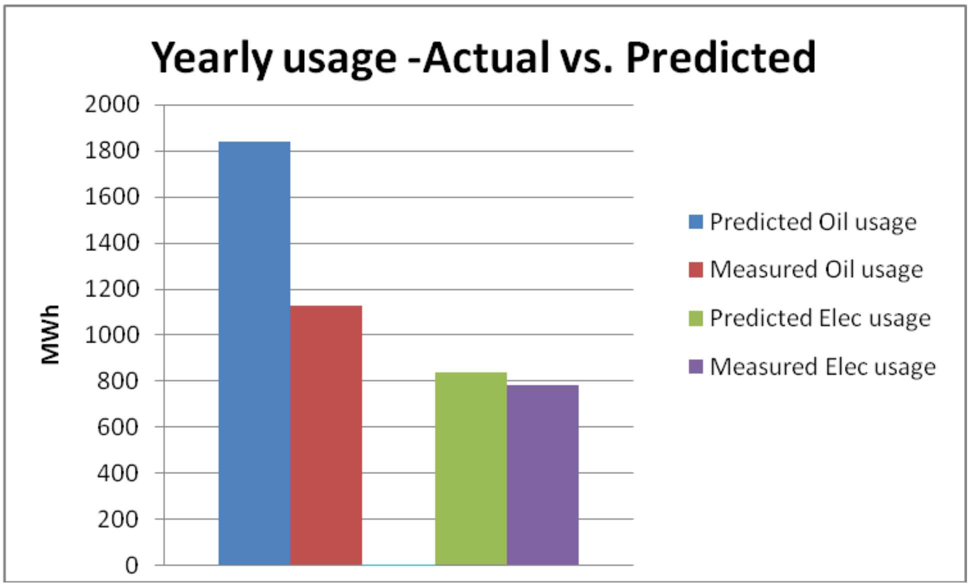

Figure 8: Yearly comparisons of yearly actual and predicted use broken down by fuel type

It was seen from the initial comparisons that the area that has to be looked at in detail is the area of heating. It is hoped that, by carrying out a sensitivity study of the SBEM tool and the other areas of investigation, it is possible to identify why there is such a large over prediction in energy use in the college campus.

7. Analysis of Results

7.1 BEMS Analysis

It was seen that the BEMS had little influence on the energy performance of the campus. The BEMS has been used, not as an energy efficiency tool, but as a one stop station to control some of the HVAC system of the campus. Throughout the last 20 years, there have been constant additions to the management system. This has resulted in the system not being integrated properly and having sporadic control over the HVAC system. The BEMS was seen to have more or less full control over the heating system of the campus buildings. However, it was seen through investigations that not all the ventilation systems were controlled by the BEMS. Some of the ventilation fans were stand alone systems which were controlled by systems built into them. This was also seen to be the case with the AHU which was independent of the BEMS system. In addition to this, a visual inspection of the ventilation fans in the Engineering and Facilities Building showed that the majority of the fans had broken fan belts that have not been replaced. The fan drives remain operational, however, resulting in wasted energy for the College.

The BEMS system of the college was seen to have little data from the three buildings. The campus' BEMS has been seen to run inefficiently and has been earmarked to be remedied from this summer (2010). It was seen, through further analysing the system controls, that there was an older BEMS system in place that is still operating that can override the current system as it has a higher hierarchy. This is an analogue control that has been installed on the two 325kW oil boilers, which supplies heat and hot water to the Rural Development and Engineering Buildings. It is obvious that integrating all the system to be run through the BEMS would be a major recommendation to improve efficiency in the campus buildings.

A test of combustion efficiency of the four boilers was carried out as part of the investigations into the HVAC system. This was carried out by the College maintenance staff that was carrying out a yearly service of the boilers at the time of the investigations carried out in this thesis. These efficiencies were verified using a flue gas analyser, which showed closely matched results. The results of the boiler tests can be seen in Table 5.

Facilities (Nu-way NOL 50-28 850kW boilers)		
	Boiler 1	*Boiler 2*
Efficiency	82.0%	87.4%
Engineering and Rural Buildings (Clyde ck40 325kW boilers)		
	Boiler 1	*Boiler 2*
Efficiency	62.3%	72.1%

Table 5: Efficiencies of main and engineering boilers

With this system in place, the heating is currently set to start operating at 7am every weekday morning and deactivate in the evening at 7pm. However, the heating times may be altered when there are night classes on that can run up to 10pm. The heating is activated during these times when the outside temperature sensors give a reading of less than 18°C. It is also activated when the outside temperature is 3°C or below, in order to prevent frost building up in the system. In the summer period, the heating system runs under a summer schedule where it is only switched on between 6.30am and 10am to heat the rooms in the campus slightly. The building spaces are heated to between 22-24°C depending on the building and the room. The heating system is shut down during the weekends due to the college being closed. The BEMS does not control the lighting in the campus buildings. The management of lighting systems is carried out manually in the buildings.

The BEMS system had data logged for around fifteen months in a database for the Facilities Building. However, there was a much shorter period logged for the Rural Development and Engineering Buildings. For these two buildings, only six months worth of data were logged.

A survey of the outside temperature sensors showed some interesting observations. It was seen that two of the three temperature sensors were positioned in shaded, north facing walls. However, the remaining outside temperature sensor was noticed to be in a position that can potentially have a detrimental effect on readings. This sensor is positioned in a corner just off the flue ducts from the main boiler room on the Facilities Building, facing west. This clearly is not an ideal area to situate a temperature sensor as heat radiating from the flue ducts can affect the readings. This will result in the temperature sensor not giving a true reading of outside temperature which can affect the building management system. Figure 9 illustrates the positioning of the discussed outside temperature sensor. This finding is similar to issues found by Donald (2010) which cites poorly positioned sensors that can adversely affect energy consumption.

Figure 9: Outside temperature sensor situated too close to flue exhaust pipe from boiler house

The possibility of issues with this temperature sensor was validated when a comparison of data gathered from the BEMS of the three outside temperature sensors was performed. The results of this comparison can be seen in Figure 10. The comparisons were carried out over a ten day period in May where the temperature fluctuates near the boiler set point temperature of 18°C. It can be seen that there were large anomalies with the facilities outdoor temperature sensor which was found to be placed next to the boiler flue exhaust. It was seen that there was a 7-9°C difference at peak temperatures between the Facilities outside air temperature sensor and the others. This would obviously affect the energy usage of the college. This issue should lower the energy consumption of the building. This is due the issue causing a higher temperature reading than the true reading. It should be expected that the heating system will shut down at a lower temperature than the set point temperature, resulting in lower energy consumption. This could explain the over projection in heating use in the campus energy prediction.

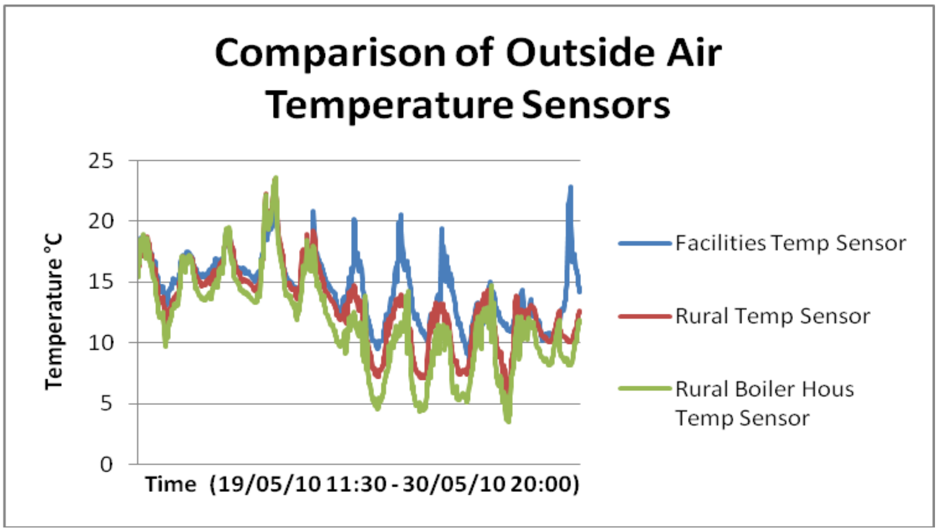

Figure 10: Comparison of the three outside air temperature sensors of the campus.

It was also seen in the BEMS data analysis that, the rooms that had internal space temperature sensors in the Engineering Building, was shown to be susceptible to overheating. This was seen to be the case in all four rooms in the Engineering Building recorded values of up to 29°C. This confirms the issues of overheating with the results of the POE questionnaires from the Engineering Building occupants and EPC data. CIBSE (Chartered Institution of Building Services Engineers. 2006) have recommended comfort criteria of 21-23°C for internal space temperatures in teaching spaces. It can be seen in Figure 11, that the Drawing Room and Electrical Installations classroom are susceptible to consistent high temperatures and has to be addressed. However, data was not available to verify the low temperatures that are experienced in the winter months in the cold periods from the POE.

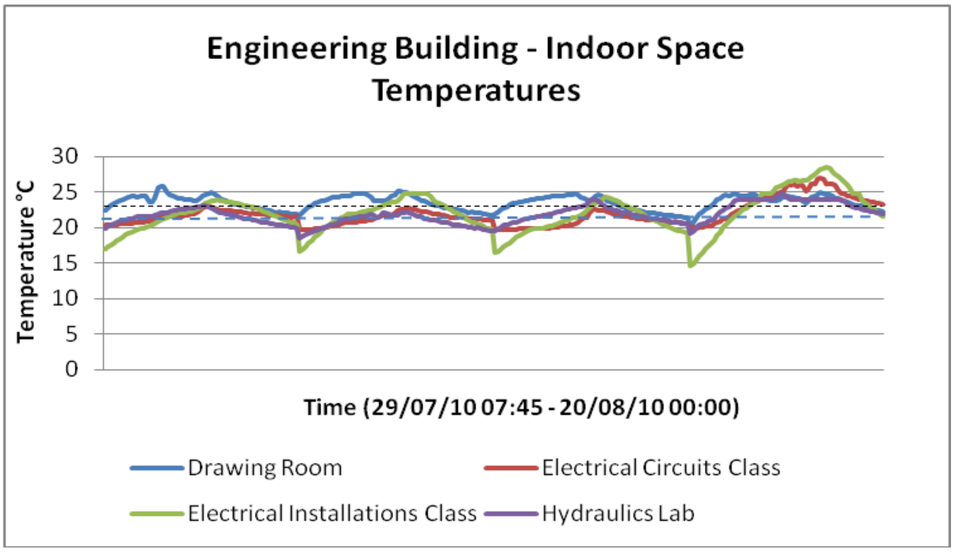

Figure 11: Indoor temperature comparisons in the Engineering Building. Dashed lines shows recommended minimum and maximum space temperatures

It was seen by analysing the BEMS system schematics that the temperature of the inflow and return flows of the heating system where very similar. This suggests that the pump flow rates are far too high and it was observed the pumps run at a fixed flow rate. This results in more work for the system meaning more energy being used. The BEMS data also showed that the flow and return temperatures do not reach the desired optimum temperature difference. An example of this can be seen in Figure 12, where the return and flow temperatures of the pipes servicing the heating system in the Rural Building are compared. It can be seen that the temperature difference in the flow rates were consistently around 4°C. As mentioned before, the difference should be around 10-12°C. Fitting a variable speed drive to the pumps can help in reaching this goal and will be one of the recommendations made for the College.

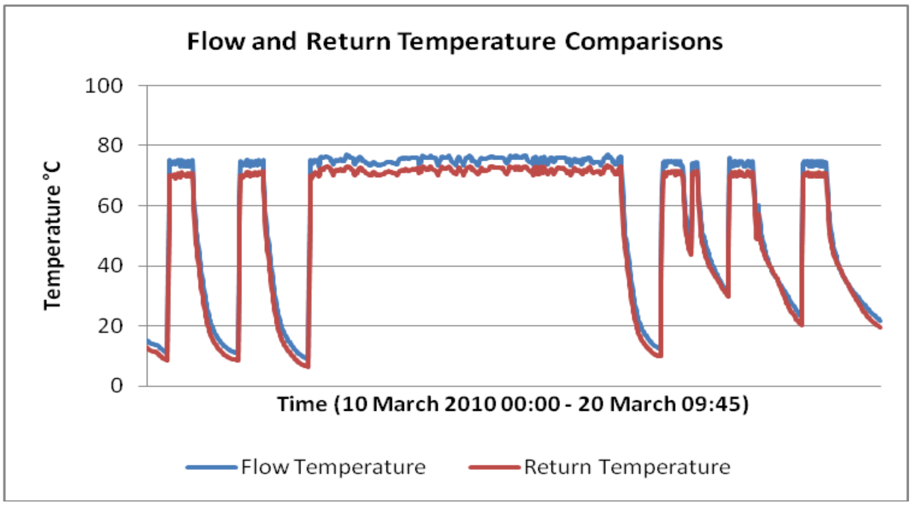

Figure 12: Flow and return boiler pipe temperature comparisons for the rural building

7.2 Post Occupancy Evaluation

The post occupancy questionnaire produced some interesting results. There were 25 questionnaires returned for the whole campus. The majority of the questionnaires received were from the Facilities Building and the Rural Development building. These were mainly from the support and research employees that remained in the college through the summer break.

7.2.1 General Results

In general, the results of the post occupancy questionnaire showed that the occupants were content with the conditions in the campus. Aspects such as humidity, comfort levels and natural and artificial lighting levels were satisfactory in the eyes of the participants. Through a visual inspection around the three buildings, it was observed that the BEMS had very little control over heating and ventilation. There were a large number of rooms that still had the heating on all day during the summer months even though the rooms were not in use. The full results of the POE questionnaires can be found in Appendix G of this report.

7.2.2 Engineering Building

The Engineering Building produced the most issues when it came to occupant comfort. The majority of the responses in the Engineering block, from the comments section of the questionnaire or through informal discussion with participants, suggest that the building was too cold in the winter, and in the summer, was prone to overheating. Several of the participants of the survey disclosed that there were a number of instances where lectures were being taught with the whole class wearing scarves and hats to keep warm. One of the main reasons for this internal temperature issue is the fibreglass and pyramid glass roof in the building, which can be seen in Figure 12. This causes a problem as in the winter a lot of heat is lost through the roof through conductive heat losses, yet in summer it will cause higher solar gains in the building. Another interesting observation was found in the questionnaire results. It was seen that all of the Engineering Block participants said that they had no control over heating at all. A visual inspection of the rooms in the building was indicative of poor thermal comfort. There was seen to be a number of convective heaters dispersed around the building, especially in the joinery department, also seen in Figure 13. As the inspection was carried out in the summer, it was seen that several of the shutter doors and external doors were left open. This was more prominent on sunny days where the building overheats due to high solar gains. This, again, indicates that the occupant answers hold true. The ceiling radiant heating panels in the rooms in this building seem to still be running throughout the day. Of course, this is a major problem as regards to energy usage. Not only is there no control of the radiant panels through the BEMS system but also heat lost to the suspended ceiling it is fixed to.

Clearly, the Engineering Building is a building with great thermal issues. With such heat loss problems in cold weather and convective heaters adding to the electrical load, it should be expected that both predicted heating and electrical load would be lower than actual usage. However, this was not the case and will be analysed further into this report.

Figure 13: Engineering Building glass/fibreglass roof (left) and use of electrical convective heaters (right)

7.2.3 Rural Development Building

The Rural Development Building also showed some interesting results. It was seen from the questionnaire answers for this building, the majority of the occupants were happy with the thermal comfort throughout the year. However, there were a number of participants that suggested that the temperature was far too warm in the summer. Further investigations showed that these occupants were situated on the upper floor of this building. It was seen through visual inspections of the rooms these participants occupy, that there was a heat pipe that runs along the length of the rooms upstairs, shown in Figure 14. This pipe will not cause issues in the winter; however, it can generate overheating in the rooms in the summer. Another aspect that was noted from the visual inspection of the building was that most of the building has a suspended ceiling. This may cause problems with heat losses through the ceiling and roof as there are a few gaps in the suspended ceiling tiles which were not fitted properly.

Figure 14: Heating pipe running along the upper floor of the Rural Building

7.2.4 Facilities Building

The Facilities Building had slightly different issues with thermal comfort. From the questionnaire results, the thermal comfort showed a variation for both the summer and winter results. The results could be justified by looking at further comments that were completed by some of the participants of the questionnaire in this building. The issue arises from the large open plan offices in this building housing the administration staff. This is due to having numerous staff members in these open plan offices having different preferences in temperatures for the room. This was seen to result in conflicts amongst the staff on what the optimal space temperature should be. There were also a number of comments regarding the size of the offices. The observation was that the offices were too large resulting in difficulties in sustaining a constant temperature throughout the room. Temperatures varied around the room with cold and hot areas, resulting in poor comfort levels. It was also noticed that the library also had ceiling radiators installed, similar to the radiators found in the Engineering Building. Results of thermal comfort in all three campus buildings can be seen in Figure 15.

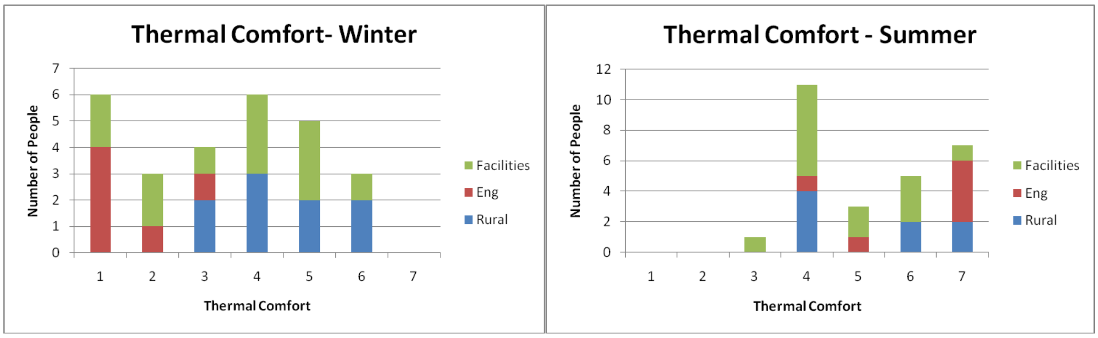

Figure 15: Thermal comfort level results from questionnaire (1- too cold, 7- too hot)

7.3. Thermal Imaging Survey

7.3.1 Internal Thermal Imaging Survey

The thermal imaging survey on the internal spaces resulted in interesting areas to investigate. Most of the experiments in building spaces in all three campus buildings were carried out with conjunction of the blower door testing kit and convective heaters that were already on campus. It was seen from the results that there was a mix bag of results. It was important to be able to distinguish between convective and conductive heat losses. Figure 16 show the distinction between the two. The top right image shows an example of convective heat loss where air leakage is prominent in a poorly sealed window frame. The bottom right picture depicts an example of conductive heat loss. The difference can be clearly seen; with conductive heat loss the colder area takes the shape of the window frame, whereas with conductive heat loss the temperature drop is created around the window frame due to the air movement.

In the classrooms in the Engineering Building, there were a number of areas that were a cause for concern in terms of heat losses. It was seen that in one of the classrooms in this building, E005, there were leakages occurring through poor workmanship. It was seen that there was air escaping through cracks in some surface joins within the building space envelope, such as with floor skirting or walls. In addition, it was seen that there was an issue with leakages occurring from poor airtightness in windows and doors in the room. An example of both areas of air leakages found can be seen in Figure 16. The results from other classrooms in this building and the other campus buildings showed similar problematic airtightness results to E005.

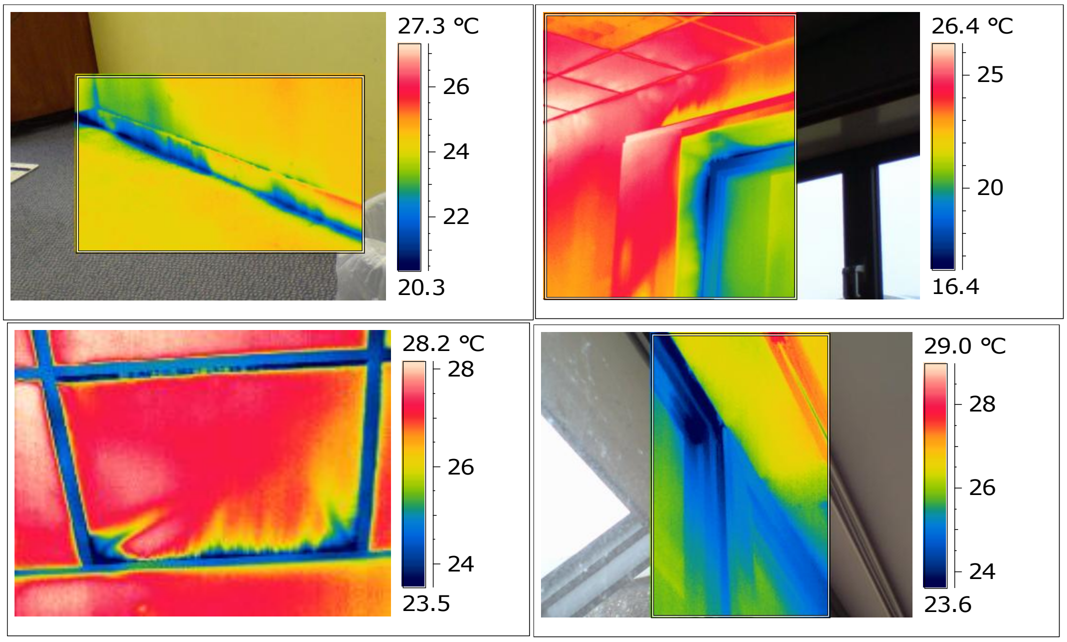

Figure 16: Examples of heat losses identified through internal thermal imaging survey carried out in conjunction with the blower door kit

The Facilities Building also showed aspects of poor workmanship through analysis of the surveys. Again, there was seen to be leakages occurring in the rooms. It was observed that there were losses occurring from some window and door frames. There were also losses from skirting boards and some wall joins observed from the testing.

Poor workmanship was also seen with the ceiling tiles in the suspended ceiling in all three buildings. It was seen from the internal thermal imaging survey that most rooms had poorly fitted or broken ceiling tiles. The bottom left picture in Figure 16 illustrates such a ceiling tile. This would invariably cause heat losses into the roof, especially in the winter. This issue could be easily addressed and rectified with little cost.

7.3.2 External Thermal Imaging Survey

Thermal imaging surveys carried out externally on the campus buildings produced some interesting results. It was seen that during the bank holiday weekend, when the College was closed, that the Air Handling Unit (AHU) was still in operation at the beginning of the holiday. This can be observed in Figure 17 which shows the AHU on in the roof of the C block of the facilities building emitting heat, indicating it is still in operation during this time.

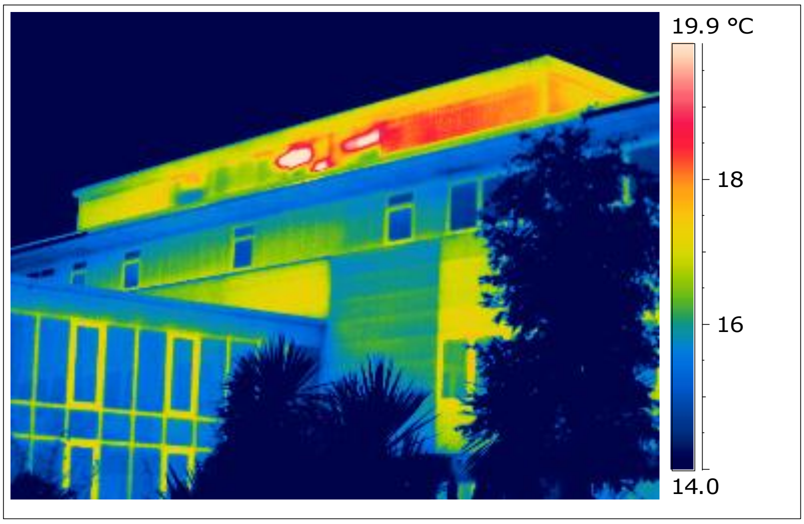

Figure 17: Thermal image of AHU during the bank holiday

It was noticed that the Engineering and Rural Development Buildings both had ventilation systems running throughout the long weekend. There were two small vents that were still running on the front and back of the Engineering Building, one of which shown in Figure 18, and a vent running at the back of the Rural Development Building. It was also observed in the Engineering Building that there were two classrooms that seemed to be warmer than the rest of the building. This seems to suggest that the ceiling radiators were on at the time.

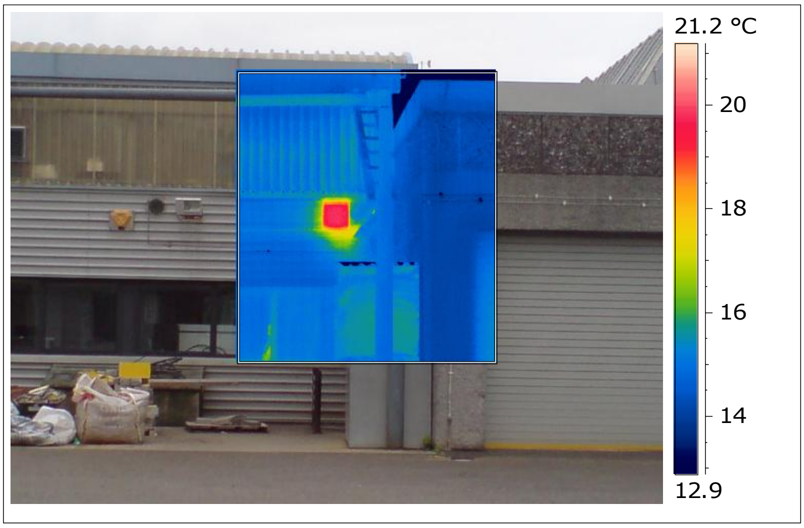

Figure 18: Exhaust vents still in operation during the bank holiday

There was an anomaly with one of the windows radiating more heat than the others in the rest in the Rural Development Building. On closer inspection, it was seen the window was from the server room which suggests the servers were on for the four days the College was closed which would require cooling.

Thermal images for the campus buildings had previously been carried out in colder weather giving a clearer indication of the thermal characteristics of the building. It was seen through analysing the images, that there are a few instances where thermal bridges are evident. This can be seen in Figure 19, where a thermal bridge is illustrated between the Engineering Building and the D Block of the Facilities Building. As it can be seen, there is a large area of heat loss where the roof areas of the two buildings join. These images were captured when the building was occupied and with the heating on.

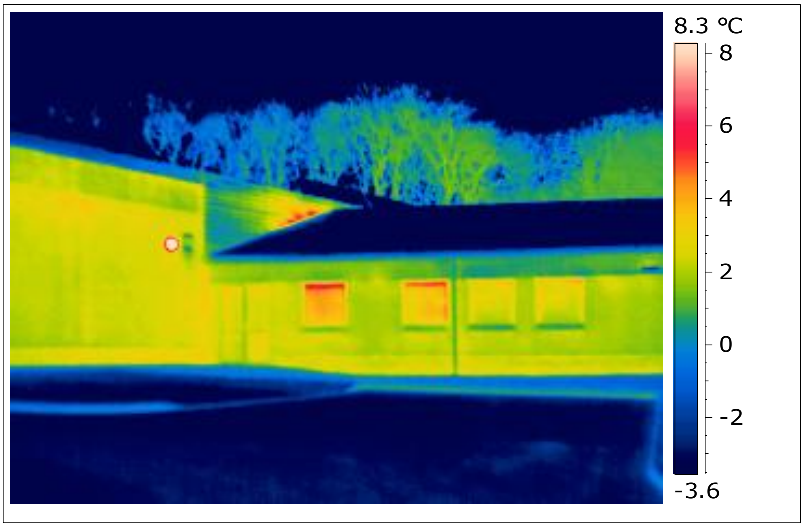

Figure 19: Winter images showing thermal bridges clearly between joining roofs of Engineering and Facilities Buildings

7.4. Air Pressure Testing

As mentioned previously, the air pressure testing could not be carried out on the whole buildings in the campus. The testing was attempted on the whole Engineering Building but the fan was not powerful enough to facilitate this. However, tests were carried out on an engineering classroom with an external door. From this test it is possible to gain the façade leakage of the room and obtain estimation for the whole building.

The results from the automated step down depressurisation test of room E005 of the Engineering Building can be seen in Figure 20. The results show that, at 50Pa, the air permeability of the room was $20m^3h^{-1}m^{-2}$ (where the area of the E005 room is $150m^2$). This value is above the upper limit of ATTMA building standards (ATTMA 2006) and the CIBSE good practise guidelines (Chartered Institution of Building Services Engineers. 2000) which states $10m^3h^{-1}m^{-2}$ air leakage as the standard. It is assumed for the purposes of the modelling that the Engineering Building has the same air leakage value. However, there are problems making this assumption as it may not be indicative of how air tight the whole building is and if the rest of the rooms in the building have similar air tightness. Therefore, it would be recommended that, if possible, to obtain larger equipment that could facilitate air pressure testing of the whole building.

Tests were also carried out in a small area of the Rural Building that had an external doorway. This produced a result of $9.25m^3h^{-1}m^{-2}$ which is less than the recommended standard indicating that this space was reasonably airtight.

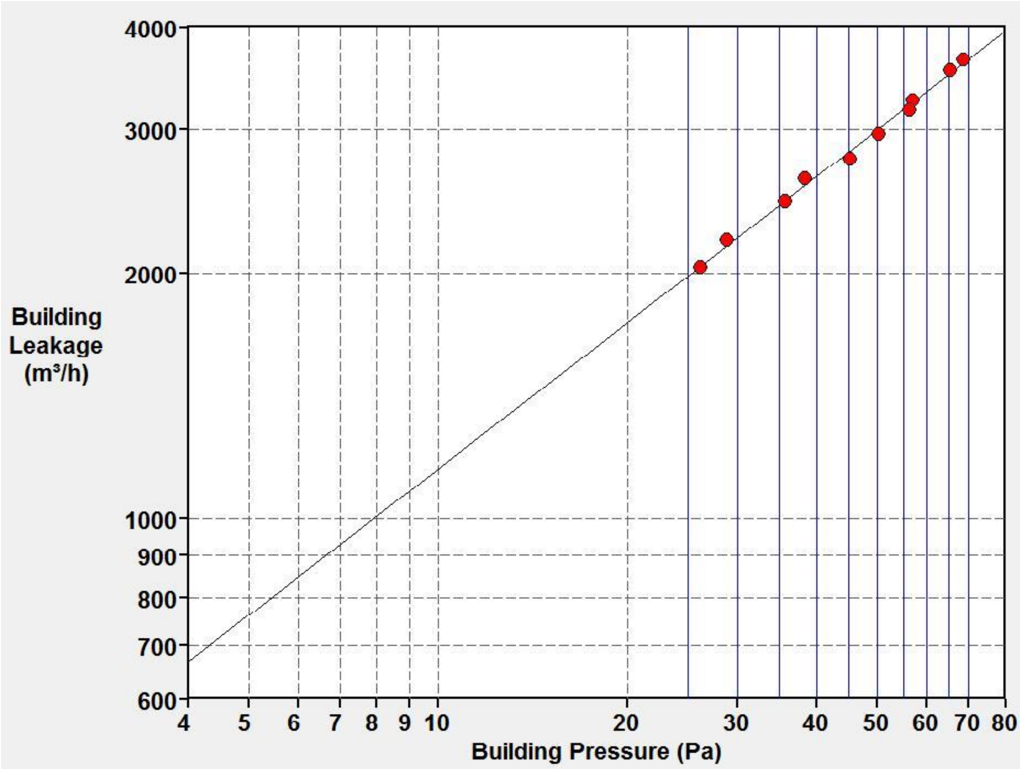

Figure 20: Results from TECTITE automated step down testing

The internal air pressure testing carried out in conjunction with the internal thermal imaging surveys, also found interesting results in the college library. Poor workmanship was seen in one of the windowsills above one of the radiators. There was an open gap that ran along the length of the windowsill that would produce substantial air leakages in the room. It would also result in heat losses, especially as the gap is situated right above a radiator. Other rooms in the campus buildings also showed areas of loss which have already been outlined in the thermal imaging results section.

7.5. SBEM Sensitivity Assessment

The results from the investigations of the modelling highlight some of the limitations in the SBEM tool that was used to carry out the EPC calculations. Although the program gives an option of optimisation of HVAC systems, it does not allow the user to specify the set times that are currently in place for operation. Nor does the program allow the user to specify the temperature that the building, or zones in the building, has been set to maintain internally or the external temperature the system is set to operate from. On top of this, as mentioned previously, a considerable pitfall of the SBEM program is that it only provides one weather data set (Glasgow) for the whole of Scotland.

The current EPCs were carried out in an older version of the SBEM program (v3.4a). It was decided to rerun the models in the latest version of the SBEM program, version v3.5a. Prior to running it in the newest version the NCT files were converted to be able to be rerun in SBEM v3.5a. Running it in the SBEM v3.5a was important as changes in the program were made from previous versions. These modifications that can affect the campus building EPC calculations include (NCM 2010):

- Frame factors for window and roof lights that can affect solar gain calculations.
- Modified calculation for hot water storage size and storage losses. These will affect water heating calculations.
- Correction of auxiliary energy costs to fan heaters.
- New adjacency for envelopes has been added to allow a better assessment of thermal mass of internal envelopes contained within a zone formed by merging of two or more neighbouring zones.

It was observed through the sensitivity study, that there were a number of discrepancies with the inputs in SBEM for the campus EPCs. It was noticed that the newly obtained U-values (Vögler et al 2010) showed different U-values to the original values that were input into the program. It was also noticed, by going through the activities assigned to building spaces, that there were some spaces that were allocated the wrong activity. An example of this was with the facilities building where the library was allocated as a bathroom. This may have been a mistake when carrying out the calculations and the allocation being omitted as a bathroom is the default assigned activity. There were a few other occasions where more apt building space activities could be assigned.

It was also noted that the original EPCs for the three buildings were carried out using natural ventilation. This was due to there not being an option in the iSBEM program to choose ‘central heating using radiators: water with mechanical ventilation’. From the studies carried out in this report, this was not seen to be the case. As a result, mechanical ventilation was added to all the building zones individually that had ventilation systems servicing them.

The results of the sensitivity study carried out on the Engineering Building can be seen in Table 6. The results of the sensitivity study showed the same trends for all the three campus buildings. Running the model under the new version of SBEM, version 3.5a, it was seen that there is a lower value being obtained. Further investigations showed the main reason behind this was that the equipment values were omitted from the overall energy calculations. It can be noted that the U-value alteration gave the largest change in energy usage. The infiltration rate and building space activity allocation changes showed relatively small changes in energy use compared to the original values. Changes to take into account mechanical ventilation in the facilities building, it can be seen that this raises the energy usage which is to be expected.

Alteration	Original Value (kWh/m^2)	New value (kWh/m^2)
Re-run of Buildings on SBEM version 3.5a	173	150
Building space activity assignment alterations	150	148
Addition of mechanical ventilation in relevant building spaces (Using SBEM default values)	150	169
Replacing U-values with more accurate figures for all constructions in the model	150	144
Altering existing air permeability of building by adding 5 $m^3h^{-1}m^{-2}$ to default value	150	156
Altering existing air permeability of building by subtracting 5 $m^3h^{-1}m^{-2}$ to default value	150	144
Building Orientation Change (0° to 180°)	150	150

Table 6: SBEM sensitivity assessment results (For Facilities Building)

7.5.1 Comparisons of New EPC Data to Actual Data

The values from the original and new EPC outputs from the sensitivity study can be seen in Table 7. It was observed that, with the new EPC results, that the predicted energy was significantly lower than the original values. Overall, it can be seen from the results that, for the whole campus, the new prediction of energy use is 25% lower than the original EPC prediction. The new prediction for the whole campus regarding CO_2 emissions produced a similar trend with a 22% reduction from the original EPC data.

When comparing the values, it is clear that the Engineering Block produced the biggest difference. Both the Facilities and the Rural Development Building also showed a significant drop in energy usage. It was seen that both the Engineering and Rural Development Buildings gained a higher rating from the changes, moving from G to F and D to C respectively.

It was found the main reason that the new EPC results are lower was due to the U-value changes. It was seen that the assumed U-values did not accurately represent some of the building constructions. This was most prominent in the glass/fibreglass roof in the Engineering Building. The difference in U-values, of assumed and calculated, was also seen to be high in some cavity wall constructions and floors. Validating and altering building space activity in the program reduced the energy use in the buildings by a small amount. Aspects, such as adding mechanical ventilation to the model and altering air permeability, would have increased the energy use of the buildings.

Campus building	Original EPC Annual Values		New EPC Annual Values	
	Energy use (kWh/m^2)	CO_2 emissions ($kgCO_2/m^2$)	Energy use (kWh/m^2)	CO_2 emissions ($kgCO_2/m^2$)
Engineering	448	126	321	93
Facilities	173	53	133	43
Rural Development	156	46	128	39
Whole Campus	249	73	186	57

Table 7: Comparisons between original EPCs and new EPC values from sensitivity study

The new values obtained from the EPCs in the sensitivity study were then compared to the actual usage to gauge if it is performing to expectations. The same comparisons were made as with the original EPC data. It was observed from this comparison that there was a marked improvement in terms of matching predicted and actual energy usage compared to the original predicted EPC values.

It was noted, with the new detailed EPC results, that the electrical usage was now under-predicted by nearly 10% compared to the actual energy use. This was a change of an over-prediction from the original EPC data. However, the oil usage prediction from the new simulations showed that it was still being over-predicted, by 22%, compared to actual heating data. Despite this, the new predicted heating loads are lower than that of the original prediction figures. The new prediction produces a value of 411.12kWh/HDD, which is 54.9kWh/HDD more than is actually being used. This is a dramatic improvement to the original prediction. It has to be noted that the occupancy levels in the SBEM database would be higher than those of the actual campus building. This would mean, overall; the actual energy usage should be lower than that of the SBEM predictions. This conclusion seem to match well with Egan (2009) who regarded occupancy levels as one of the reasons that discrepancies occur between predicted and actual energy use. The comparisons of the new and original predicted energy use to the actual energy usage can be seen in graphical form in Figure 21.

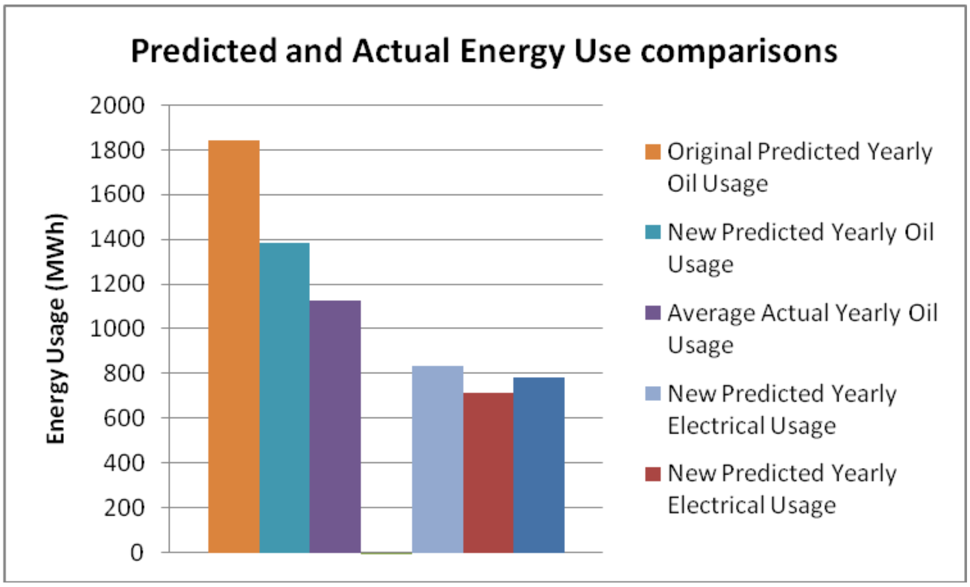

Figure 21: Annual comparisons of energy usage (by fuel type) of original and new EPC values with actual usage

An analysis was carried out for comparisons of the new predicted and actual monthly electrical usage. The results of the comparisons are illustrated in Figure 22. It can be seen that with the new prediction, the new electrical usage prediction is much lower than the actual usage in the winter months. This is most prominent between the months of November to March. This meets expectation as there was seen to be a fair number of convective heaters being used in the Engineering Building to keep occupants warm. This would undoubtly mean a higher electrical consumption would be evident, especially in the winter months. As with the original comparison, there is an over-prediction in the summer months, especially in July, where occupancy levels are extremely low.

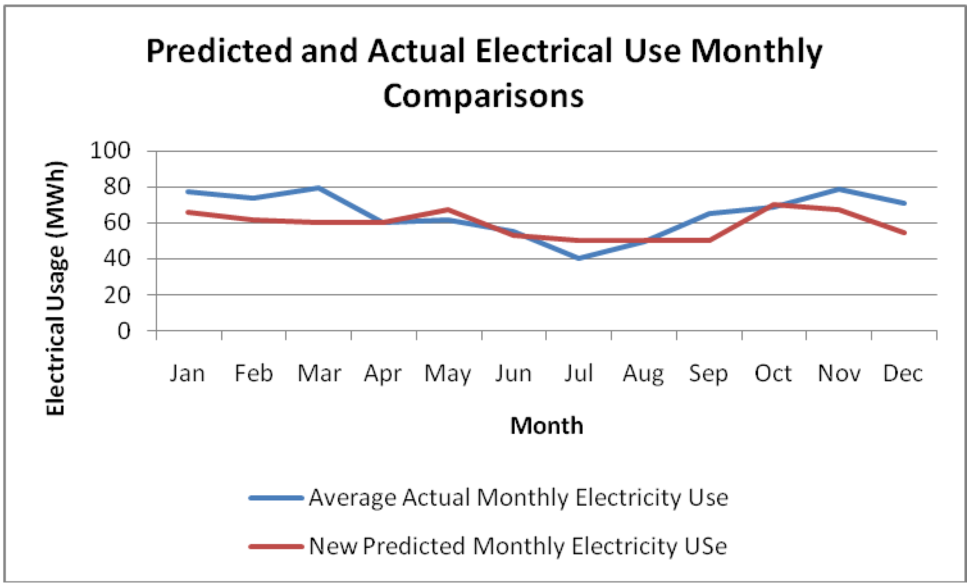

Figure 22: Monthly electrical usage comparisons between new predicted and actual usage

These new EPC values are from initial studies still have to be verified. A more detailed analysis has to be carried out to ascertain the right U-values and to check the correct assignment of materials have been given to building structures in the building model.

7.6 Further Analysis

For further analysis of the campus buildings, the CIBSE TM22 energy assessment and reporting procedure was carried out (J Field & Chartered Institution of Building Services Engineers. 2006). This TM22 procedure allows comparisons to benchmark buildings and actual energy usage. It is based on the ECON 19 analysis for office buildings (UK Government Energy Efficiency Best Practice Guide 2000) and also PROBE investigations. However, with the TM22 procedure it allows a more detailed analysis of buildings. It is possible to analyse multiple zones and buildings in this procedure and gives a breakdown of the different areas of energy use in the buildings; such as lighting, heating and ventilation, in relation to actual usage inputs. The procedure will then compare the actual usage to good practice and typical buildings of the same type.

7.6.1 TM22 Analysis

The TM22 procedure (J Field & Chartered Institution of Building Services Engineers. 2006) was carried out for the Lews Castle College Campus. The exercise of the TM22 procedure was to compare the energy use of the campus to rough benchmarks to see how it was performing. For the TM22 procedure for the campus, the multi-zone system assessment option was chosen to be carried out. Three zones were added for each campus building being regarded as one building. The areas of the campus buildings were then entered into each relevant zone assignment. The Engineering Block was assigned as a light manufacturing building whilst the Rural Development and Facilities Building were assigned as offices with mechanical ventilation. Adjustments were made to the building's energy use assumptions with actual gathered data to gain a more valid and accurate comparison to the benchmarks. Changes were made to the number of computer workstations in the building zones, from a count that had already been carried out on the campus. The occupancy periods were also changed to a more appropriate level for the college buildings. Finally, the heating degree days value was altered to the correct value for the campus and location.

7.6.2 Results of TM22 Analysis

The results of the TM22 analysis showed that the College performed just below a typical building. It also showed that the campus buildings were required to significantly improve energy efficiency to reach the good practice benchmark in the TM22 procedure. The results of the detailed TM22 analysis can be found in Figure 23.

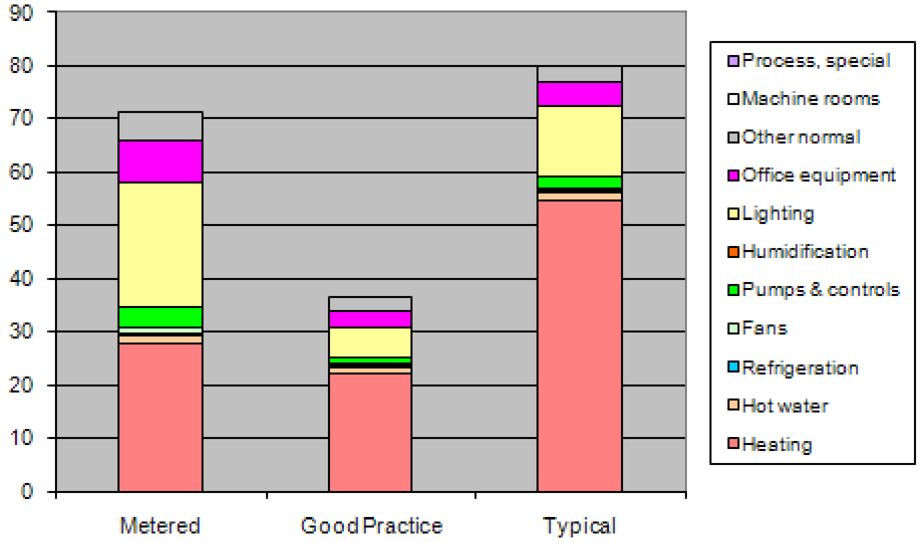

Figure 23: TM22 detailed results for actual usage compared to benchmarks for CO_2 emissions (in $kgCO_2/m^2$ of gross internal floor area)

8. Methodology for Analysing Actual and Predicted Energy Usage

As mentioned in the aims of this thesis, a methodology to find discrepancies between predicted and actual energy use in a buildings was one of the main objectives. This section details the methodology that has been produced through this project.

The methodology can be illustrated in a flowchart in Figure 24. This flowchart is a simplified step by step guide on how to tackle discrepancies between predicted and measured energy usage.

8.1 Initial Steps

The first step is to obtain the EPC data for the relevant buildings and the energy bills. If there is detailed BEMS data logged and available for energy usage around the building, then this would be even better for identifying areas of discrepancy. Data from the energy bills and the BEMS have to be converted to the relevant units in the EPC. This would require converting usage to kWh/m^2 and requiring floor area of the building in order to carry this out. Comparisons also have to be made in terms of CO_2 emissions. For this, CO_2 factors can be found from resources, such as the Carbon Trust (Carbon Trust 2005), for the fuel(s) that are being used in the building(s).

It has to be noted that, ideally, as detailed actual usage that could be possibly obtained should be used for the comparison. This is so that any discrepancies that occur can be pinpointed to an area of the building(s), whereby testing can be taken and recommendations made. With actual energy use deduced mainly from energy bills, most of the recommendations will be fairly generalised for the building(s).

The EPC results will not only produce the energy certificates, but also a breakdown of various aspects of energy usage in monthly steps which can be found in the SBEM sim.csv files. If possible, a breakdown of the average monthly energy usage in terms of electrical and heating usage, for a reasonable amount of time of about 5 years, for the building(s) should be carried out. These could then be plotted against each other illustrating if the energy usage match. This would allow the energy assessor to deduce where and what periods or areas discrepancies occur and to investigate further.

8.2 Investigation Stage

Once the initial analysis is carried out, and the difference of actual and predicted energy usage is established, focus can be turned onto why the discrepancies are occurring.

The first area to look at is a post occupancy survey that should be carried out in order to investigate the building characteristics and the behaviour of the occupants in the building. This is important; especially when measured energy use is higher than predicted energy use, as occupants can often have controls over such aspects as heating in certain building zones. This could have a large impact on energy use in the building(s). A questionnaire and visual inspections around the building(s) would be sufficient to observe the performance of the building in terms of thermal, air quality and lighting comfort. This should give the analyst a good indication of where the possible deficiencies are in terms of energy efficiency. The questionnaire used for this thesis could be used as a template for a POE of the building or, alternatively, there are abundant resources on the internet on the subject. Visual inspections can give clues on how the building is performing. Any additional stand alone heaters or fans in rooms can indicate if a building is not performing properly.

If the building has a BEMS in place, then this is the next area that requires to be looked at as well to find possible discrepancies. The BEMS is not only useful to potentially gather detailed actual energy use, but also is an area where energy inefficiencies could originate. The BEMS has to be looked at in more detail to see if operations are being used optimally. This means investigating the BEMS digitally and analysing the system and its schedules. Optimisation times may differ for different seasonal periods. For example, many buildings have a summer running time where heating may only be activated for several hours a day. Aspects, such as occupancy levels, should be looked at to optimise heat to the building. As well as looking at the BEMS, it is important to carry out an inspection of the HVAC system in the building(s). This is to see if there are any issues deriving from the performance of the system. Discrepancies can occur from a number of sources, such as inefficient or broken systems and conflict in control systems. A survey should also be carried out on sensors around the building(s) as the some could affect the energy usage of the building(s). This is to see if there are discrepancies such as between external temperature sensors that can affect energy performance of the building. Data that is logged from the sensors can be compared to each other to see if there are any discrepancies between them. Similar comparisons can be made to logged data, with the likes of internal temperature systems or pipe flow temperatures, to see if the building or building systems are performing to recommended standards.

The next step of the methodology is to carry out thermal imaging surveys around the building internally, in conjunction with air pressure testing, to give an indication of where heat losses are occurring and assess the quality workmanship in the building spaces. More significantly would be to carry out thermal imaging surveys on the outside of the building(s) to see where heat losses are occurring. Not only this, but an external thermal imaging survey can also be used as an investigation tool. It would be useful to carry out the thermal imaging survey during times of occupancy and building closure to see if the building is performing as expected. However, it is important to carry out the thermal imaging survey when the weather is cold so heat losses can be clearly defined. Once these measurements have been carried out and analysed, recommendations can be made to remedy any issues that occur.

Air pressure testing of the whole building can indicate how airtight the building is in terms of infiltration rates at various pressure differentials. Air pressure testing can be carried out internally of the building as well which shows where air leakages are occurring in individual rooms using smoke visualisation. Again, this test can indicate poor workmanship in building spaces that can result in losses. By carrying out this testing, it is possible to quantify how airtight the building is. The air leakages of the building(s) can then be altered in the EPC tool if it is different to the original value.

The procedure can then move on to the inputs and assumptions that were used in the EPC analysis, on tools such as SBEM or otherwise. If the EPC was carried out in a previous version of the modelling tool, it would be good practice to rerun it in the newest available version as it may affect the comparisons, but not by much. This is especially important when the EPC is depicting higher energy use than the building is actually using, which is the case with Lews Castle College campus. It is important to make sure that the values being entered into the modelling analysis are accurate or reasonable. The climatic data has to be chosen that has the best representation of the location of the building analysed. Assumptions have to be questioned and investigated to see if it is being modelled correctly. These could be any of the following:

- U values of the building materials and constructions
- Heating efficiencies and ventilation
- Optimisation times of heating and cooling
- Infiltration rates
- Assignment of building space activity use

The aspects above could affect the accuracy of energy usage in the building and can result in inaccurate EPCs being produced. This will, in turn, lead to discrepancies to the predicted and actual energy usage comparisons. A new EPC should be generated for the building(s) from this simulation assessment and compared to the original prediction.

8.3 Post Processing Stage

If the difference between the original and new EPC values is significant, then it would be worthwhile to carry out a new comparison with the measured data to see if the energy uses of the building(s) are better matched. The new EPC then has to be verified, to make sure the changes are indeed correct, and new certificates produced.

From the testing and analysis of the building, it should be possible to make recommendations on what improvements are required, or in the case of modelling tools what limitations that can affect energy predictions. Preferably, the recommendations should be split into two categories, short term and long term, and prioritised. This is to allow the client to implement measures that can be cost effective or help efficiency in the building(s)

The results from following this methodology should allow the building energy assessor to identify areas that can cause discrepancies between predicted and measured energy use. Although this method focuses on qualitative data, the outcome of the methodology gives scope to carry out changes to the major areas of energy losses. In addition, this methodology has the added advantage of checking the inputs entered into the simulation program to obtain the EPC for the building(s). With the results, the assessor can then make recommendations on how to improve energy efficiency of the building(s) through. This can be through improvements on the buildings itself, optimisation of systems in the buildings or behavioural education for the building occupants. The improvements can then be implemented in the building.

After a sufficient amount of time, the methodology should be run again with new data to see if the upgrades have improved the match up in predicted and actual energy use. The process can be repeated as many times as deemed necessary.

8.4 Further Analysis Stage

Optional analysis could be carried out using the CIBSE TM22 procedure to see how the building(s) perform under typical and good practice benchmarks for the building types. This will allow comparisons to give an accurate representation on how the building is performing to typical standards in terms of energy use. This procedure is highly recommended to be carried out as it can also show an estimated breakdown of actual usage. In addition, this procedure can be performed after improvements have been made to the building(s) to give an indication of how much has been actually saved.

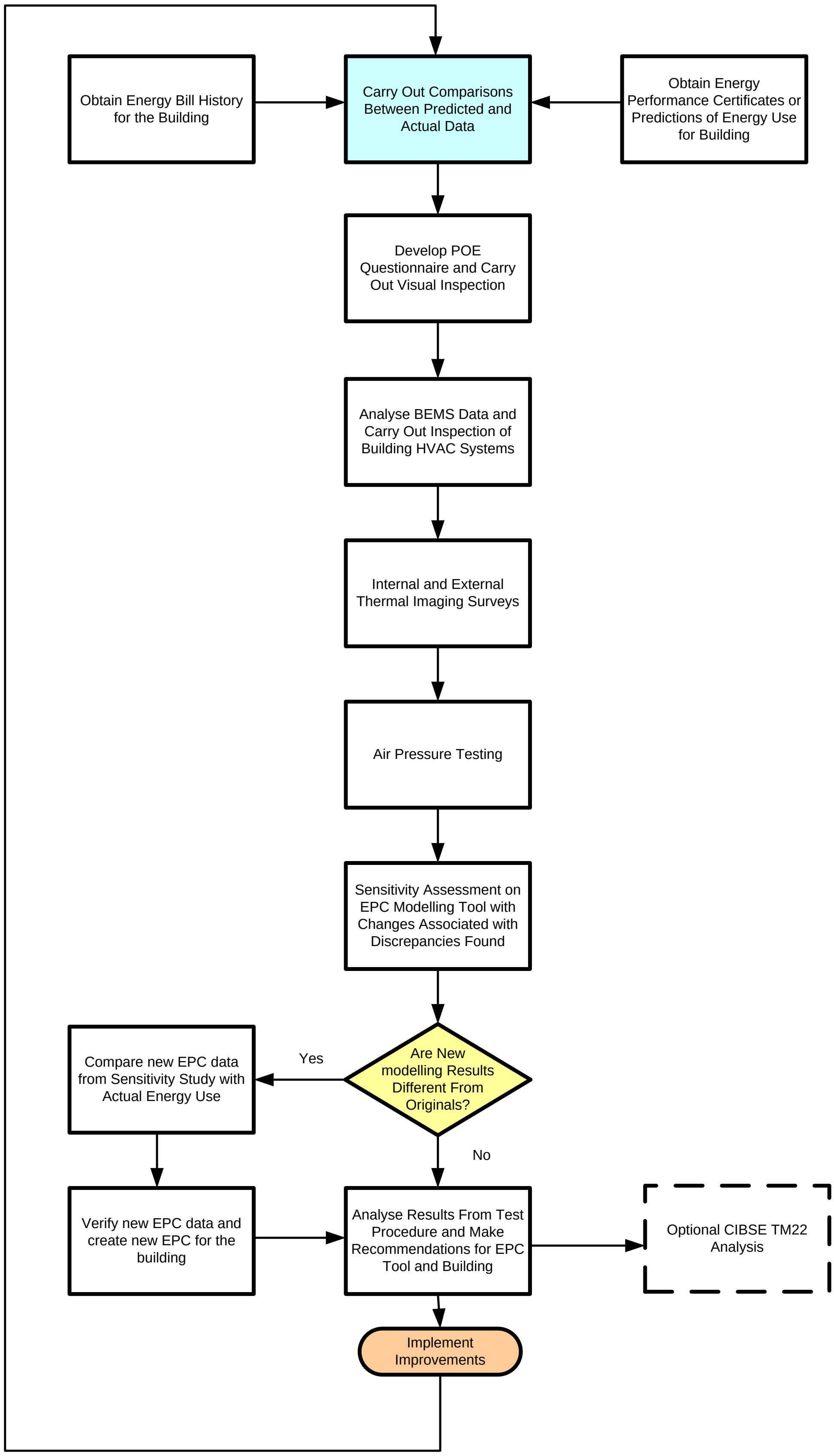

Figure 24: Flowchart illustrating the methodology to identify discrepancies between predicted and actual energy use

9. Recommendations

There have already been recommendations on how the building could be improved suggested by the EPCs. These suggestions include adding time control to the heating system, replacing halogen light bulbs to more energy efficient ones and an efficiency survey on the heat generation system. The EPCs also recommended that some areas of the campus have too much lighting fixtures for a given area and should be reduced. Indeed, visual inspections of this building brought up some observations that could affect energy efficiency. It was seen that, in several corridors in the building, there was over use in lighting in these areas. This is predominant in the Facilities Building, which can be illustrated in Figure 25.

Figure 25: Images of excess lighting in the Facilities Building

It was also recommended that solar control measures, such as shading devices, should be put into place in order to reduce the risk of overheating in areas around the campus, especially in the summer. Priority for solar control measures has to go to the Engineering Block, where it was found solar gains in the summer creates high temperatures in the building due to the glass roof. Consideration should be given to installing mechanical roller blinds on the roofs in order to reduce the risk of overheating. Installation of blinds would have the added advantage of reducing heat losses on cold days by bringing down the flow of air across cold glass.

Recommendations have to be made to the SBEM tool that was being used to calculate the EPC. More climate data for locations, especially Scotland, to be added to the SBEM database must be a priority as it was observed there are a very limited number of locations.

It may be useful to create a model in a more detailed modelling tool, such as ESP-r developed by the University of Strathclyde, to gain a better prediction in terms of energy use in the campus buildings and to verify the EPC results.

9.1 Short Terms Measures

Short term measures to improve energy efficiency, found through the analysis carried out in this report, is to improve airtightness in the campus buildings. This holds true especially for the Engineering and the Facilities Building. It was seen that around these buildings there were issues with workmanship in some areas. This was observed in thermal images on window seals and blower door tests in the rooms indicating leakages in rooms. Replacing poorly fitted ceiling tiles around the campus can help with heat losses throughout the campus. Poor workmanship was also apparent through visual inspections. It was observed that there were large gaps on some doors which would affect energy efficiency. This is illustrated in Figure 26 where the gaps between the doors and the ground are apparent. It was seen that some doors had a gap of up to 20mm from the bottom of the door to the floor. Draughtproofing of these areas should help with energy efficiency with little financial burden.

Figure 26: Image of doors leading from Facilities Building to Engineering Building. Gap from floor to bottom of door is 15mm

Further short term improvements that could be made are to replace the existing lighting, the majority of which is halogen tubes, with LED lighting. This has already been carried out partially on a small proportion of the lighting fixtures around the campus, but the majority have to be changed. This could have a large impact on energy usage; however, the cost of these bulbs is fairly expensive.

A variable speed drive installed in the pumps, which is currently running at a fixed speed, in the heating system would also aid in energy efficiency in the short term. By installing variable speed drives, the flow rates can be optimised in order to gain as much efficiency out of the heating system. This would create an appropriate temperature differential between inflow and return temperatures, between 10-12K, that is not being achieved at present.

9.2 Long Term Measures

Moving onto longer term measures, a major area of improvement that could be carried out on the campus would be to install lighting control. It was seen that corridors and certain rooms, such as toilets, that were not in use regularly often had the lights still running. Of course this would result in issues in energy efficiency which could be easily remedied. Motion sensing light control could be installed in corridors and toilets. Daylight sensing controls could also be placed in office spaces in order to save on energy use from lighting. Improving insulation in the constructions of the campus buildings will also aid better energy performance. Installing cavity wall insulation and insulation on exposed floors will help reduce heating loads.

One of the main challenges that have to be overcome is to utilise the BEMS fully in the campus for the purposes of energy efficiency. Integration of the various systems, such as ventilation and heating, has to be carried out to gain effective control. Currently, there are too many areas of controls of different systems. Algorithms can be produced in order to turn the boiler on at optimum times in the morning. The reason for doing this is that one morning can have very low temperatures requiring more heating to get a space up to temperature. However, the following morning could have very mild temperatures, requiring less heating to get the building space up to temperature. Other aspects that could be integrated into the BEMS to improve efficiency of the HVAC system, is to put in more sensors so that more feedback loops can be put into action. CO_2 sensors can be installed to monitor air quality and the AHU in the buildings setup in the BEMS to operate from the CO_2 readings, which will fluctuate depending on occupancy levels. This will allow zonal control of ventilation and would also be made more efficient with variable speed drives installed. Maintaining and fixing the ventilation systems is also an important recommendation as many have broken fan belts resulting in wasted energy.

Installing Smart meters in the campus buildings can also allow the College to manage its energy usage more efficiently. Work has already started on the looking at installing a number of smart meters in various locations on the campus to monitor energy usage (Vögler et al 2010). These meters could be integrated into the BEMS, where energy usage could be more effectively monitored and control of energy systems can be carried out. This can lead to logged actual usage data that would allow a more detailed and accurate comparison to predicted usage. This, in turn, will enable easier identifications of the areas that cause the mismatches.

All these recommendations should be taken into account in order to try and improve efficiency in the buildings. Training should also be given to occupants in the building on how the BEMS actually works and change their behaviour in terms of energy use in the campus buildings.

"Flow, continual flow, continual change, continual transformation"

Rina Swentzel – Pueblo Indian architectural historian - (Brand 1995)

Table 8 shows estimations of payback periods and possible impact that recommendations, both in the short and long term, made in this report can have on the college buildings. These payback periods were deduced mainly from detailed EPC recommendation output files as well as research into prices and the effectiveness of the technology.

Recommendation	**Payback Period**	**Potential Impact**
Replacing current T8 lamps with T5 conversion kit	Less than 3 years	Medium
Mechanical Blinds or other shading devices on glass/fibreglass roof	Less than 3 years	Medium
Reduce number of light fittings	Less than 3 years	Low
Install SMART meters	Less than 3 years	Low - Medium
Integrating BEMS and optimising control	3-7 years	Medium - High
Install cavity wall insulation	3-7 years	Medium
Secondary glazing for glass/fibreglass roof	3-7 years	Medium
Lighting control	3-7 years	Low – Medium
Replacing boilers for condensing or biomass CHP boilers	7+ years	High
Install insulation to exposed floors	7+ years	Medium

Table 8: Payback periods and possible impact of recommendations made for the College

10. Future Work

There is still much that could be researched in terms of analysis of the campus buildings. Through initial research here improvements of how energy usage is monitored have to be made in order to carry out a thorough comparison of actual and predicted energy use.

10.1 Lews Castle College

Future work for the campus, once recommended improvements have been completed, is to look into the feasibility of renewable means to generate electricity and heat. The college could look into utilising the abundance of natural resources in this area of the UK. The North West of Scotland has been seen to have the highest resources of tidal and wind resources in Europe. Indeed, Greenspace Research is already in the process of carrying out a feasibility study to place wind turbines in open terrain near the campus. This scheme will consist of two 250kW medium scale turbines and a micro scale wind setup consisting of a 6kW and 5kW turbine (Vögler et al 2010). A feasibility study could also be carried out on creating a micro-hydro scheme in the burn that is near campus. This has a head height of 5-10m and would be suitable to generate electricity. Heating the campus is the biggest challenge in terms of energy efficiency of the College building. There are plans to replace the oil 850kW boilers, which are due for replacement in the near future, with a biomass burner fuelled by locally sourced wood chips. A study of producing woodchip fuel has already been looked into and the benefits published (Vögler & Bradley 2009).

10.2 Methodology

In terms of future work on the methodology introduced in this thesis, the primary aim would be to validate it with other similar buildings in and around Scotland. This is to see if the methodology is suitable and to ascertain if there should be any alterations made as it is in the initial stages. Further work has to be carried out in the air pressure testing in the methodology. Further to this, the methodology can be used in other building types, such as supermarkets and office buildings, to gauge its effectiveness. There could be scope to carry out a more in depth look into identifying and quantifying thermal losses by using test procedures such as the STEM (Short Term Energy Modelling) method. The STEM method can be integrated in with the investigation stage and would involve gathering relevant data by excitations to the building, which includes;

- Co-heating test to obtain overall heat loss coefficients
- Cooling test to obtain heat capacitance
- Floating temperature test to obtain the effect of solar energy to the building with opaque and transparent surfaces
- Measurement of solar energy and other meteorological variables
- Air pressure testing

(Judkoff et al. 2000)

This methodology can be carried out with and without the HVAC system operating to see how much influence the HVAC system has. The gathering of data should take three days and can be analysed through energy balance equations. The STEM method would be important to integrate into the current methodology, as it is mainly qualitative and the STEM method will add some quantitative results in the assessment of discrepancies. Further future work could include modifying the methodology so that it can be applied to warmer climates.

11. Conclusions

11.1 Case Study Conclusion

In terms of drawing conclusions on the case study, it was seen that there are large scope to improve efficiencies of the Lews Castle College campus buildings. Initial analysis showed that the energy predictions vastly over projected heating use in the campus. However, after a sensitivity study carried out on the campus EPCs, run through SBEM, the over projection still occurred, but was much lower. The electrical usage showed to match more to in line with expectations after investigations of the campus and carrying out a sensitivity study was carried out in the SBEM prediction tool.

From thermal imaging and post occupancy evaluations, it was seen that utilising the BEMS system to maximise its full potential is an important aspect to investigate. It was seen that there were too many conflicting systems vying for control in the building and better integration of the system has to be carried out. It was also seen in the investigations that the Engineering Building produces the largest problem when addressing energy efficiency. Improvements were recommended to improve the airtightness of the building, such as through draft proofing of doors, suspended ceiling tiles and windows, as well as dealing with the heat losses and gains associated with the glass and fibreglass roof.

The analysis of the EPC simulation model, SBEM, showed that the program has its limitations. It was found that the tool relies on broad assumptions to produce EPCs. This is to allow comparisons to be made with buildings of similar types and location. However, it was seen in this report that some of the assumptions were too broad. The most significant issue is that there is only one set of climate data, Glasgow, which covers the whole of Scotland. This poses a problem especially when carrying out simulations in the North of Scotland where the temperature can be several degrees below Glasgow and experience higher wind loads. It was recommended in this report to possibly use a more detailed modelling program, such as ESP-r, to verify and gain more accurate predictions.

11.2 Methodology Conclusions

Looking retrospectively at the methodology for identifying discrepancies between predicted and actual energy use, this main objective has been completed. The methodology was produced from the analysis carried out on Lews Castle College. The methodology still, however, needs work to be carried out on it. The methodology still has to be verified to see if it produces results for similar and different non domestic building types. In addition, it is yet to be seen how powerful this methodology is when detailed actual energy use is used. As the methodology is in its early stages, there will be modifications and improvements that may have to be made to it as it progresses. Such modifications are to try and quantify the losses and discrepancies as the method outlined in this report is very much qualitative. Other alterations to the methodology include adding more testing procedures, such as incorporating the STEM procedure, or to modify it to be used in different climates around the world.

Energy efficiency is no longer an optional extra in buildings - it has now become a basic requirement. In developing this methodology for this thesis, it is hoped that it will aid in understanding and improving building performance of non domestic buildings. In addition, it is hoped that the results of running the methodology will make people and occupants realise the importance of energy efficiency.

"There is no energy crisis, only a crisis of ignorance"

- R. Buckminster Fuller (1895-1983) *American Architect, Inventor, Futurist*

"The cheapest energy is the energy you don't use in the first place."

- Sheryl Crow (1962- Present) *American Singer/Songwriter*

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Appendix

Appendix A - Climate and Heating Degree Days Graphs

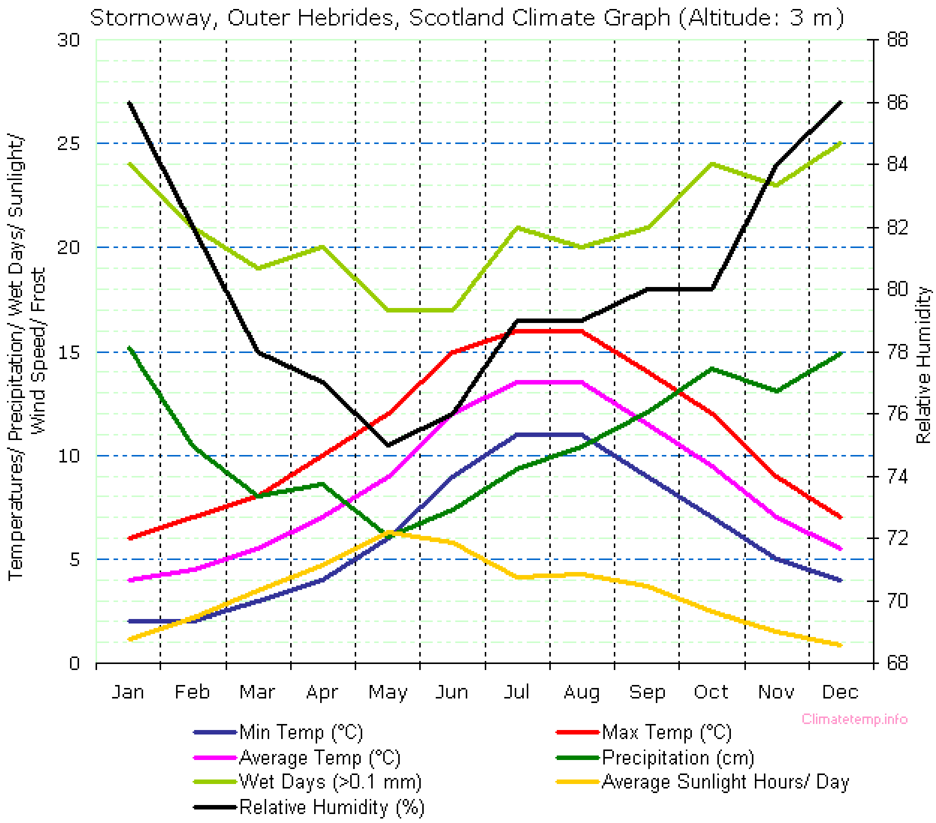

Figure A-1: Climate Data for Stornoway, Scotland. Taken from www.climatetemp.info

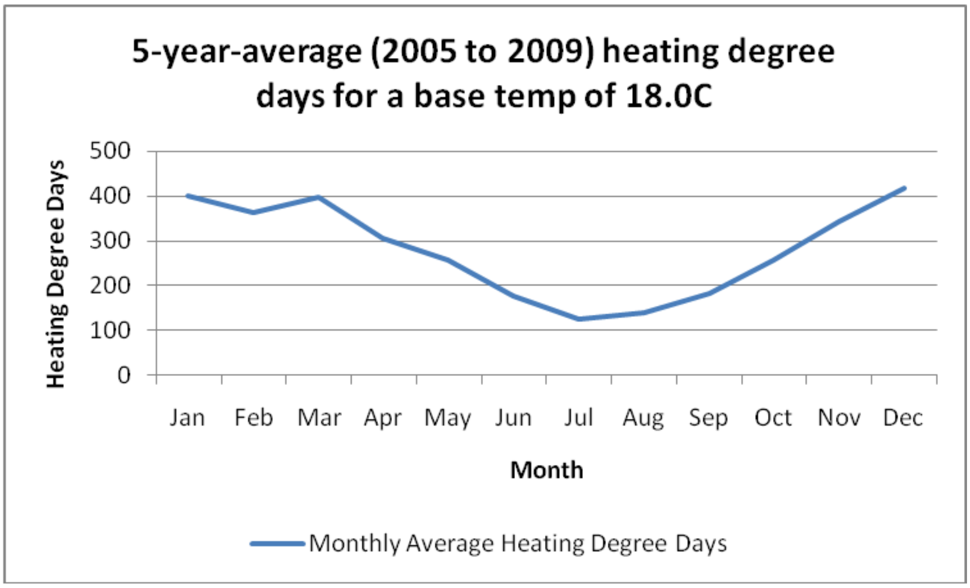

Figure A 2: Heating Degree Days (HDD) for Stornoway with base temperature of 18°C

Appendix B – Building Plans

Figure B-1: Building Plans for Lower Floor (Top Image) and Top Floor (Bottom Image) of Engineering Building

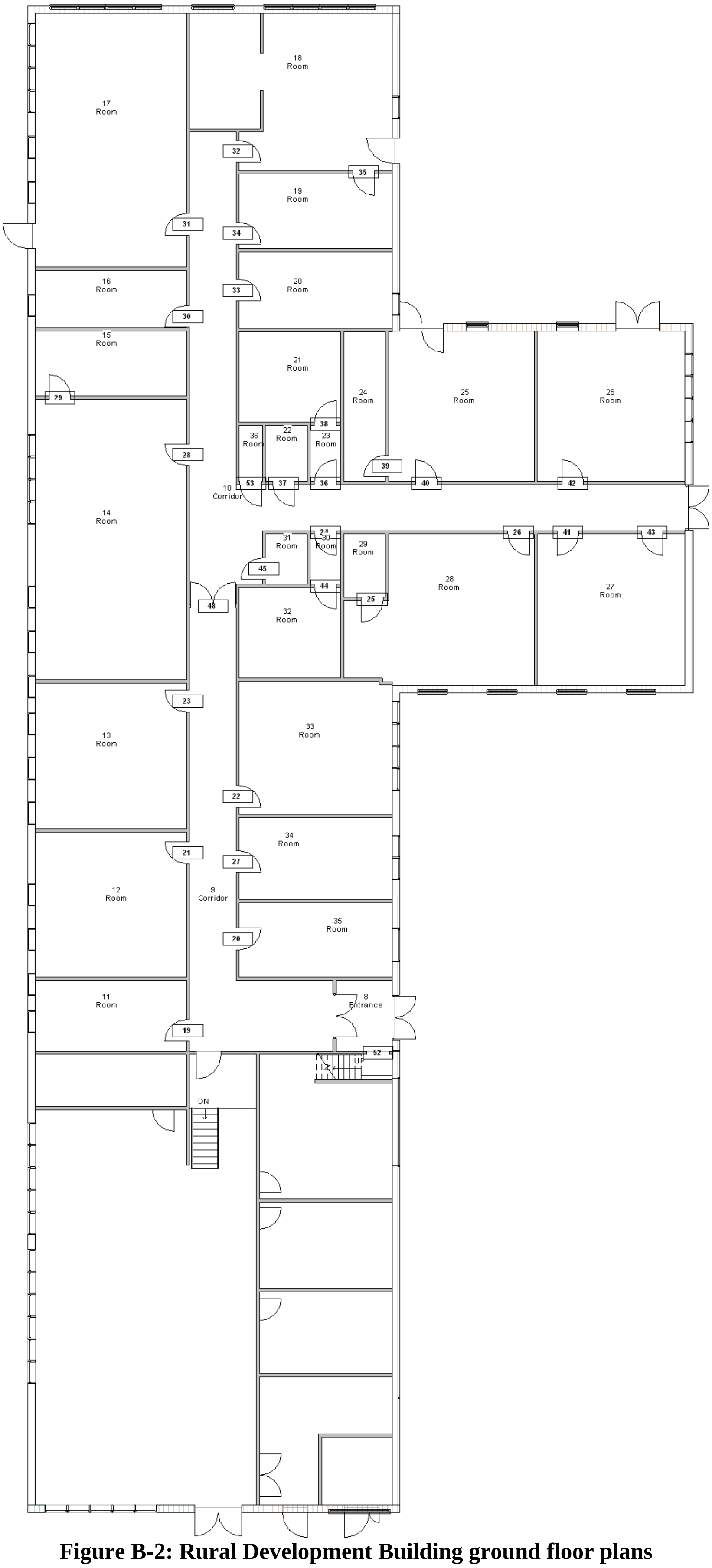

Figure B-2: Rural Development Building ground floor plans

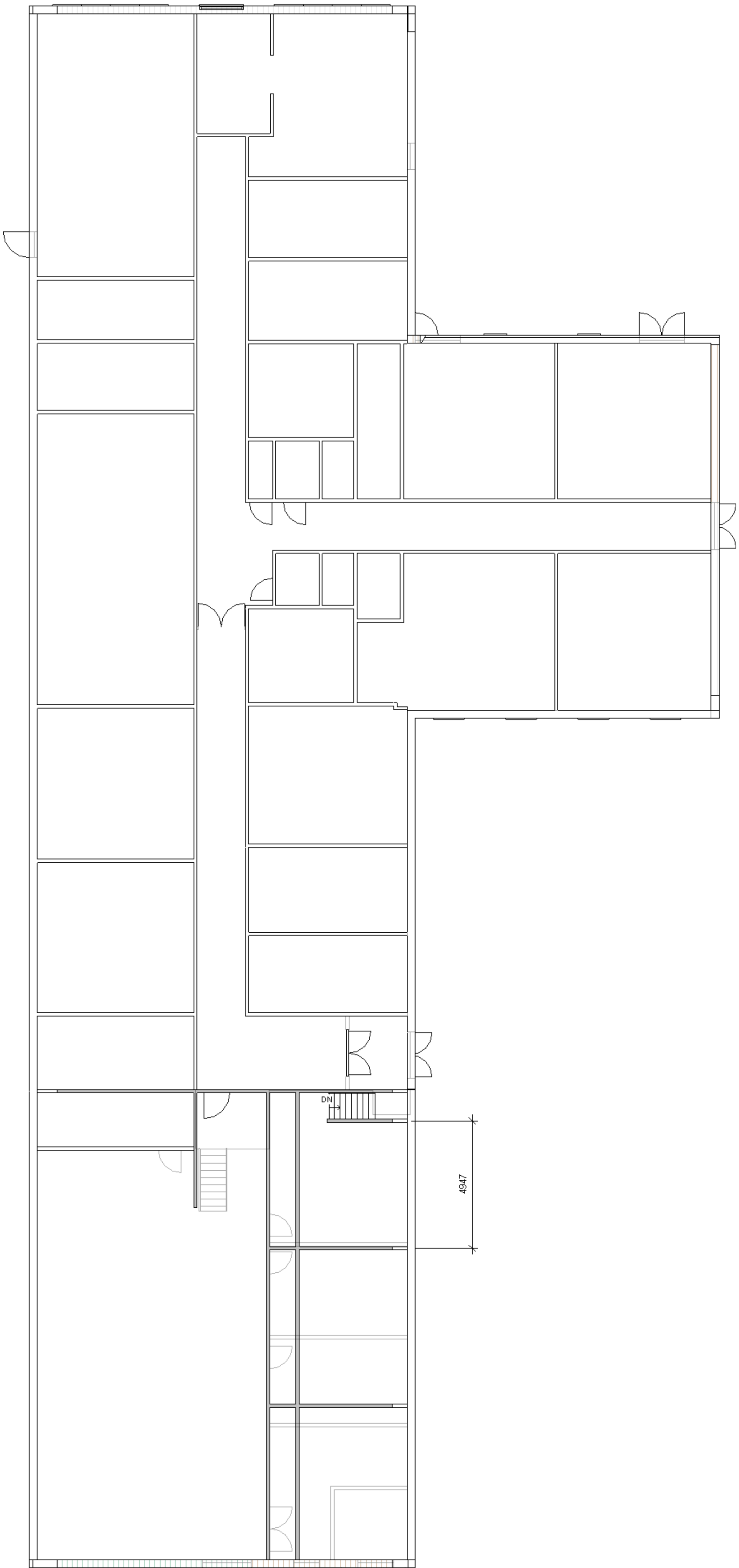

Figure B-3: Rural Development Building top floor plans

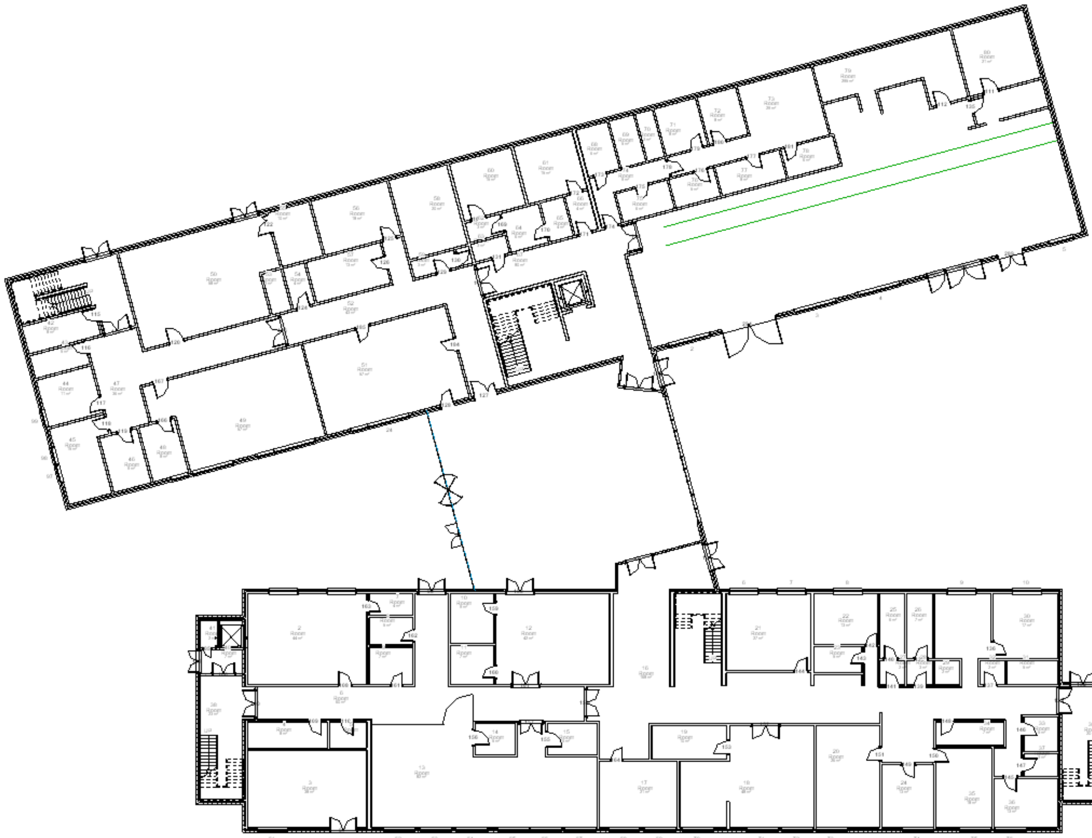

Figure B-4: Facilities Building ground floor plans

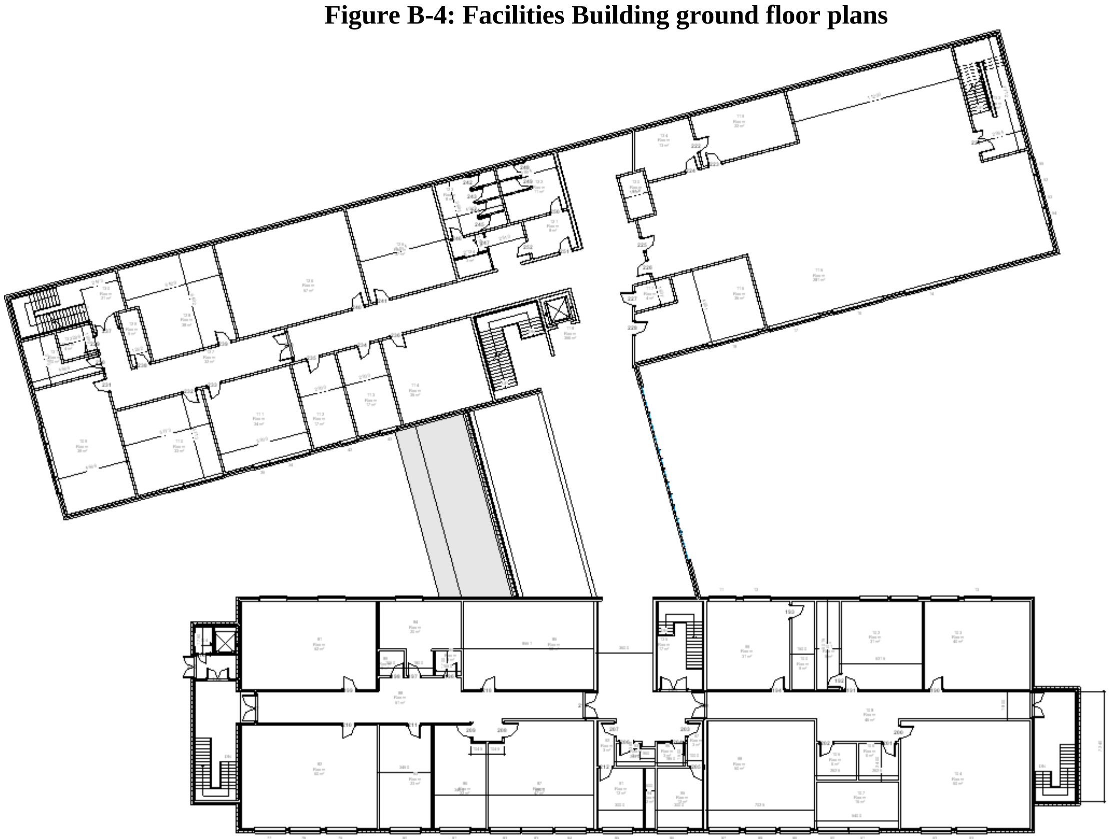

Figure B-5: Facilities Building 1st floor plans

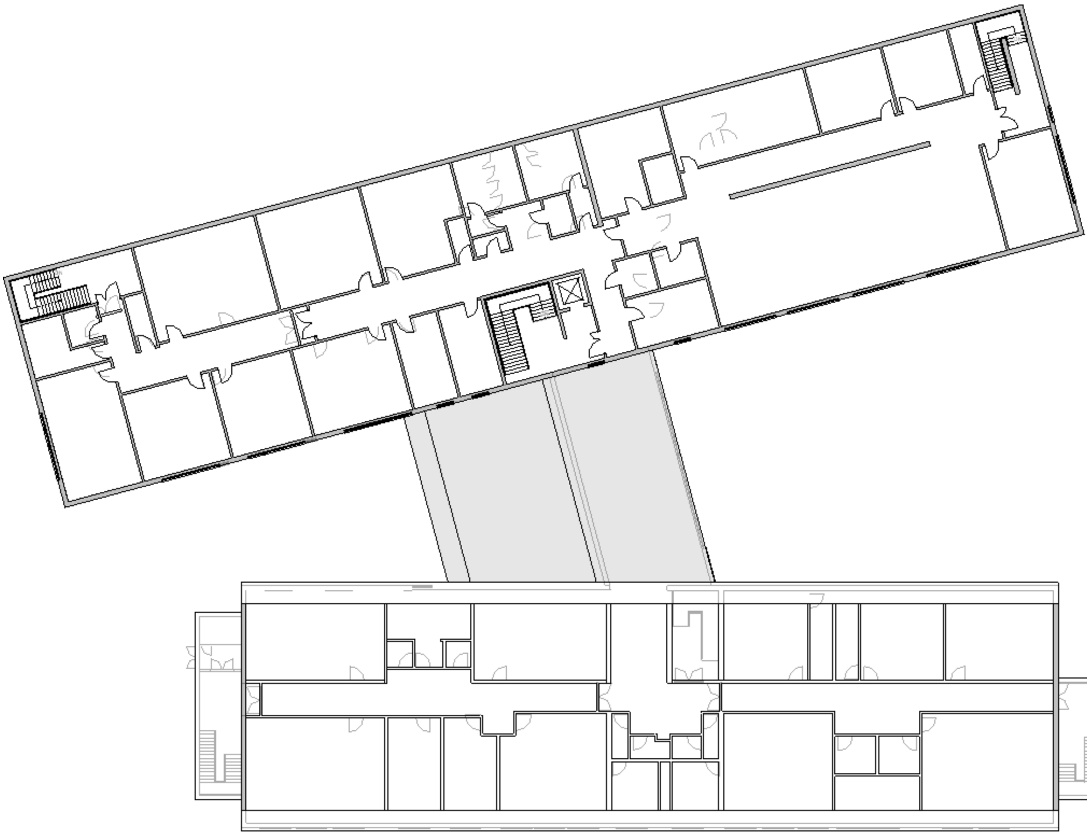

Figure B-6: Facilities Building top floor

Appendix C – Energy Performance Certificates

Energy Performance Certificate for buildings other than dwellings

Energy Performance Certificate

Building Energy Performance | **Scotland**

Calculated asset rating using iSBEM v3.4.a [SBEM]	Building type Further education universities	Current rating

Excellent

Carbon Neutral

A (0 to 15)

B (16 to 30)

C (31 to 45)

D (46 to 60)

E (61 to 80)

F (81 to 100)

G (100+)

Current rating: **G** Very Poor

Carbon Dioxide Emissions The number refers to the calculated carbon dioxide emissions in terms of kg per m² of floor area per year	**126**
Approximate current energy use per m² of floor area:	**448** kWh/m²

Main heating fuel: Oil **Building Services:** Heating with Nat. Vent.

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

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

Benchmarks

A building of this type built to building regulations standards current at the date of issue of this certificate would have a rating:	30	**B**
Where the accompanying recommendations for the cost effective improvement of energy performance are applied, this building would have a rating:	83	**F+**

Recommendations for the cost-effective improvement (lower cost measures) of the energy performance

1. Consider replacing T8 lamps with retrofit T5 conversion kit.

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

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

4. Add optimum start/stop to the heating system.

5. Some walls have uninsulated cavities - introduce cavity wall insulation.

6. Some windows have high U-values - consider installing secondary glazing.

Address: Engineering Block, Lews Castle College, Stornoway, Isle of Lewis, HS2 0XR
Conditioned area (m^2): 2928
Name of protocol organisation: CIBSE Certification Ltd, [LCEA029636]
Date of issue of certificate: 31 Jul 2009 (Valid for a period not exceeding 10 years)
This certificate is a requirement of EU Directive 2002/91/EC on the energy performance of buildings.

NB THIS CERTIFICATE MUST BE AFFIXED TO THE BUILDING AND NOT REMOVED UNLESS REPLACED WITH AN UPDATED VERSION AND FOR PUBLIC BUILDINGS DISPLAYED IN A PROMINENT PLACE

Figure C-1: Energy Performance Certificate for Engineering Building

Energy Performance Certificate for buildings other than dwellings

Building Energy Performance — Scotland

Energy Performance Certificate

Calculated asset rating using iSBEM v3.4.a [SBEM]	Building type Further education universities	**Current rating**

Excellent

Carbon Neutral

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

Very Poor

Carbon Dioxide Emissions The number refers to the calculated carbon dioxide emissions in terms of kg per m² of floor area per year	**53**
Approximate current energy use per m² of floor area:	**173** kWh/m²

Main heating fuel: Oil **Building Services:** Heating with Nat. Vent.

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

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

Benchmarks

A building of this type built to building regulations standards current at the date of issue of this certificate would have a rating:	32	C+
Where the accompanying recommendations for the cost effective improvement of energy performance are applied, this building would have a rating:	49	D+

Recommendations for the cost-effective improvement (lower cost measures) of the energy performance

1. Consider replacing T8 lamps with retrofit T5 conversion kit.
2. Some spaces have a significant risk of overheating. Consider solar control measures such as the application of reflective coating or shading devices to windows.
3. Introduce HF (high frequency) ballasts for fluorescent tubes: Reduced number of fittings required.
4. Add optimum start/stop to the heating system.
5. Some walls have uninsulated cavities - introduce cavity wall insulation.
6. Add local time control to heating system.

Address: Facilities Building, Lews Castle College, Stornoway, Isle of Lewis, HS2 0XR
Conditioned area (m²): 4965
Name of protocol organisation: CIBSE Certification Ltd, [LCEA029636]
Date of issue of certificate: 10 Aug 2009 (Valid for a period not exceeding 10 years)
This certificate is a requirement of EU Directive 2002/91/EC on the energy performance of buildings.
NB THIS CERTIFICATE MUST BE AFFIXED TO THE BUILDING AND NOT REMOVED UNLESS REPLACED WITH AN UPDATED VERSION AND FOR PUBLIC BUILDINGS DISPLAYED IN A PROMINENT PLACE

Figure C-2: Energy Performance Certificate for Facilities Building

Energy Performance Certificate for buildings other than dwellings

Energy Performance Certificate

Building Energy Performance — Scotland

Calculated asset rating using iSBEM v3.4.a [SBEM]	Building type Further education universities	Current rating
Carbon Neutral		Excellent
A (0 to 15)		
B (16 to 30)		
C (31 to 45)		
D (46 to 60)		D+
E (61 to 80)		
F (81 to 100)		
G (100+)		Very Poor

Carbon Dioxide Emissions
The number refers to the calculated carbon dioxide emissions in terms of kg per m² of floor area per year — **46**

Approximate current energy use per m² of floor area: **156** kWh/m²

Main heating fuel: Oil
Renewable energy source:
Building Services: Heating with Nat. Vent.
Electricity: Grid supplied

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

Benchmarks

A building of this type built to building regulations standards current at the date of issue of this certificate would have a rating:	29	B
Where the accompanying recommendations for the cost effective improvement of energy performance are applied, this building would have a rating:	37	C+

Recommendations for the cost-effective improvement (lower cost measures) of the energy performance

1. Some spaces have a significant risk of overheating. Consider solar control measures such as the application of reflective coating or shading devices to windows.
2. Consider replacing T8 lamps with retrofit T5 conversion kit.
3. Add optimum start/stop to the heating system.
4. Some walls have uninsulated cavities - introduce cavity wall insulation.
5. Introduce HF (high frequency) ballasts for fluorescent tubes: Reduced number of fittings required.
6. Add local time control to heating system.

Address: Rural Building, Lews Castle College, Stornoway, Isle of Lewis, HS2 0XR
Conditioned area (m²): 2237
Name of protocol organisation: CIBSE Certification Ltd, [LCEA029636]
Date of issue of certificate: 31 Jul 2009 (Valid for a period not exceeding 10 years)
This certificate is a requirement of EU Directive 2002/91/EC on the energy performance of buildings.
NB THIS CERTIFICATE MUST BE AFFIXED TO THE BUILDING AND NOT REMOVED UNLESS REPLACED WITH AN UPDATED VERSION AND FOR PUBLIC BUILDINGS DISPLAYED IN A PROMINENT PLACE

Figure C-3: Energy Performance Certificates for the Rural Development Building

Appendix D – Actual Energy Usage

Actual Energy Use

Period	Grid Electricity	Electricity CO2	Electricity (kWh/m2)	Oil used (litres)	Oil (kWh)	Oil (kWh/m2)	Oil CO2	Total Energy Used	Total CO2	Energy kWh/m2	CO2 kg/m2 per annum	Cost Oil (£)	Cost Elec (£)	Cost Oil (£/m2)	Cost Elec (£/m2)	Average unit cost per kWh (oil)	Average unit cost per kWh (elec)	Ratio oil/total kWh
2004-2005	816667.8	444267.3	80.8582	134000	1380200	151.8372	340909.4	2196868	785176.7	217.5117	77.7403	39505.78	44241.06	4.346	4.86700	0.028623	0.05417	0.628258105
2005-2006	843923.4	459094.3	92.84086	124000	1277200	140.5061	315468.4	2121123	774562.7	210.0122	76.6894	47960.85	76975.23	5.276	8.46812	0.037552	0.09121	0.602133756
2006-2007	777823.4	423135.9	85.56913	110800	1141240	125.549	281886.3	1919063	705022.2	190.0063	69.8042	43747.99	66556.76	4.813	7.32198	0.038334	0.08557	0.594685929
2007-2008	786332.3	427764.8	86.5052	119800	1233940	135.747	304783.2	2020272	732548	200.0270	72.5295	62644.42	68834.34	6.892	7.57253	0.050768	0.08754	0.610779052
2008-2009	678854.1	369296.6	74.68142	92600	953780	104.9263	235583.7	1632634	604880.3	161.6469	59.8891	43785.15	58697.59	4.817	6.45738	0.045907	0.08647	0.584197035
Average	780720.2	424711.8	84.09096	116240	1197272	131.7131	295726.2	1977992	720438	195.8408	71.3305	47528.838	63060.996	5.229	6.93740	0.040237	0.08099	0.604010775

Figure D-1: Actual energy use summary over a 5 year period

Appendix E – BEMS Schematics

Facilities Building

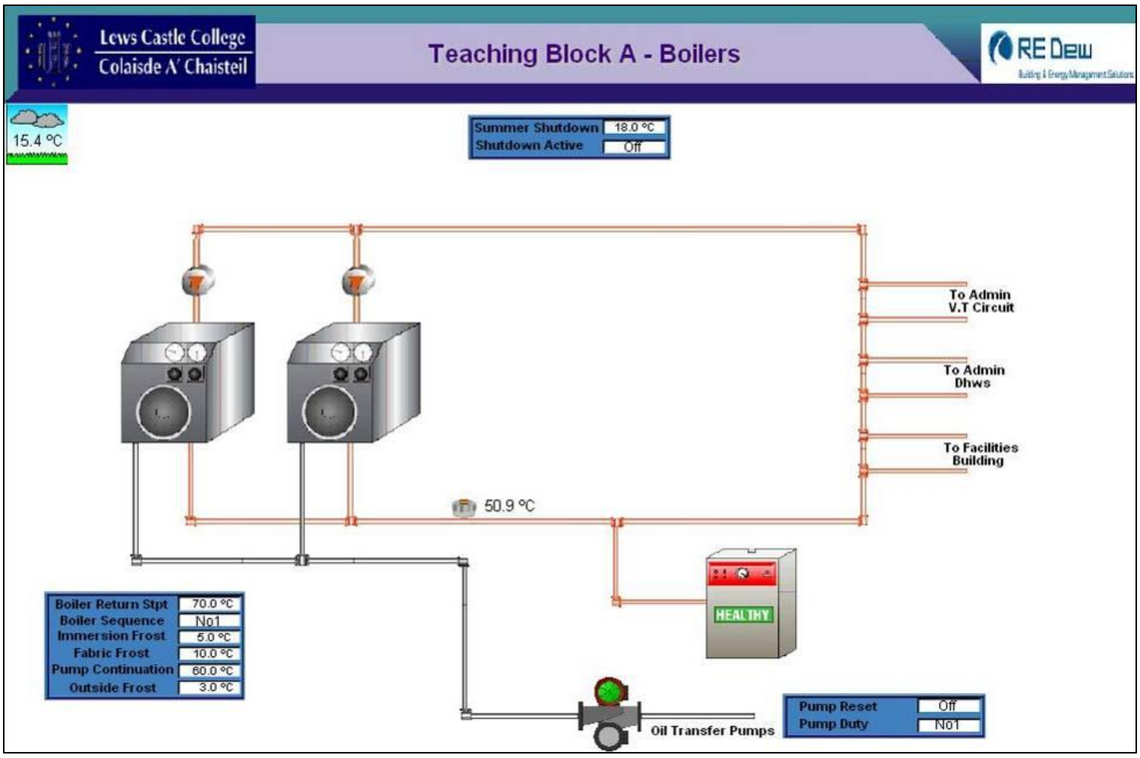

Figure E-1: Facilities boiler room

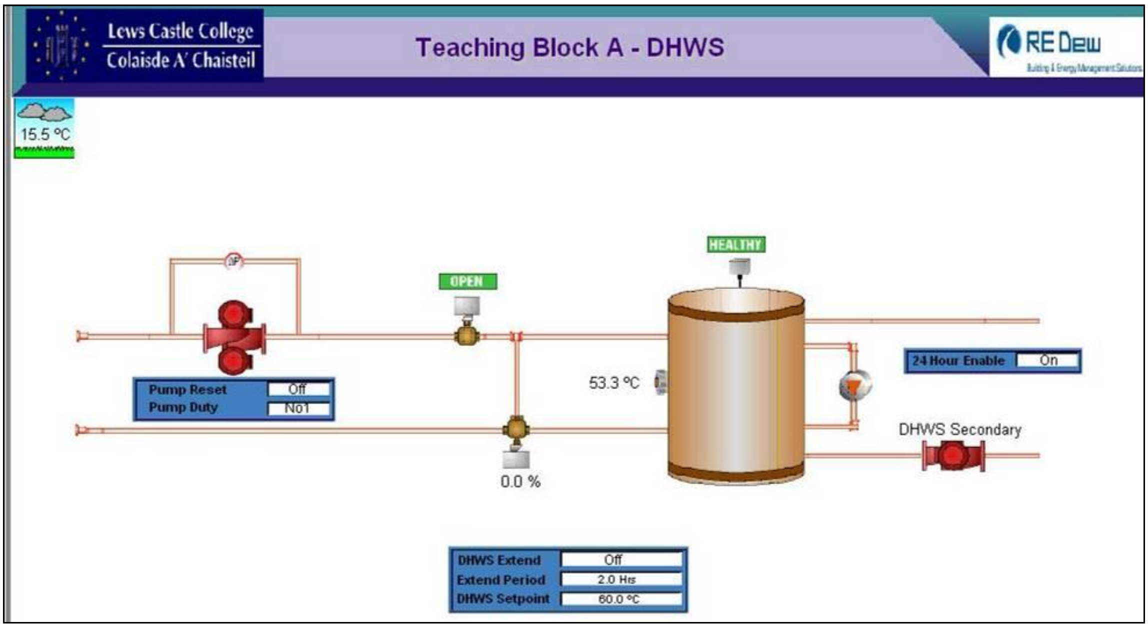

Figure E-2: Facilities hot water system (Block A)

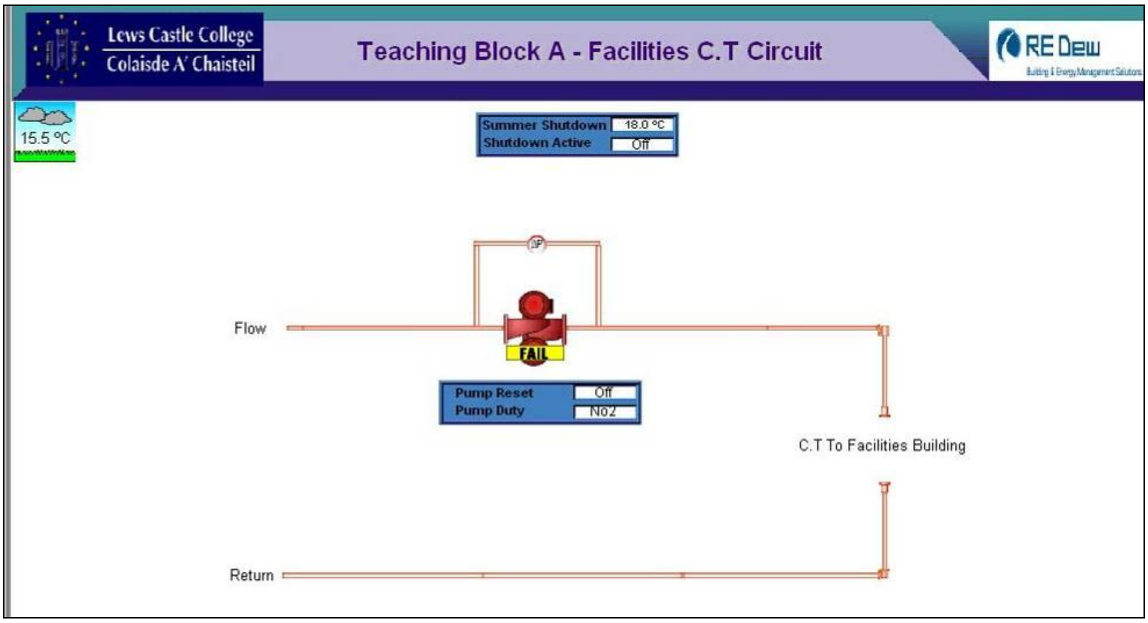

Figure E-3: Facilities heating circuit (Block A)

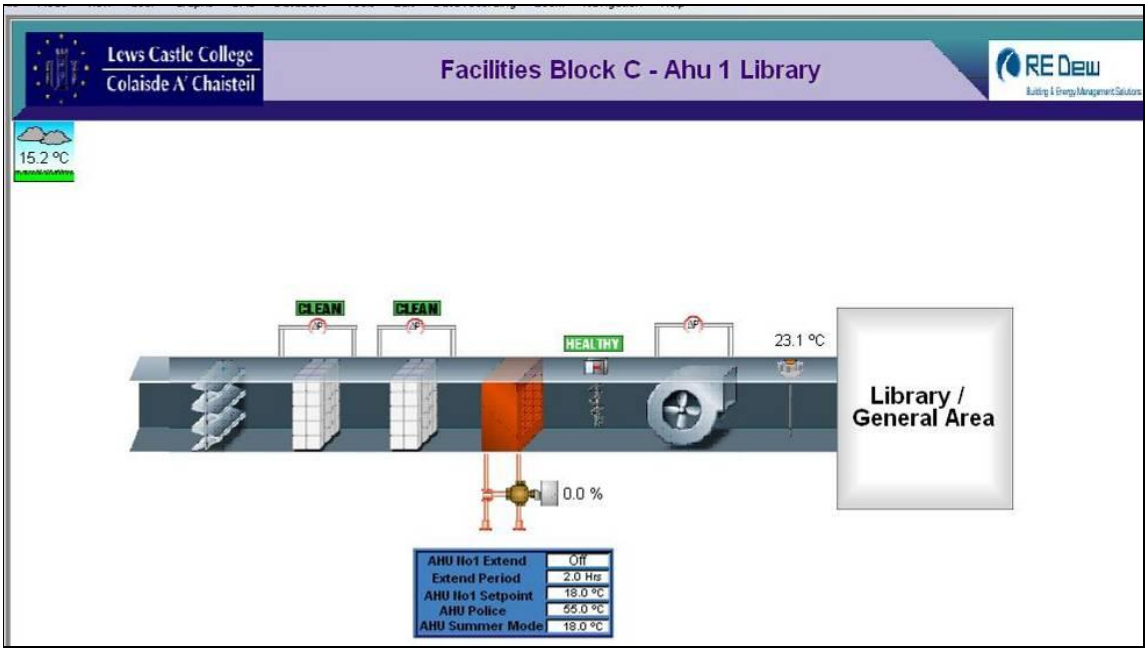

Figure E-4: Facilities air handling unit (library)

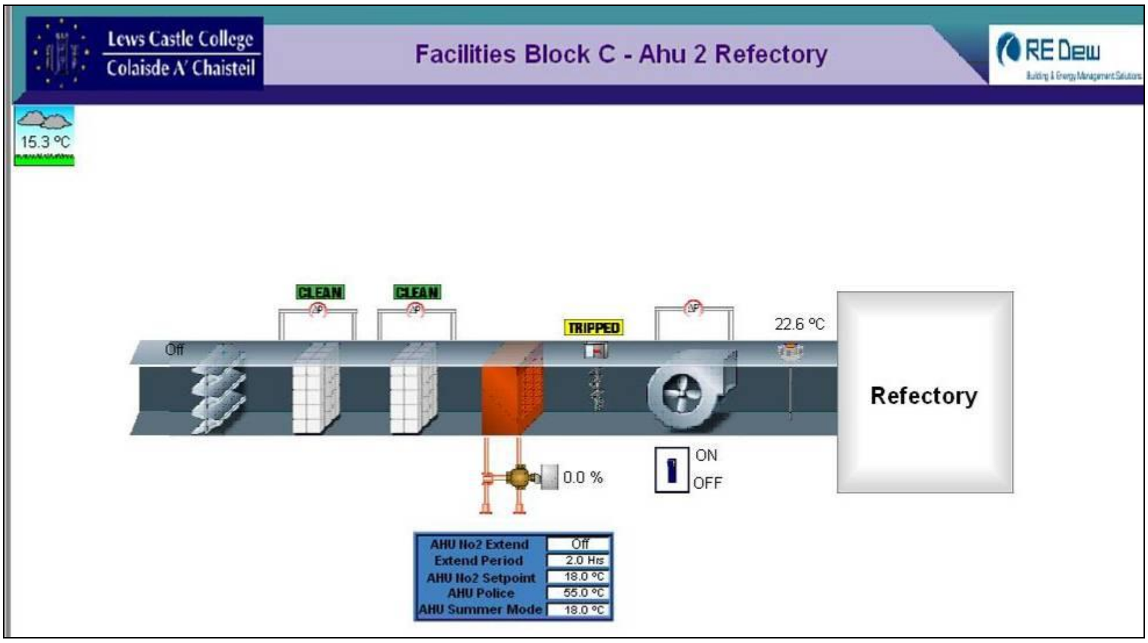

Figure E-5: Facilities air handling unit (refectory)

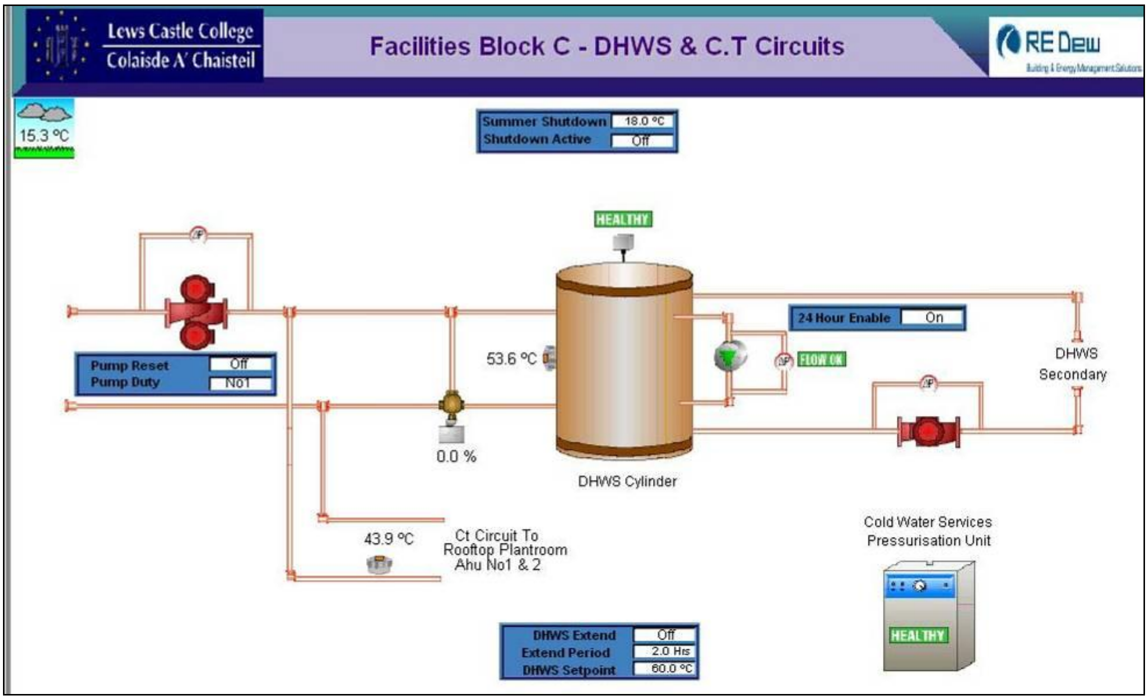

Figure E-6: Facilities hot water system (Block C)

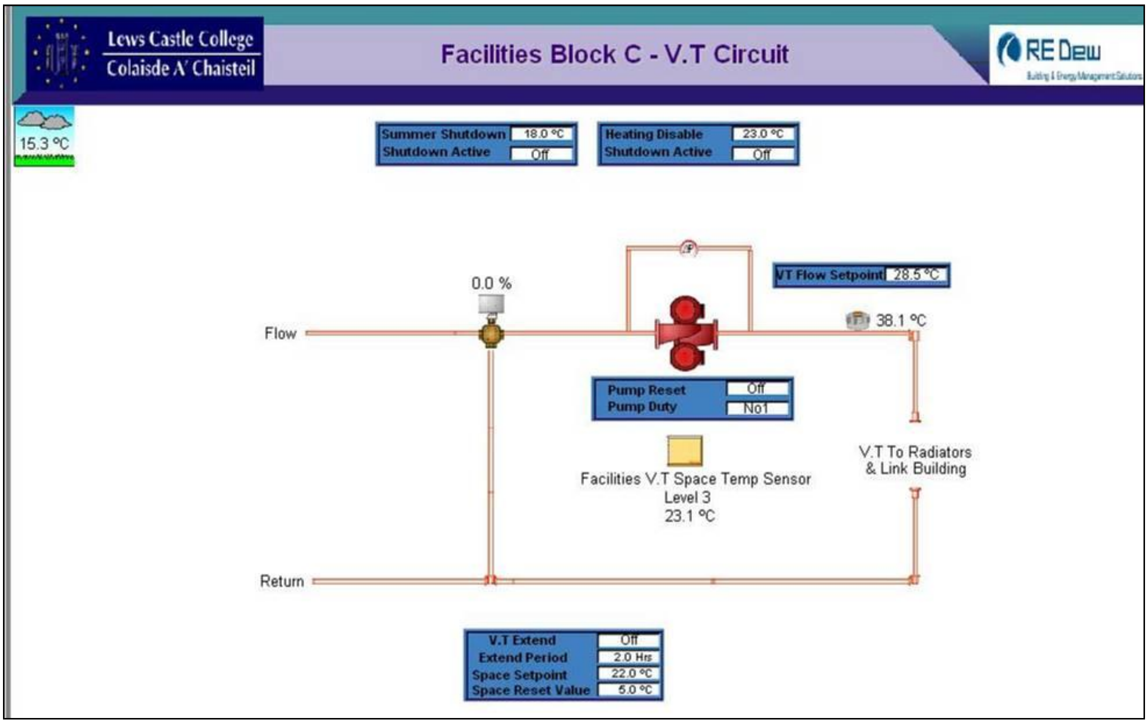

Figure E-7: Facilities heating circuit (Block C)

Engineering Block

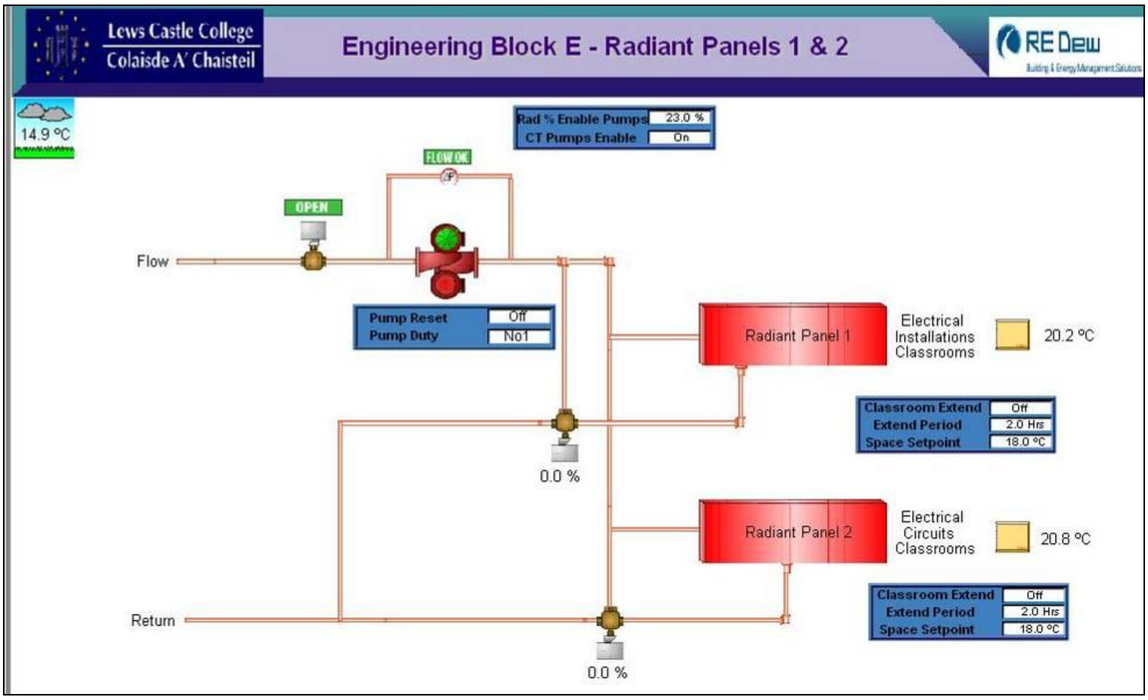

Figure E-8: Engineering Building heating circuit 1

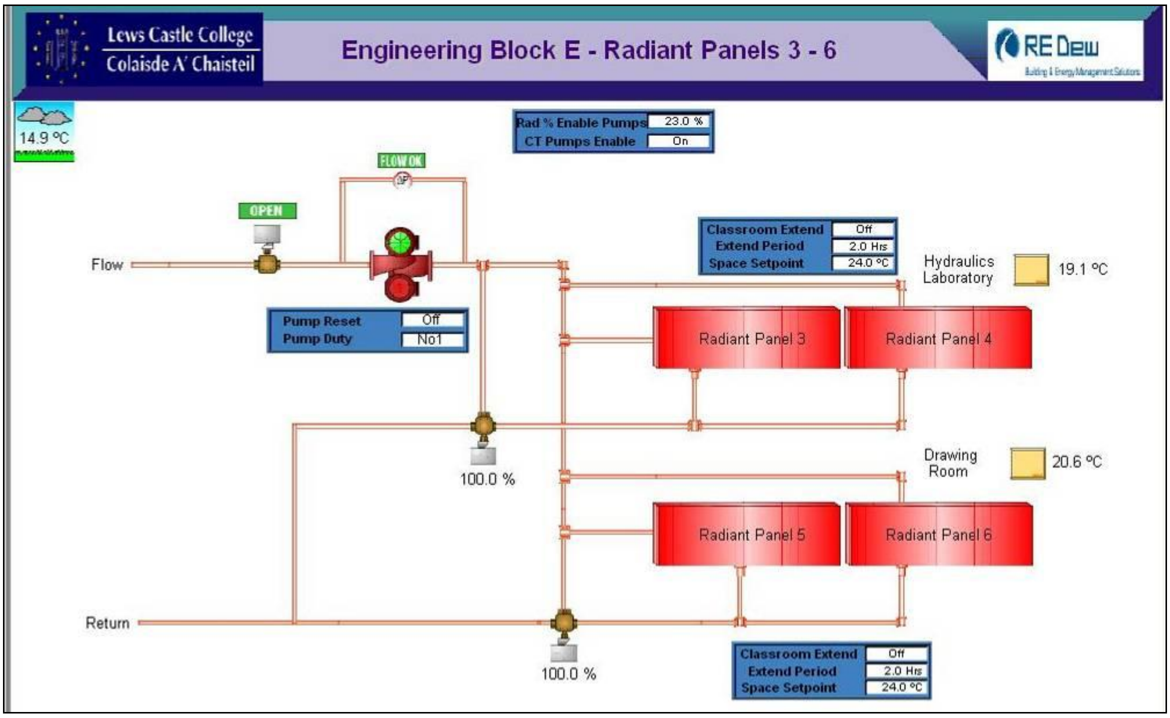

Figure E-9: Engineering Building heating circuit 2

Rural Development Building

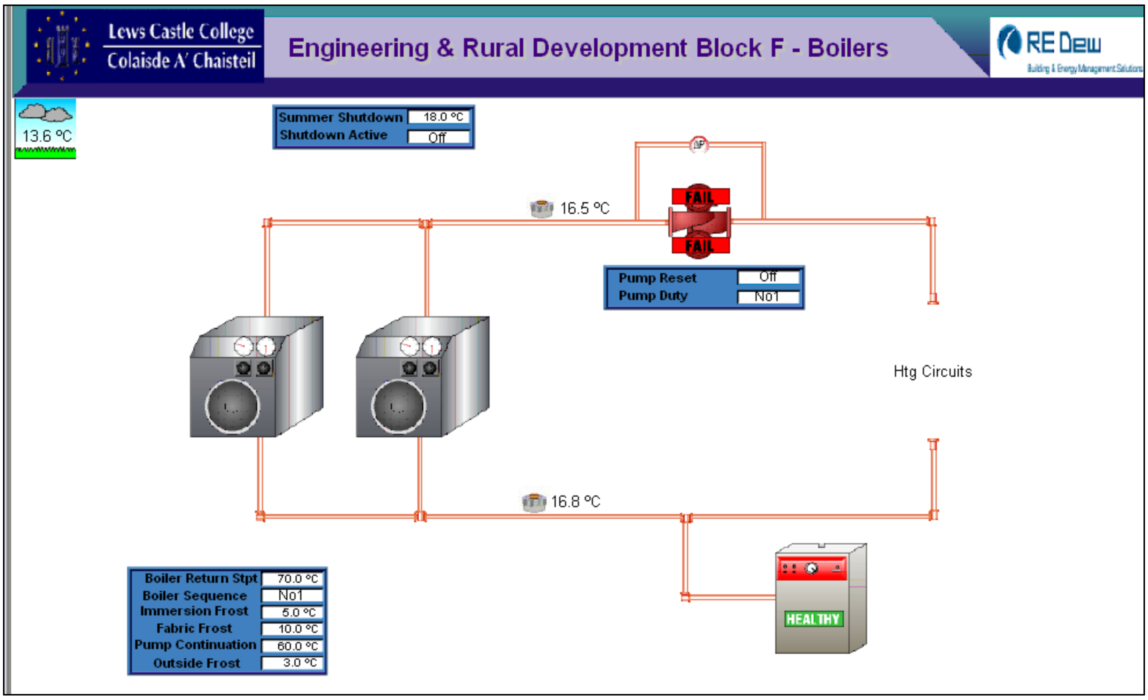

Figure E-10: Rural Building boiler room

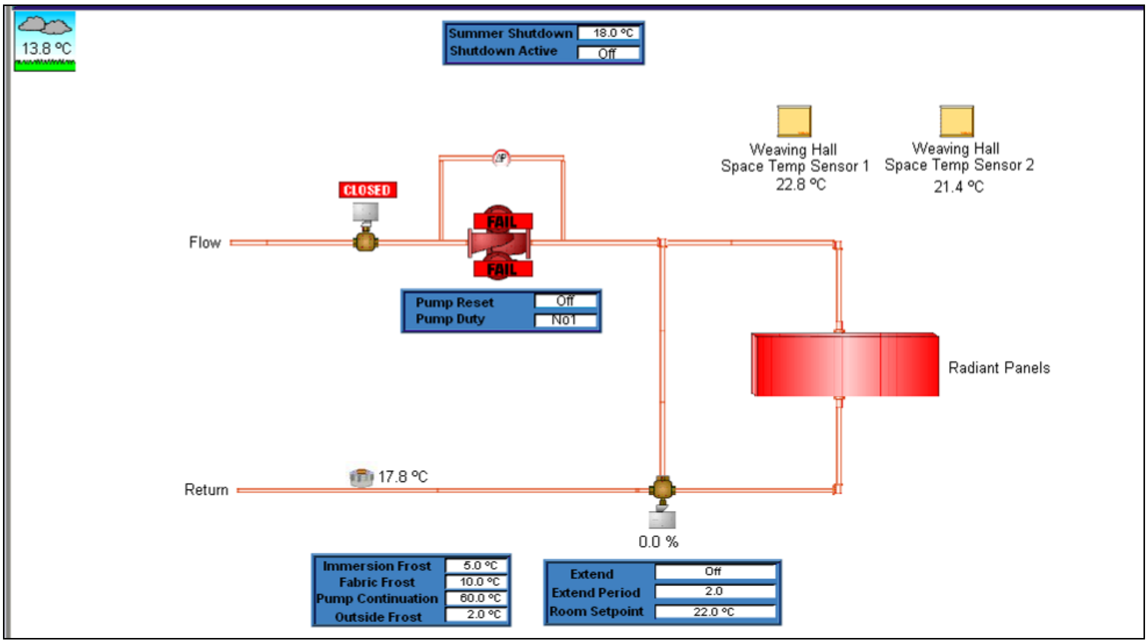

Figure E-11: Rural Building heating circuit

Appendix F – POE Questionnaire

Lews Castle College: Occupancy Questionnaire

Date:

Building:

Introduction

We are conducting an evaluation of your building to assess how well it performs for those who occupy it. This information will be used to assess areas that need improvement, provide feedback for similar buildings and projects and to help us better manage the environment.
Responses are anonymous. Please answer all the relevant questions.

General

1. Gender

Male **Female**

(Please circle)

2. Occupation (Please tick most relevant or state in 'other')

Administrative staff
Researcher
Lecturer
Student
Other: ………..

Full-time
Part time

3. Time in building

a. How long do you spend in the building during the day?

Hours	>1	1-2	3-4	5-6	7-8	>8

4. Hours at VDU

a. How long do you spend working at a computer (average hours per day)

Hours	>1	1-2	3-4	5-6	7-8	>8

Location in building

5. Location

In an average week how much time do you spend in the following types of space? (if you are a student assume during term time)

a: Office

Hours	0-5	6-10	11-15	16-20	21-25	26-30	31-35	>35

b: Lecture room

Hours	0-5	6-10	11-15	16-20	21-25	26-30	31-35	>35

c: Laboratory

Hours	0-5	6-10	11-15	16-20	21-25	26-30	31-35	>35

d: Library

Hours	0-5	6-10	11-15	16-20	21-25	26-30	31-35	>35

e: Café

Hours	0-5	6-10	11-15	16-20	21-25	26-30	31-35	>35

f: Other *(Please state)*

……………………………………………

Hours	0-5	6-10	11-15	16-20	21-25	26-30	31-35	>35

Location specific

6. Air quality

a). Does the quality of the air in this part of the building have a negative effect on your work performance?

Not significant	1	2	3	4	5	6	7	Very significant

b). Is the air fresh or stale?

Stale	1	2	3	4	5	6	7	Fresh

c) Is the air humid or dry?

Too humid	1	2	3	4	5	6	7	Too dry

d) Is there air movement?

Still	1	2	3	4	5	6	7	Good circulation

e) Do you have control over ventilation?

No control	1	2	3	4	5	6	7	Full control

7. Temperature

a). Does the temperature in this part of the building have a negative effect on your work performance?

Not significant	1	2	3	4	5	6	7	Very significant

b) Is the temperature in winter too cold or too hot?

Too cold	1	2	3	4	5	6	7	Too hot

c) Is the temperature during the summer too cold or too hot?

Too cold	1	2	3	4	5	6	7	Too hot

d) Do you have control over heating?

No control	1	2	3	4	5	6	7	Full control

e) Do you alter the heating in the room often? (Please Circle)
Never **Sometimes** **Often**

8. Light

a). Does the quality of light in this part of the building have a negative effect on your work performance?

Not significant	1	2	3	4	5	6	7	Very significant

b) Is there too much or too little natural light?

Too little	1	2	3	4	5	6	7	Too much

c) Is the artificial light too bright?

Not bright	1	2	3	4	5	6	7	Too bright

10. Comfort

a) How do you rate the comfort levels in the building?

Poor	1	2	3	4	5	6	7	Excellent

b) Does the comfort levels affect the way you work?

Not significant	1	2	3	4	5	6	7	Very significant

c) Does the comfort levels affect the way your health in anyway (dry skin, headaches, etc)

Not significant	1	2	3	4	5	6	7	Very significant

10. Comments

If you have any additional comments that you would like to make about any aspect of your work environment please note them here.

Thank you for taking your time to carry out this survey.

Appendix G – Occupancy Questionnaire Results

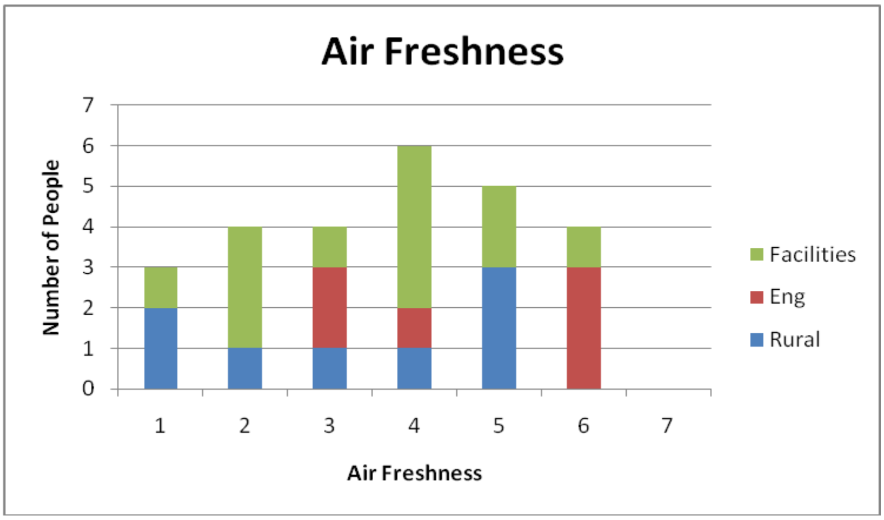

Figure G-1: Air Freshness results (1 Stale - 7 Fresh)

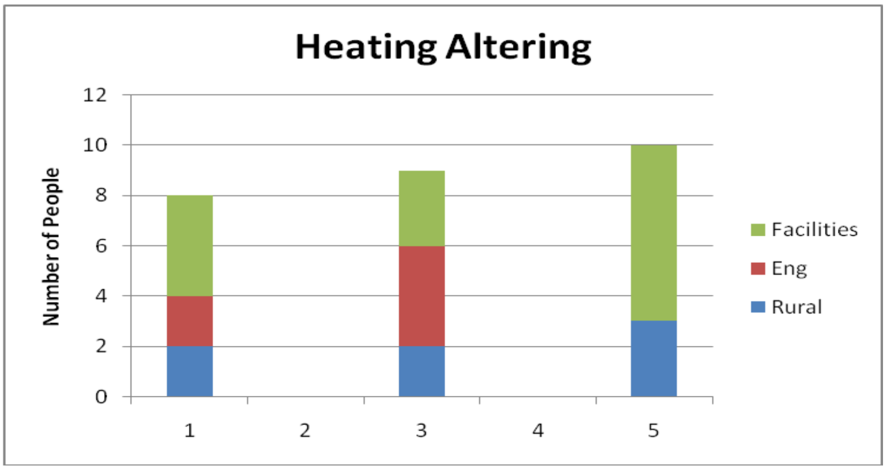

Figure G-2: Alteration of Heating (1 - Never, 3 - Sometimes, 5 - Often)

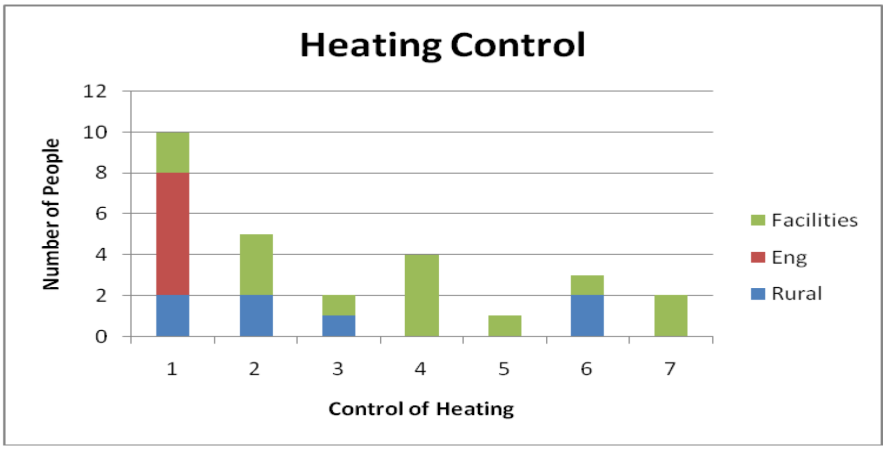

Figure G-3: Heating Control (1- no control 7- full control)

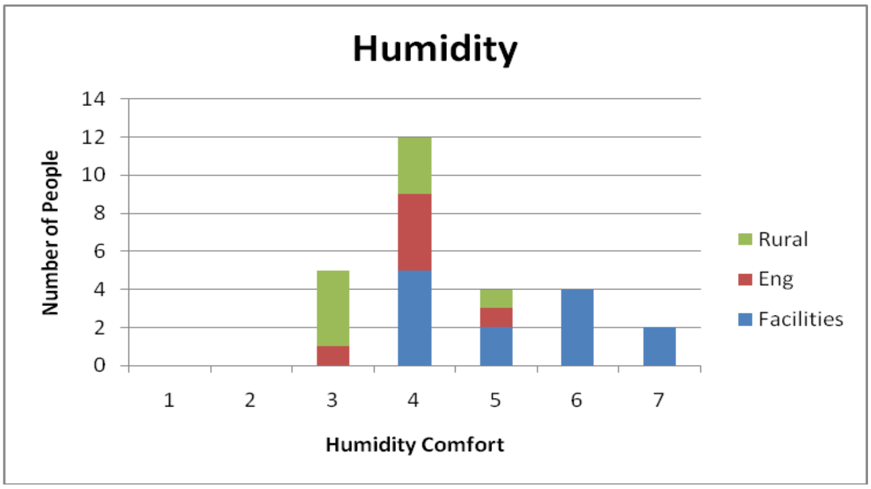

Figure G-4: Humidity comfort (1- too humid 7 - too dry)

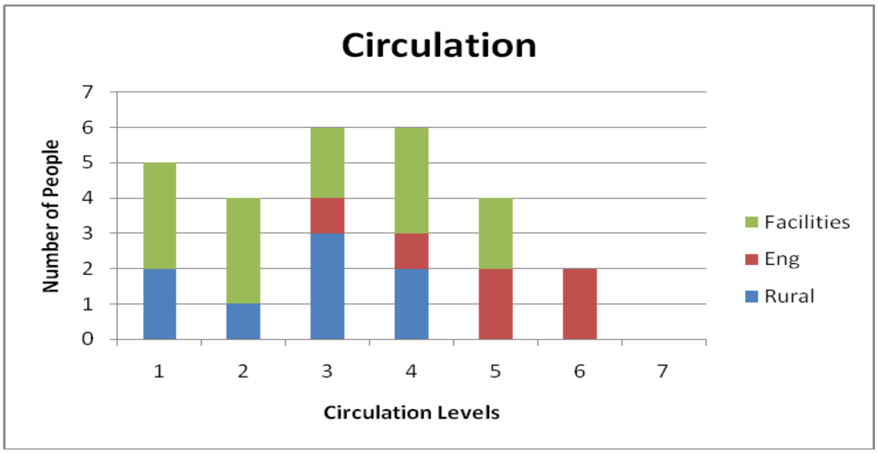

Figure G-5: Circulation levels (1-Still 7- Good Circulation)

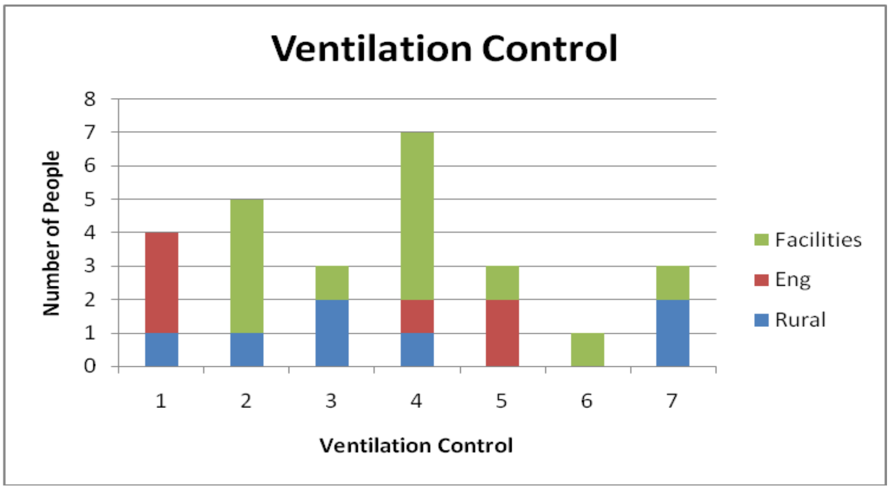

Figure G-6: Ventilation Control (1- no control 7- full control)

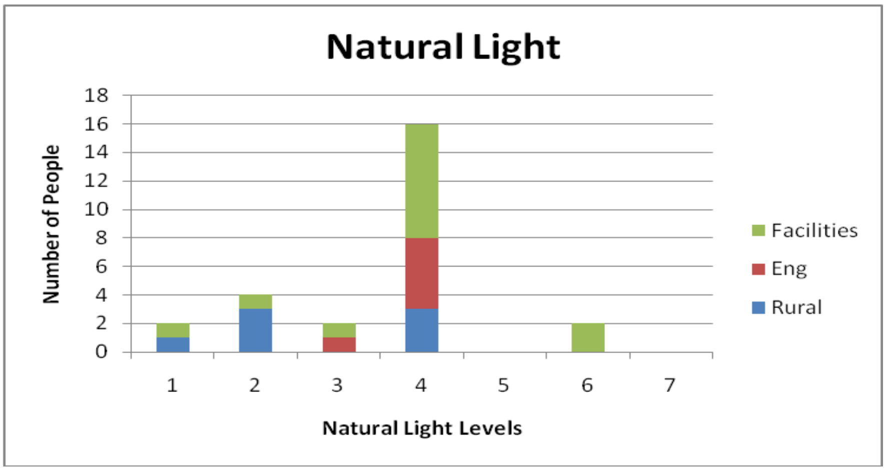

Figure G-7: Natural light levels (1- too little 7- too much)

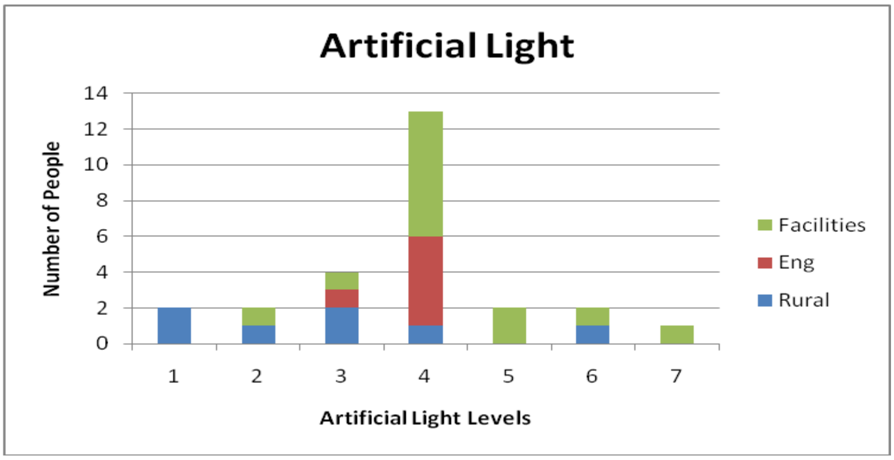

Figure G-8: Artificial Light (1- not bright 7- too bright)

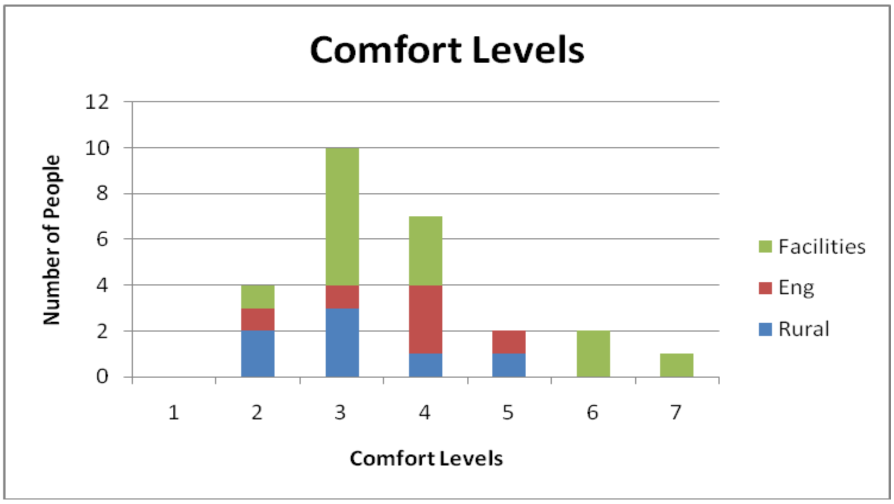

Figure G-9: Comfort levels (1-poor 7- excellent)