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# Generic Energy Demand Profile Generation

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Signed: Raheal McGhee Date: 10th September 2012

# Abstract

Electrical and thermal demand profiles were collected and analysed for a range of different buildings. Various factors were calculated for each of these buildings, such as their annual energy consumption per floor area, and were utilised to generate Generic Profiles for each building type such as Schools, Offices, and Houses etc. A Profile Library was designed which stores and provides relevant information and demand profiles of all buildings used in this project. This database also allows the demand data for each individual building to be exported which can then be readily imported into energy-matching tools such as Merit.

A Generic Electricity Consumption Calculator was developed which can be used to approximate the annual electrical consumption of a specific type of building by scaling a number of features such as floor area and average daily occupancy.

A taxonomy was created to illustrate the demand profiles contained within the Profile Library. A range of categories were included to allow easier and clearer understanding.

For the demonstration of the latest version of Merit, two demand profiles from buildings James Young and John Anderson, part of the University of Strathclyde, were used for supply/demand energy matching analysis. The supply profiles used in conjunction with these demand profiles consisted of data generation from Wind Turbines and Solar PV Cells. It was found that, with the generated supply profiles, James Young received an optimal Match Rate of 44.11 % when combined with 10 Proven WT600 Wind Turbines. John Anderson received an optimal Match Rate of 2.83 % with 10 Proven WT600 Wind Turbines and 10 165 W Sharp Poly Solar Panels.

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# Chapter 1: Introduction

## 1.1 Overview

Renewable energy, a phenomenon which enables diverse forms of energy to be converted and utilised, is captured by a range of technologies such as wind turbines, solar PV cells, heat pumps etc (Abulfotuh, 2007). There is also widespread misconception amongst the general population who believe that there were sparse amounts of renewable technologies from the 1990s compared to 2000 and beyond (Mitchell & Connor, 2004). Taking wind power generation as an example to highlight this misunderstanding, the following table shows the amount of World Power Generation from 1990 to 2008. It can be seen that in the 10 years from 1990 to 2000, there has been an increase of 30.2 % of global power generation via wind. From 1990 to 2008, the power produced rose to more than two-thirds of the initial value in 1990 to 70.7 %.  This shows that there were still a significant amount of renewable wind technologies almost 20 years ago even though a large number of people were not aware of it.

| Year | World Power Generation (TWh) | % Increase of World Power Generation compared to 1990 |
|---|---|---|
| 1990 | 11,821 | - |
| 2000 | 15,395 | +30.2 |
| 2005 | 18,258 | +54.5 |
| **2008** | **20,181** | **+70.7** |

Table 1. World power generation by wind technology (Energy in Sweden facts and figures 2010).

Renewable energy has become a mainstream topic in newspapers, magazines, television etc in recent times mainly due to increasing energy costs and Government carbon-emission targets. With the surge of renewable technologies being developed and built within the last 20 years has caused a fair proportion of the public to favour renewable energy and would prefer nuclear power to be removed (Krohn & Damborg, 1999; Pidgeon *et al*, 2008).

All available renewable technologies have both positive and negative factors, therefore due care must be taken when planning on setting up such a device (Ramakumar & Chiradeja, 2002). For example, it is extremely common for wind turbines to be built near the sea as there are typically higher wind speeds when compared to areas which are more inland.

Although setting up renewable technology systems primarily depends on the given situation, when they are suitable, they can be of great benefit by supplying electricity inadvertently generated by the forces of nature. Combining this with the constant progression in energy-efficiency of electrical devices provides a scenario in which a larger proportion of the electrical demand can be supplied by 'free' electricity (Hvelplund, 2006).

Currently, it is common to see solar PV panels on the roofs of buildings or wind turbines built on hills or near the coast. Vast amounts of investment are being made into the research and development of renewable technologies with a number of Governments around the world encouraging their inhabitants to accept such equipment being built – even if the aesthetics of the landscape is somewhat ruined (Ackermann *et al*, 2001). Incentives are also available for individuals and business to purchase these devices which could help fuel the renewable technology market.

Taking the British Government as an example, policies which have been introduced and those which are continuously being drafted (HM Government, 2008), are greatly pushing for the success of a number of targets:

- improvements in building efficiency
- incentives for small-scale renewable technologies
- lower carbon-levels from electricity-generation
- higher efficiency for electrical appliances
- increased insulation levels of buildings

The main focus and end-goal for these targets is to dramatically reduce the electrical/thermal demand of buildings (Wang *et al*, 2009). It has been proposed that tackling these issues would ensure long-term sustainability for the future. In fact, the Scottish Government is so determined in its belief of sustainable engineering (the systematic designing of a system utilising renewable energy and resources) that it is aiming to achieve 100 % in renewable energy production by the year 2020 (2020 Route map for Renewable Energy in Scotland, 2011). Whether or not this target is feasible within the next decade is a completely different matter.

## 1.2 Scope and Objective

An abundance of information relating to renewable energy is available in many formats such as books, internet and so on (Bang *et al*, 2000) which describes the need to harness its effects in order to supply cheaper electricity and heat for homes, industrial buildings etc. Ironically, there is a scarcity of high-resolution (monitored half-hourly or hourly) data available on exactly how much electricity or gas homes, industrial buildings etc actually consume (Fischer, 2008). The question we should ask is: Why are there very little high-resolution electrical/gas demand data, or profiles, available?

The World Wide Web – THE largest information system in the world which presently allows billions of pages of information to be created, viewed and shared by its 1.5 billion users (Curran *et al*, 2012) – is an incredible resource to search for energy demand data. However, after conducting a search for high-resolution demand data in the UK, little comprehensive data could be found. Instead, there was a profound amount of data available online which consisted of annually-recorded data and not hourly (or half-hourly). It is unsure if the reason for this is due to confidential grounds or if the data is not seen as constructive for anyone to use.

Therefore, obtaining such data for a diverse set of buildings involved directly contacting councils, companies and certain individuals to determine if they possessed practical high-resolution data. The majority of data collected are based in Scotland with some based in England. One of the reasons that the data is kept on a local scale is due to the Scottish Government in particular, which aims for Scotland to produce its energy entirely from renewable technology (2020 Route map for Renewable Energy in Scotland, 2011). Therefore, collecting data from Scottish buildings and examining how much energy is consumed would be beneficial when comparing the amount of renewable energy produced.

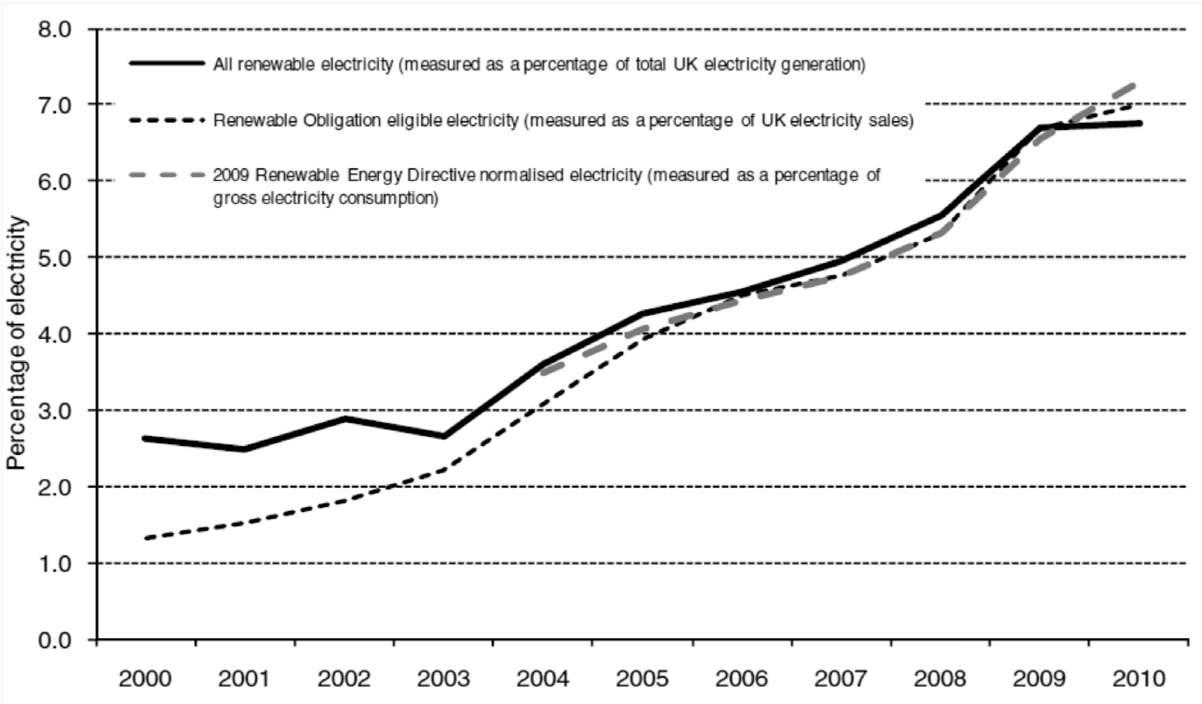
This report examines implementing electrical/thermal demand profiles into a Dynamic Computational Modelling Tool (DCMT) and scrutinising the similarities and differences for each type of building (i.e. schools, offices, homes etc). High-resolution data was essential to providing a more accurate interpretation of the profiles which were classed according to the type of building they described. These were illustrated via taxonomy and would be capable to support supply/demand matching analysis.

This study would generate a database of individual and Generic Profiles – a standard model of a particular building with a set electrical/thermal demand which can be scaled to match certain characteristics. By doing so, users can experiment how much energy demand a given floor area of a particular building can potentially yield. When this Generic Profile database is coalesced with Merit, a Supply/Demand Energy Matching Tool developed by the ESRU (Energy System Research Unit) department of the University of Strathclyde and equipped with a catalogue of various renewable technologies, it would demonstrate if such a renewable supply would be suitable.

# Chapter 2: Literature Review

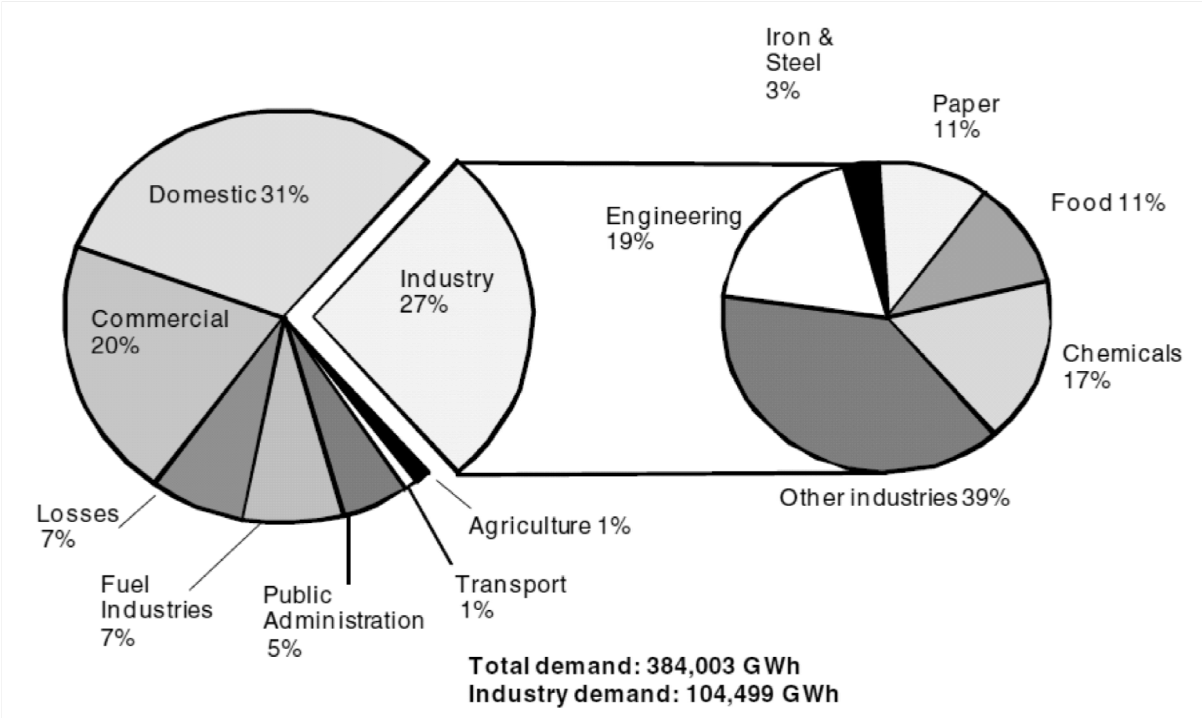
## 2.1 Renewable Electricity

The electricity consumption within Europe has risen to approximately 21 % of the final energy demand with the domestic sector consuming ~25 % of the final demand (DG for Energy and Transport, 2009) in the past few years. If we focus solely on the UK, there has been an increasing growth in the deployment and the generation of electricity from renewable technologies in the past decade, as shown below:




Graph 1. Growth in electricity generation from renewable sources since 2010 (DUKES, 2011).

The year 2010 will be used as the focal point when describing the generation and consumption of electricity as this is the latest year with the most comprehensive data. The graphs shown were generated from the available temporal data. It was found that within the UK, the total electricity consumption in 2010 was measured to be 328 TWh, +1.7 % more than in 2009 which was recorded at 323 TWh (DUKES, 2011). Overall demand had risen by 1 % from 379 TWh in 2009 to 384 TWh in 2010. The following graph illustrates the electrical demand required by the different sectors:




Graph 2. Electricity demand by sector in 2010 (DUKES, 2011).

The total electricity generation in 2010, taking into account the renewable technologies connected to the National Grid, was measured to be 381 TWh, +1.2 % more than in 2009 which was recorded at 377 TWh. The amount of electricity generated from renewable technologies alone accounted for 25.7 TWh, a 2 % increase than in 2009 (excluding non-biodegradable waste). For the total UK electricity generation, the contribution of all the renewable technologies connected to the grid accounted for 6.8 %. Below is a table depicting the electricity generated from a given renewable technology in 2010:

| Renewable Technology | Electricity Generation in 2009 (TWh) | Electricity Generation in 2010 (TWh) | % Difference from 2009 |
|---|---|---|---|
| Wind Onshore | 7.564 | 7.137 | -6 |
| Wind Offshore | 1.740 | 3.046 | +75 |
| Solar PV | 0.020 | 0.033 | +61 |
| Small-Scale Hydro | 0.598 | 0.511 | -17 |
| Large-Scale Hydro (inc. Refurbished) | 2.016 | 1.310 | -53 |
| Co-firing of Biomass with Fossil Fuels | 1.806 | 2.506 | +39 |
| Landfill Gas | 4.592 | 5.037 | +9 |
| Animal Biomass | 0.620 | 0.670 | +8 |
| Plant Biomass | 1.109 | 1.406 | +27 |

Table 2. Electricity generation by common renewable technologies (DUKES, 2011).

There has been a steadily increasing rate of possession of a variety of commodities such as televisions, computers, air conditioning systems etc within the commercial and domestic sector owing to major advances made into engineering and science (Almeida *et al*, 2008; Bertoldi & Atanasiu, 2007; Atanasiu & Bertoldi, 2008). With constant research and development, there are a number of sources projecting appliance-efficiencies for the future, from 2020 to as far as 2050 (Borg & Kelly, 2011; Eldridge *et al*, 2008).

In fact, by 2050, a UK Government policy is considered to 'label' light bulbs/electrical appliances in terms of how energy efficient they are (2050 Commercial Lighting and Appliances, 2008). This policy considers setting up 4 levels of energy efficiency with each electrical appliance belonging to one of these levels: level 1 depicts appliances with ~20 % efficiency; level 2, ~34 %; level 3, ~61 %; and finally, level 4 which depicts appliances with a high ~73 % efficiency. As these values are currently merely speculation, they do represent the notion and impetus to increase energy efficiency and reduce demand in electrical appliances. So much so that household forecasts were made to express the quantity of electrical consumption in 2050 compared to the 2007 total consumption, assuming the steady trajectory of technological and behavioural change, which are conveyed in the following table:

| 2007 (TWh/y) | 2050 – Level 1 (TWh/y) | 2050 – Level 2 (TWh/y) | 2050 – Level 3 (TWh/y) | 2050 – Level 4 (TWh/y) |
|---|---|---|---|---|
| 176 | 213 | 184 | 136 | 108 |

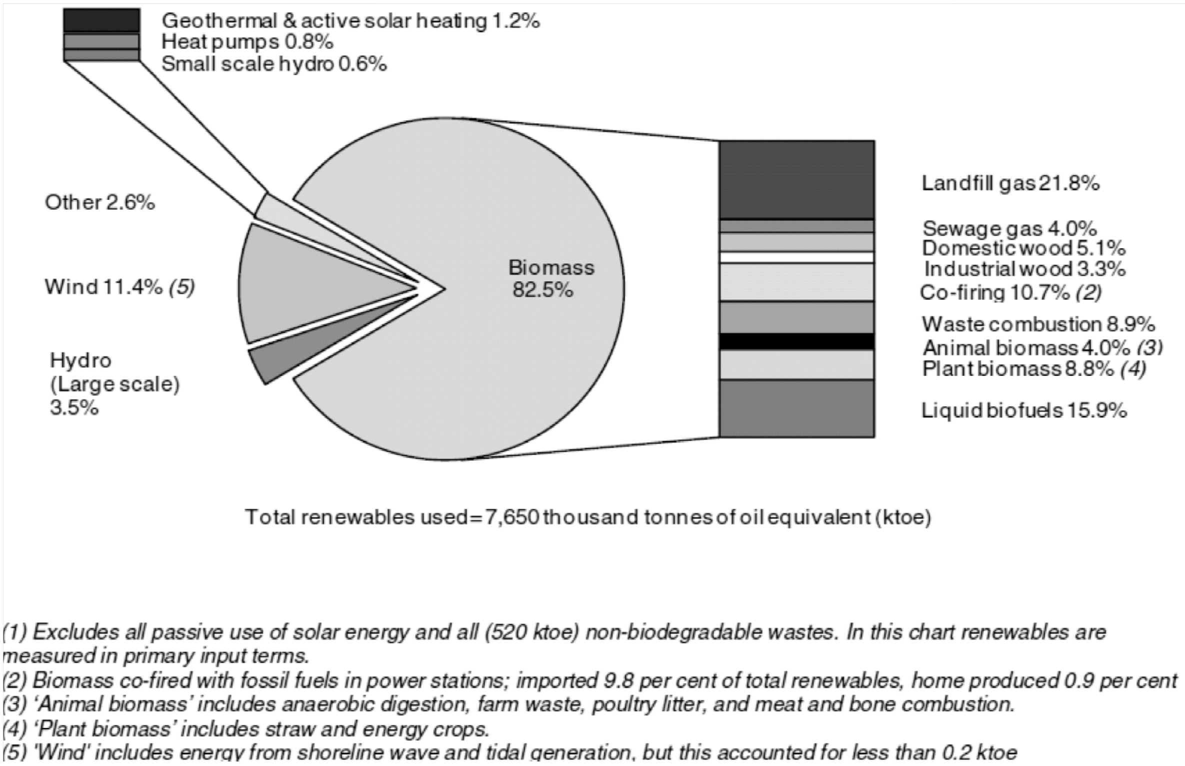
Table 3. Predicted electricity consumption for future scenarios (2050 Commercial Lighting and Appliances, 2008).

A clear and concise method to see the effects of energy-efficiency in appliances over a period of time is to monitor and record the data. By doing so, annual sets of data can then be compared and any changes witnessed. The database associated with this project can be updated with such data for the same building over a number of years and graphs can be shown to portray differences.

## 2.2 Renewable Heat

Renewable technologies play a significant role not only in electricity generation but also in the production of heat (Nast *et al*, 2007). It was found that in the UK, approximately 16 % of renewable sources were exploited to produce heat in 2010, amassing to a total of 1,212 ktoe (kilo tonnes of oil equivalent). This is 17 % more than what was produced in 2009 and 103 % more than in 2005 (DUKES, 2011).

Within the last few years, there has been a surge of renewable technologies being used to generate heat after a period of decline which began more than a decade ago. The reason for this was due to restrictions being placed on emission controls, which consequently discouraged the onsite combustion of biomass (DUKES, 2011). Nowadays, the growth within the domestic sector is primarily due to wood-burning (Lee *et al*, 2005); whereas plant biomass has been widely used in the agricultural sector (Upreti & van der Horst, 2004). The industrial sector are also consuming more wood than they did previously, which could be due to financial reasons. Studies have shown that the consumption of wood has been the main contributor in terms of renewable heat, this was found to ~32 % of the total heat produced by renewable resources. The next 2 principal contributors, both of which summed up to 17 % each, was the non-domestic use of wood and plant biomass (DUKES, 2011). The following graph illustrates the input proportion of various renewable energy fuel-types:




Graph 3. Input of renewable energy fuel-types in 2010 (DUKES, 2011).

For the first time in 2012, heat pumps (both air & ground sources) have been incorporated into the DUKES statistics published by the Government – the data has been accumulated since 2008. It should be noted that only the net gain in energy (i.e. overall energy from heat subtracted from the electricity used to operate the pump) is regarded as renewable energy (DUKES, 2011). Unfortunately, heat pumps tend to use a considerable quantity of electricity to power the compression cycles involved. Therefore, a Renewable Energy Directive was drafted which considered proposing a method to surmise the possible amount of renewable energy generated. This integrated a Seasonal Performance Factor (SPF) whereby a cut-off is introduced in the performance of the heat pump if it is no longer considered in producing energy from renewable means (Omer, 2008; Doherty *et al*, 2004). The minimum requirement for a heat pump to be considered to generate renewable energy is for the technology to attain an SPF of 3 – this is the value assumed for all heat pumps set-up during 2008 and beyond (DUKES, 2011).

At the end of 2010, it was approximated that the total installed capacity of ground-sourced heat pumps (assuming a stable growth throughout the year) was 596 MW. Overall, heat pumps were calculated to generate renewable heat within the region of 710 GWh (DUKES, 2011).

The UK Government had announced information concerning a Renewable Heat Incentive (RHI) on the 10$^{th}$ March 2011. These tariffs were set to begin in late 2011 with anticipation of creating 57 TWh of renewable heat (Kelly & Cockroft, 2011). This would result in 12 % of heat to be produced from recent technologies and could possess the potential to cut 44 million tonnes of carbon by the year 2020 (DUKES, 2011). In terms of renewable heating within the domestic sector, an 'RHI premium payment scheme' from the Government would commence during late 2011 and end until October 2012 in which case the Green Deal scheme begins – this is where RHI tariffs would include households (Smith, 2011).

A renewable method which utilises the energy is Active Solar Heating (ASH) in which solar collectors are exploited in order to heat water (Weiss, 2003). This has primarily been used for domestic use but it has gradually been applied to other purposes such as swimming pools. In 2010, it was surmised that 122 GWh of hot water generation by ASH in the domestic sector replaced that which were originally produced via electrical heating and gas. It was also found that heating swimming pools with ASH substituted 640 GWh for gas, oil and electricity where initially each accounted for 45 %, 45 %, and 10 % respectively (DUKES, 2011). Below is a table depicting the heat generated from a given renewable technology in 2010:

| Renewable Technology | Heat Generation in 2009 (ktoe) | Heat Generation in 2010 (ktoe) | % Difference from 2009 |
|---|---|---|---|
| Active Solar Heating | 69.5 | 87.0 | **+25.2** |
| Heat Pumps | 28.8 | 61.0 | **+211.5** |
| Landfill Gas | 13.6 | 13.6 | **-** |
| Sewage Sludge Digestion | 51.0 | 72.8 | **+42.7** |
| Wood - Domestic | 375.2 | 391.8 | **+4.4** |
| Wood - Industrial | 223.4 | 255.7 | **+14.4** |
| Animal Biomass | 40.3 | 45.1 | **+11.9** |
| Plant Biomass | 203.0 | 259.0 | **+27.5** |
| Biodegradable Municipal Solid Waste | 31.3 | 25.6 | **-22.1** |
| Geothermal Aquifers | 0.8 | 0.8 | **-** |

Table 4. Heat generation by common renewable technologies (DUKES, 2011).

If thermal data was monitored accurately and stored within databases, comparisons can easily be made – similarly to electricity – in order to see if buildings consume less generated heat over a period of time.

## 2.3 Energy-Saving Buildings

There is much research being conducted in order to better comprehend and reduce energy consumption in buildings, these can include both industrial and dwelled. On average, there are high levels of energy usage in terms of space heating which in the EU, has been estimated to be ~57 % of the final energy consumption; for domestic hot water and electricity, the energy values were ~25 % and ~11 % respectively (Chwieduk, 2002). There is mention that buildings can be classified in terms of the how effective they consume energy, these categories are: energy-efficient buildings; environmentally-friendly buildings; and sustainable buildings.

The first category involves the traditional energy-saving measures such as installing double or triple glazing windows, improving the amount of insulation material in the building, introducing heating and electric metering etc (M'Sirdi *et al*, 2012). The second category focuses on the architecture of the building and how effective it stores/delivers energy. This can include a building design which utilises passive solar as the main heat contributor, underground thermal heating storage, and incorporating photovoltaic cells to name a few methods (Yang *et al*, 2012). The final category concentrates on the protection of present and future energy, water and land resources. Factors which can influence the mentioned resources include the quality of the indoor environment, residential area and of building materials (Hseih *et al*, 2011).

It is the aim of many organisations and Governments across the world to encourage and convert all manner of buildings to those which can obtain the status of a 'sustainable building'. Studies have shown that the behaviours of those organisations can influence how effective and efficient the level of energy-saving of buildings can be. This impact can be hugely significant especially to businesses as Governments can offer grants depending on the level of sustainability the business wishes to achieve (Xue & Li, 2011). These grants can also be given to local housing schemes to aid consumers to invest in small-scale renewable energy methods.

With current monitoring technologies which allows consumers to see extremely accurately how much energy they are consuming, these monitoring devices can be applied to sustainable buildings which could help achieve the best possible combination of technical, social, economic and environmental factors. Sustainable buildings which boasts this type of screening advancement are sometimes captioned '**sustainable intelligent buildings**' and is considered to be a significant part of a sustainable life cycle assessment (LCA) (Yu *et al*, 2011). The LCA is a method in which various aspects of a sustainable development are measured (Guo *et al*, 2011). Some of these aspects include those which were mentioned previously such as the amount of insulation in the building, efficient use of natural heating and lighting etc. Different countries have differing policies and regulations, therefore the LCA requirements can vary for buildings within these locations. If a building manages to pass the LCA, then it can be considered to be a 'sustainable building' or a 'sustainable intelligent building' if it is equipped with energy-reading devices.

## 2.4 SMART Buildings

A SMART building, or house, is one which has been installed with a particular system consisting of hardware, software and wiring to allow the occupants to monitor and manage the consumption of energy. This is accomplished by selecting which devices in the building can be active at any given time by simply entering a single instruction when accessing the systems network (Agarwal *et al*, 2010). This technology is seen as a major step in reducing energy consumption – which in turn reduces carbon emissions.

SMART technology in buildings and dwellings are expanding swiftly along with electrical technology with many buildings nowadays equipped with all manners of systems such as security, entertainment, communication etc. Similar to electrical devices, there are a number of SMART systems developed and deployed with similar and unique attributes. A typical technology used is Powerline Carrier Systems (PCS) which involves the transmission of encoded signals via the buildings electrical wiring network. These signals are delivered to programmable switches which in turn are transmitted to specific devices – the signals contain commands processed by the particular device (Yu-Ju *et al*, 2002).

A common procedure for PCS is a signalling method named X10, primarily used to command electrical appliances connected to the network. The digital commands sent via X10 consist of shortwave radio-frequency pulses capable of allowing communication between receivers and transmitters (Arora *et al*, 2002).

In Europe, collaboration between a number of countries had led to the creation of the European Installation Bus (EIB) – or Instabus (Langhammer & Kays, 2011). This innovative system utilised the use of a 2-wire bus line set up with the common electrical wiring network and unites all connected electrical equipment to a decentralised communication mainframe. The Instabus does not require an electrical switchboard or control console for operation, instead a personal computer (PC) can be exploited to observe and ensure all appliances are functioning correctly and at the scheduled time. These aspects of the Instabus aids in decreasing power consumption and increasing comfort, security and building efficiency. In fact, the association Konnex – which converged and improved the EIB and two other network protocols – endeavours to regulate SMART building networks throughout Europe (Ruta *et al*, 2011).

A number of energy providers such as Scottish Power, Ofgem etc, are also developing and improving SMART metering for consumers to see very precisely how much energy they are using (Smart Meter Testing & Trialling Discussion Paper, 2011). This can help consumers to manage their energy consumption much more efficiently, which provides them with the added benefit better manage their energy costs. The SMART metering system is also designed to let consumers know how much their monthly bill would be compared to receiving estimated bills which would consequently cease meter-readers visiting homes. Due to advantages of SMART metering, the UK Government hopes to have all households installed with the meter by 2020 with the rollout of the device beginning this year (Quantitative Research into Public Awareness, Attitudes, and Experience of Smart Meters, 2012). Although it is very beneficial and effective that SMART metering can monitor energy consumption at high-resolution, it is unknown if any of the data monitored would be stored – in which case, analysis of demand profiles could prove difficult.

## 2.5 Hybrid Renewable Energy Systems

A Hybrid Renewable Energy System integrates two or more combinations of energy-conversion technologies in order to achieve greater system flexibility, efficiency and productivity than an individual renewable energy device. There is a diverse range of Hybrid Systems such as Biomass-Wind-Fuel Cell System, Photovoltaic-Wind System etc (Deshmukh & Deshmukh, 2008). Although still in its early stages, many producers are opting to develop low-costing Hybrid Renewable Energy Systems. This would aid in the global market's acceptance of such systems which in turn could provide substantial investment into research and development (Burch, 2001).

These systems are designed to be highly resourceful by combining a selection of very efficient technologies (such as fuel cells, progression in material-science etc). Energy storage devices can also be used to improve reliability of a Hybrid Renewable Energy System if any surplus energy has been generated (Rodolfo *et al*, 2008). Environmentally, these systems are very capable in producing lower carbon-emissions than those systems which require fossil fuels to operate (Ashok, 2007).

It is apparent that such systems are required, particularly since the Hybrid Systems operate depending on environmental conditions. For example, installing Solar PV Panels in a region in Scotland may provide a certain amount of energy but only if the intensity of sunlight available is sufficient, otherwise the energy production is low. However, incorporating Wind Turbines into the system alongside the Solar PV Panels can potentially generate much more energy as Scotland receives a considerable amount of wind, particularly near the coast. Thus, if there was little light present and an ample source of wind (or vice-versa), the Hybrid Renewable Energy System could possess the ability to compensate for any limitations (Ekren & Ekren, 2008).

Fortunately, there are DCMTs available which can analyse demand profiles with a collection of different renewable technologies and hybrid systems: Merit is one such software which will be used in this project.

## 2.6 Merit – Supply/Demand Energy Matching Tool

### 2.6.1 Overview

Developed by the ESRU department of the University of Strathclyde, Merit is a quantitative evaluation software which enables the user to analyse the match between supply and demand mechanisms and determine which combinations are the most suitable for a given scenario. This analysing protocol processes various criterion such as matching the temporal demand of the profile, reducing the required energy storage capacity and maximising the utilisation factor of the renewable energy system. Within the simulation procedure, complex algorithms exploit internal datasets, derived from weather/geographical sources and the producer's specifications, which are integrated to emulate physical practice. Merit can also provide the option of recording the results in a high-resolution format such as half-hourly demand profiles.

Although Merit can be used independently and offline, it does possess the capabilities of exchanging data with several energy-analysing software over the internet. The type of data communicated can range from simulated demand profiles from virtual building models to weather conditions for a given geographical location. All these exchanges are accomplished by the program connecting to a remote SQL (Structured Query Language) database.

2.6.2 Procedure

As Merit is a dynamic supply/demand matching-design tool for renewable energy systems, a range of criteria must be entered depending on the user's requirements. The analysis aims to reach the highest possible temporal match between the combinations of both the supply and demand factors - this establishes the successfulness of the combination when installed.

The procedural steps of using this supply/demand matching tool involve the user first selecting the weather profile for their defined scenario. Next, the demand and renewable supply profiles are chosen which form the significant prerequisite of the analysis. An auxiliary or back-up system (battery, hot-water storage etc) can also be selected with corresponding performance information displayed; a cost-indication of additional energy may also be provided in the final analytical report as a function of a selected tariff. However, it is not a compulsory option.

Once Merit collects the necessary input from the user-defined criterion, statistical techniques are employed to analyse the supply and demand profiles. One of these techniques is based on the Spearman's Rank Correlation Coefficient which describes the trend between two variables but does not take into account the relative magnitudes of the individual variables (Scheaffer and McClave, 1982). The Correlation Coefficient, *CC*, results in a value which will always lie between -1 and 1. When one variable increases towards 1 (perfect positive correlation), the other variable decreases at exactly the same rate towards -1 (perfect negative correlation). If $CC = 0$, then this would indicate that there is no correlation between the variables.

The *CC* between supply and demand profiles in Merit is calculated by using Equation (1). If the size of the supply profile was then increased in size (for example, twice as much), and the demand profile remained the same, the *CC* would also remain the same regardless if the surplus supply was greater. If, however, the supply and demand profiles possessed varying quantities but were in perfect phase, the outcome would be a perfect correlation even though the match would not be perfect. This technique gives a metric of potential matches which could be possible if alterations are made, such as modifying the size of the renewable energy system or increasing energy efficiency.

$$CC = \frac{\sum_{t=0}^{n}(D_t - d)(S_t - s)}{\sqrt{\sum_{t=0}^{n}(D_t - d)^2 \sum_{t=0}^{n}(S_t - s)^2}} \tag{1}$$

Where $D_t$ = demand at time, t

$S_t$ = supply at time, t

d = mean demand over time period, n

s = mean supply over time period, n

Another statistical technique used to analyse the match between supply and demand profiles is based on an Inequality Coefficient described by Williamson and was primarily used to confirm estimated thermal performance models (Williamson, 1994). The Inequality Coefficient, *IC* (or Match Rate), expresses the difference of 3 variables in a time-series: the unequal tendency (mean); the unequal variation (variance); and finally, the imperfect co-variation (co-variance) (Born, 2001).

For Merit, the *IC* between supply and demand profiles is calculated by using Equation (2). The *IC* results in a value which will always lie between 0 and 1. When *IC* = 0, the match is perfect; when *IC* = 1, there is no match. Various matches due to inequalities can then be termed by either ‘good matches’, particularly for those which range between 0 and 0.1; or ‘bad matches’ which range between 0.9 and 1 (Born, 2001).

$$IC = \frac{\sqrt{\frac{1}{n}\sum_{t=0}^{n}(D_t - S_t)^2}}{\sqrt{\frac{1}{n}\sum_{t=0}^{n}(D_t)^2} + \sqrt{\frac{1}{n}\sum_{t=0}^{n}(S_t)^2}} \tag{2}$$

This dynamic supply/demand matching method can be revised and replicated to study the outcome of differing supply/demand parameters, time periods, weather data etc rapidly and effortlessly.

# Chapter 3: Collection, Collation and Interpolation of Electrical/Thermal Demand Profiles

## 3.1 Collection and Collation of Demand Data

The majority of demand data collected for the purpose of this project was achieved by means of contacting the necessary parties either by phone or email. In very few cases, the electrical and thermal profiles were available for immediate download on dedicated websites. As mentioned earlier, the origin of most of the data is based in Scotland; the remaining data are located in England (excluding BAA Airport where the location will remain anonymous). All profiles consist of annual data with a data resolution of half-hourly, hourly or monthly. The following table shows obtained demand profiles for the type of building and the country they are situated in:

| Type of Building | No. of Buildings for Each Type | No. of Electrical Demand Profiles | No. of Thermal Demand Profiles | Country Location |
|---|---|---|---|---|
| Care Home | 7 | 7 | 3 | Scotland |
| Community Centre | 5 | 5 | 1 | Scotland |
| Emergency Services | 3 | 3 | 2 | Scotland |
| Hall/Venue | 3 | 3 | 1 | Scotland |
| Houses: 2-Bed Mid-Terrace | 5 | 5 | 5 | England |
| 2-Bed Semi-Detached | 24 | 24 | 24 | England |
| 3-Bed Detached | 12 | 12 | 6 | England |
| 3-Bed End-Terrace | 6 | 6 | - | England |
| 3-Bed Semi-Detached | 14 | 14 | 6 | England |
| 4-Bed Detached | 18 | 18 | 18 | England |
| High/Secondary School | 24 | 24 | 4 | Scotland |
| Leisure Centre | 4 | 4 | 3 | Scotland |
| Library | 3 | 3 | 1 | Scotland |
| Maintenance Services | 5 | 5 | - | Scotland |
| Museum/Art Gallery | 1 | 1 | - | Scotland |
| Nursery/Primary School | 23 | 23 | 7 | Scotland |
| Office | 19 | 19 | 12 | Scotland/England |
| Specialist School | 5 | 5 | - | Scotland |
| Transport | 4 | 4 | - | UK |
| University of Strathclyde | 10 | 10 | 2 | Scotland |

Table 5. Type, no. of electrical/thermal and location of demand profiles for given building.

Although electrical demand data were acquired for ALL the buildings, only 32 % of the buildings also possessed thermal (gas) demand data. In other words, with a combined total of 301 profiles collected: 206 are electrical; 95 are thermal. The profiles were all provided in a Microsoft Excel format to allow data to be easily sorted, manipulated and edited if necessary.

While the profiles could still be used without the thermal consumption data, generating the Generic profiles (which are discussed later) may have a reduction in accuracy if describing thermal demand.

The main contributor to the data collected were various city councils such as Glasgow City Council, Edinburgh City Council and so forth. Other sources included organisations such as BAA, Building Research Establishment etc – all of whom are acknowledged. However, due to the process of contacting the parties for the required information, the length of time in which to receive the data in 80 % of the cases exceeded 3 weeks. This period of waiting for the data could have been easily avoided had the data been made previously available online, there would not have been any restrictions to the public accessing the data due to the Freedom of Information Act 2000 and Freedom of Information (Scotland) Act 2002 (Legislation: Freedom of Information Act, 2000; Legislation: Freedom of Information (Scotland) Act, 2002).

## 3.2 Interpolation of Demand Data

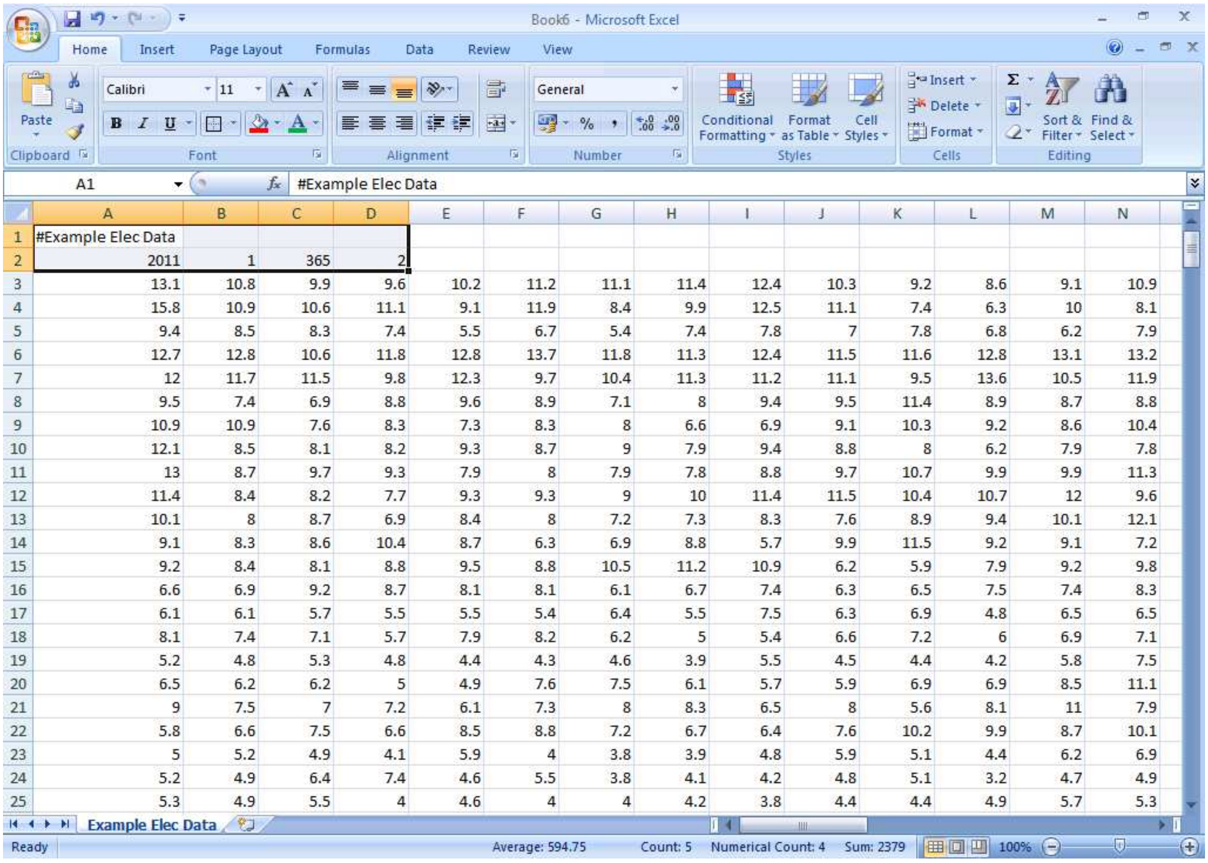
Once a profile was obtained, the data was thoroughly scrutinised to check the initial format of the profile and to inspect for any obvious errors or missing data, in which case interpolation techniques are employed.

### 3.2.1 Format of Data

The format of the collected demand profiles were important as they were to be tested in the new supply/demand energy-matching software version of Merit. This tool requires profiles to be in a comma-delimited format (.csv) and must not exceed 8,760 individual data cells for an hourly resolution; 17,520 individual data cells for half-hourly resolution. The first 2 rows must contain additional information of the data as shown in Figure 1: A1 – name of profile;

A2 – year of data; B2 and C2 – start and end day respectively; D2 – data resolution (1 = hourly; 2 = half-hourly).

The data can then begin from A3 with each row representing a day and each column representing an hour or half-hour. If hourly resolution data is used, the data for the first day would start and end at A3 and X3 respectively (24 cells horizontally); for half-hourly resolution, the data would start and end at A3 and AV3 respectively (48 cells horizontally).



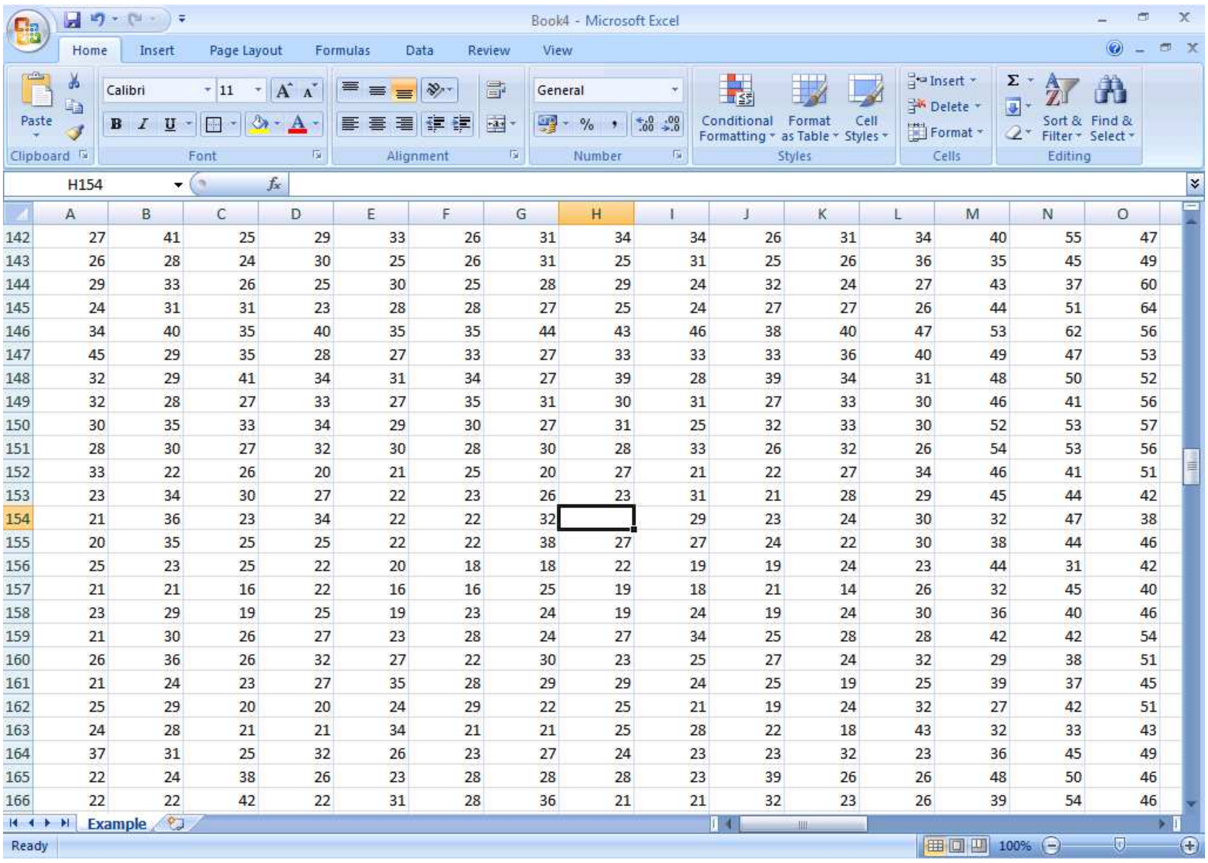
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | #Example Elec Data | | | | | | | | | | | | | |
| 2 | 2011 | 1 | 365 | 2 | | | | | | | | | | |
| 3 | 13.1 | 10.8 | 9.9 | 9.6 | 10.2 | 11.2 | 11.1 | 11.4 | 12.4 | 10.3 | 9.2 | 8.6 | 9.1 | 10.9 |
| 4 | 15.8 | 10.9 | 10.6 | 11.1 | 9.1 | 11.9 | 8.4 | 9.9 | 12.5 | 11.1 | 7.4 | 6.3 | 10 | 8.1 |
| 5 | 9.4 | 8.5 | 8.3 | 7.4 | 5.5 | 6.7 | 5.4 | 7.4 | 7.8 | 7 | 7.8 | 6.8 | 6.2 | 7.9 |
| 6 | 12.7 | 12.8 | 10.6 | 11.8 | 12.8 | 13.7 | 11.8 | 11.3 | 12.4 | 11.5 | 11.6 | 12.8 | 13.1 | 13.2 |
| 7 | 12 | 11.7 | 11.5 | 9.8 | 12.3 | 9.7 | 10.4 | 11.3 | 11.2 | 11.1 | 9.5 | 13.6 | 10.5 | 11.9 |
| 8 | 9.5 | 7.4 | 6.9 | 8.8 | 9.6 | 8.9 | 7.1 | 8 | 9.4 | 9.5 | 11.4 | 8.9 | 8.7 | 8.8 |
| 9 | 10.9 | 10.9 | 7.6 | 8.3 | 7.3 | 8.3 | 8 | 6.6 | 6.9 | 9.1 | 10.3 | 9.2 | 8.6 | 10.4 |
| 10 | 12.1 | 8.5 | 8.1 | 8.2 | 9.3 | 8.7 | 9 | 7.9 | 9.4 | 8.8 | 8 | 6.2 | 7.9 | 7.8 |
| 11 | 13 | 8.7 | 9.7 | 9.3 | 7.9 | 8 | 7.9 | 7.8 | 8.8 | 9.7 | 10.7 | 9.9 | 9.9 | 11.3 |
| 12 | 11.4 | 8.4 | 8.2 | 7.7 | 9.3 | 9.3 | 9 | 10 | 11.4 | 11.5 | 10.4 | 10.7 | 12 | 9.6 |
| 13 | 10.1 | 8 | 8.7 | 6.9 | 8.4 | 8 | 7.2 | 7.3 | 8.3 | 7.6 | 8.9 | 9.4 | 10.1 | 12.1 |
| 14 | 9.1 | 8.3 | 8.6 | 10.4 | 8.7 | 6.3 | 6.9 | 8.8 | 5.7 | 9.9 | 11.5 | 9.2 | 9.1 | 7.2 |
| 15 | 9.2 | 8.4 | 8.1 | 8.8 | 9.5 | 8.8 | 10.5 | 11.2 | 10.9 | 6.2 | 5.9 | 7.9 | 9.2 | 9.8 |
| 16 | 6.6 | 6.9 | 9.2 | 8.7 | 8.1 | 8.1 | 6.1 | 6.7 | 7.4 | 6.3 | 6.5 | 7.5 | 7.4 | 8.3 |
| 17 | 6.1 | 6.1 | 5.7 | 5.5 | 5.5 | 5.4 | 6.4 | 5.5 | 7.5 | 6.3 | 6.9 | 4.8 | 6.5 | 6.5 |
| 18 | 8.1 | 7.4 | 7.1 | 5.7 | 7.9 | 8.2 | 6.2 | 5 | 5.4 | 6.6 | 7.2 | 6 | 6.9 | 7.1 |
| 19 | 5.2 | 4.8 | 5.3 | 4.8 | 4.4 | 4.3 | 4.6 | 3.9 | 5.5 | 4.5 | 4.4 | 4.2 | 5.8 | 7.5 |
| 20 | 6.5 | 6.2 | 6.2 | 5 | 4.9 | 7.6 | 7.5 | 6.1 | 5.7 | 5.9 | 6.9 | 6.9 | 8.5 | 11.1 |
| 21 | 9 | 7.5 | 7 | 7.2 | 6.1 | 7.3 | 8 | 8.3 | 6.5 | 8 | 5.6 | 8.1 | 11 | 7.9 |
| 22 | 5.8 | 6.6 | 7.5 | 6.6 | 8.5 | 8.8 | 7.2 | 6.7 | 6.4 | 7.6 | 10.2 | 9.9 | 8.7 | 10.1 |
| 23 | 5 | 5.2 | 4.9 | 4.1 | 5.9 | 4 | 3.8 | 3.9 | 4.8 | 5.9 | 5.1 | 4.4 | 6.2 | 6.9 |
| 24 | 5.2 | 4.9 | 6.4 | 7.4 | 4.6 | 5.5 | 3.8 | 4.1 | 4.2 | 4.8 | 5.1 | 3.2 | 4.7 | 4.9 |
| 25 | 5.3 | 4.9 | 5.5 | 4 | 4.6 | 4 | 4 | 4.2 | 3.8 | 4.4 | 4.4 | 4.9 | 5.7 | 5.3 |

Figure 1. Example of required format of demand profile.

### 3.2.2 Missing Individual Data Cells

It was found in a number of cases that there were missing individual pieces of data within the profiles. An example can be seen below in Figure 2 which shows the format of a demand profile – in this case, a Care Home in Scotland is illustrated with half-hourly data resolution. The rows represent a day of the year; the columns represent the time in a half-hourly or hourly period. For monthly data, all cells within the monthly duration of rows (i.e. 30 rows for January; 28 for February etc) would be exactly the same. This level of accuracy is much lower than that of a half-hourly or hourly resolution.

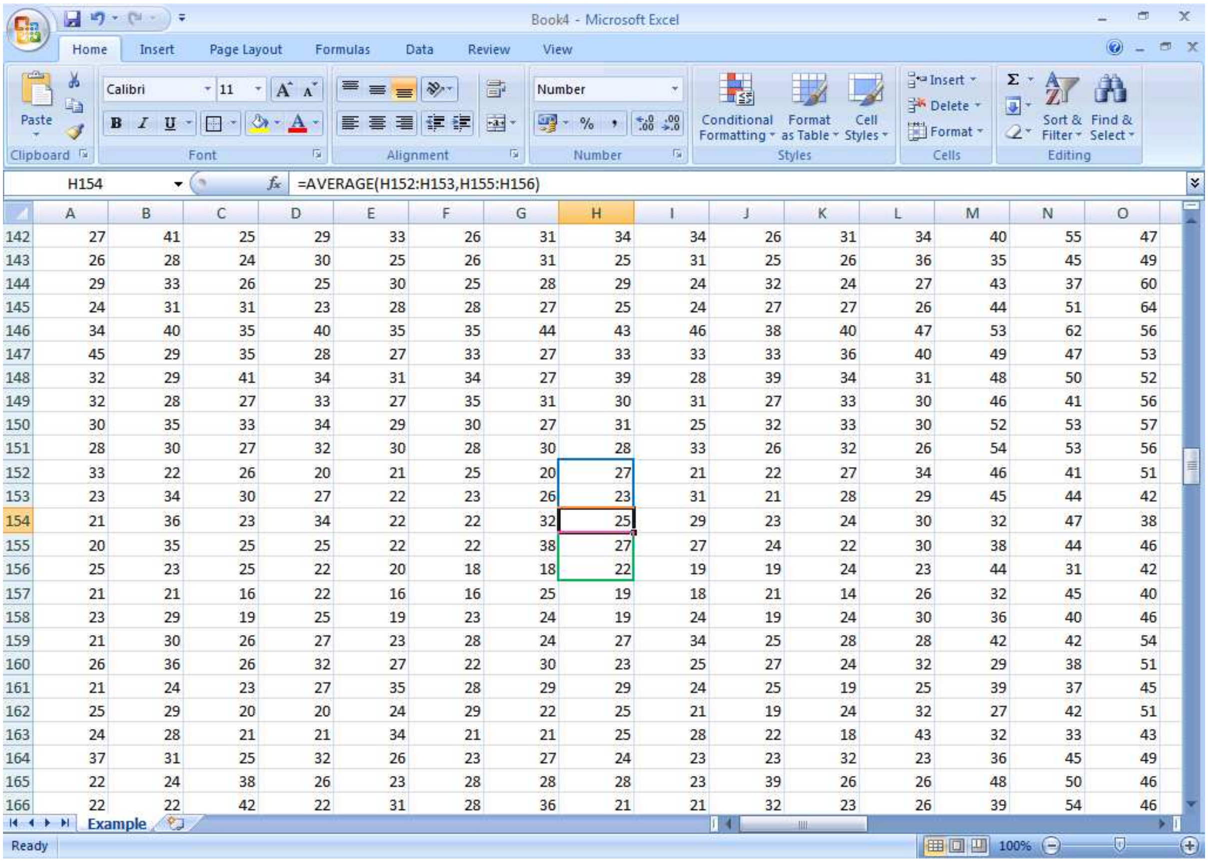
It must be noted that if the demand data contained few missing or inaccurate data – the source will NOT be identified. This decision was made in order to protect the council/organisations' credibility.



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 142 | 27 | 41 | 25 | 29 | 33 | 26 | 31 | 34 | 34 | 26 | 31 | 34 | 40 | 55 | 47 |
| 143 | 26 | 28 | 24 | 30 | 25 | 26 | 31 | 25 | 31 | 25 | 26 | 36 | 35 | 45 | 49 |
| 144 | 29 | 33 | 26 | 25 | 30 | 25 | 28 | 29 | 24 | 32 | 24 | 27 | 43 | 37 | 60 |
| 145 | 24 | 31 | 31 | 23 | 28 | 28 | 27 | 25 | 24 | 27 | 27 | 26 | 44 | 51 | 64 |
| 146 | 34 | 40 | 35 | 40 | 35 | 35 | 44 | 43 | 46 | 38 | 40 | 47 | 53 | 62 | 56 |
| 147 | 45 | 29 | 35 | 28 | 27 | 33 | 27 | 33 | 33 | 33 | 36 | 40 | 49 | 47 | 53 |
| 148 | 32 | 29 | 41 | 34 | 31 | 34 | 27 | 39 | 28 | 39 | 34 | 31 | 48 | 50 | 52 |
| 149 | 32 | 28 | 27 | 33 | 27 | 35 | 31 | 30 | 31 | 27 | 33 | 30 | 46 | 41 | 56 |
| 150 | 30 | 35 | 33 | 34 | 29 | 30 | 27 | 31 | 25 | 32 | 33 | 30 | 52 | 53 | 57 |
| 151 | 28 | 30 | 27 | 32 | 30 | 28 | 30 | 28 | 33 | 26 | 32 | 26 | 54 | 53 | 56 |
| 152 | 33 | 22 | 26 | 20 | 21 | 25 | 20 | 27 | 21 | 22 | 27 | 34 | 46 | 41 | 51 |
| 153 | 23 | 34 | 30 | 27 | 22 | 23 | 26 | 23 | 31 | 21 | 28 | 29 | 45 | 44 | 42 |
| 154 | 21 | 36 | 23 | 34 | 22 | 22 | 32 | | 29 | 23 | 24 | 30 | 32 | 47 | 38 |
| 155 | 20 | 35 | 25 | 25 | 22 | 22 | 38 | 27 | 27 | 24 | 22 | 30 | 38 | 44 | 46 |
| 156 | 25 | 23 | 25 | 22 | 20 | 18 | 18 | 22 | 19 | 19 | 24 | 23 | 44 | 31 | 42 |
| 157 | 21 | 21 | 16 | 22 | 16 | 16 | 25 | 19 | 18 | 21 | 14 | 26 | 32 | 45 | 40 |
| 158 | 23 | 29 | 19 | 25 | 19 | 23 | 24 | 19 | 24 | 19 | 24 | 30 | 36 | 40 | 46 |
| 159 | 21 | 30 | 26 | 27 | 23 | 28 | 24 | 27 | 34 | 25 | 28 | 28 | 42 | 42 | 54 |
| 160 | 26 | 36 | 26 | 32 | 27 | 22 | 30 | 23 | 25 | 27 | 24 | 32 | 29 | 38 | 51 |
| 161 | 21 | 24 | 23 | 27 | 35 | 28 | 29 | 29 | 24 | 25 | 19 | 25 | 39 | 37 | 45 |
| 162 | 25 | 29 | 20 | 20 | 24 | 29 | 22 | 25 | 21 | 19 | 24 | 32 | 27 | 42 | 51 |
| 163 | 24 | 28 | 21 | 21 | 34 | 21 | 21 | 25 | 28 | 22 | 18 | 43 | 32 | 33 | 43 |
| 164 | 37 | 31 | 25 | 32 | 26 | 23 | 27 | 24 | 23 | 23 | 32 | 23 | 36 | 45 | 49 |
| 165 | 22 | 24 | 38 | 26 | 23 | 28 | 28 | 28 | 23 | 39 | 26 | 26 | 48 | 50 | 46 |
| 166 | 22 | 22 | 42 | 22 | 31 | 28 | 36 | 21 | 21 | 32 | 23 | 26 | 39 | 54 | 46 |

Figure 2. Example of a missing individual data cell.

To solve this issue; an average value was determined by taking the value of the corresponding half-hour, 2 days before and 2 days after. Although this rectification is only a calculated approximation, the limit of 4 days was decided in order to maintain a reasonable accuracy around the actual time of day. Increasing this parameter by several days may initially have little impact; however, it would eventually involve data from a different week, different month or albeit season which could greatly affect the outcome. Figure 3 illustrates the process of the calculated approximation.

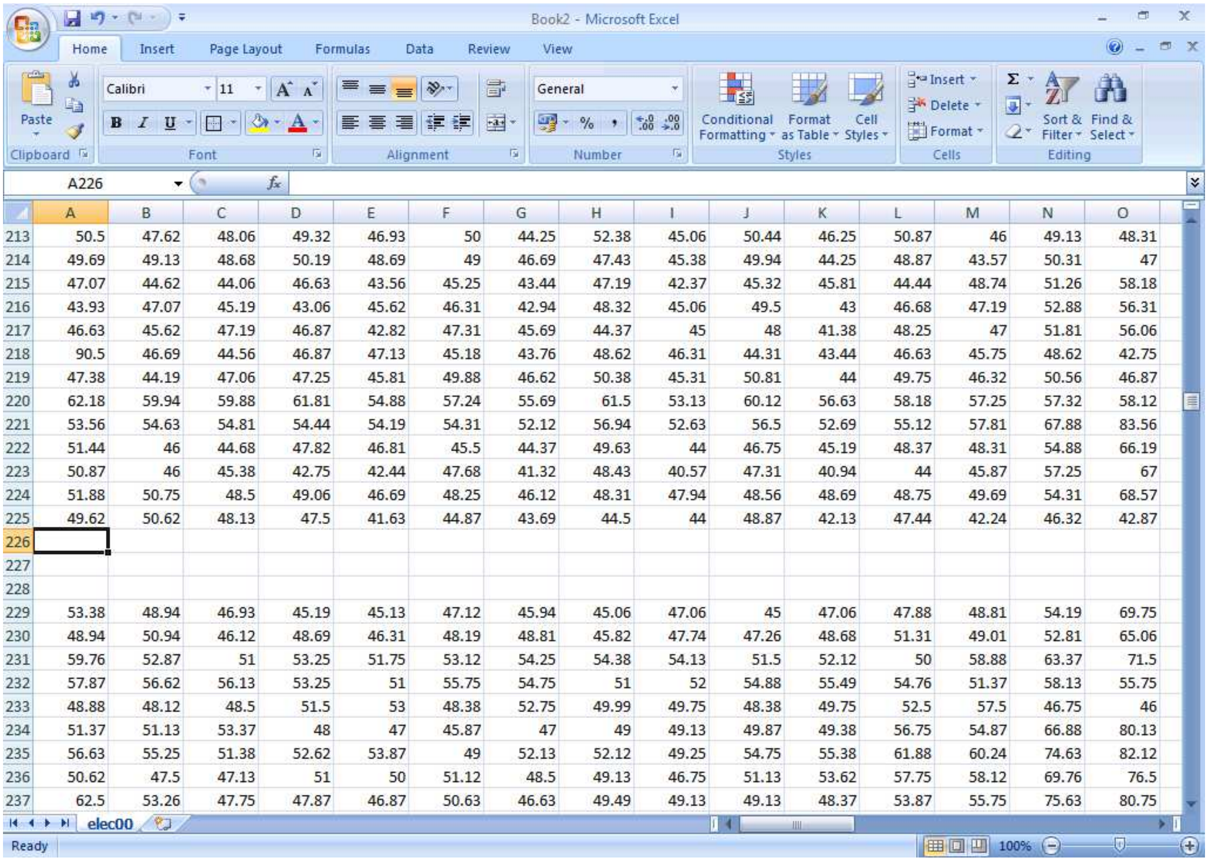



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 142 | 27 | 41 | 25 | 29 | 33 | 26 | 31 | 34 | 34 | 26 | 31 | 34 | 40 | 55 | 47 |
| 143 | 26 | 28 | 24 | 30 | 25 | 26 | 31 | 25 | 31 | 25 | 26 | 36 | 35 | 45 | 49 |
| 144 | 29 | 33 | 26 | 25 | 30 | 25 | 28 | 29 | 24 | 32 | 24 | 27 | 43 | 37 | 60 |
| 145 | 24 | 31 | 31 | 23 | 28 | 28 | 27 | 25 | 24 | 27 | 27 | 26 | 44 | 51 | 64 |
| 146 | 34 | 40 | 35 | 40 | 35 | 35 | 44 | 43 | 46 | 38 | 40 | 47 | 53 | 62 | 56 |
| 147 | 45 | 29 | 35 | 28 | 27 | 33 | 27 | 33 | 33 | 33 | 36 | 40 | 49 | 47 | 53 |
| 148 | 32 | 29 | 41 | 34 | 31 | 34 | 27 | 39 | 28 | 39 | 34 | 31 | 48 | 50 | 52 |
| 149 | 32 | 28 | 27 | 33 | 27 | 35 | 31 | 30 | 31 | 27 | 33 | 30 | 46 | 41 | 56 |
| 150 | 30 | 35 | 33 | 34 | 29 | 30 | 27 | 31 | 25 | 32 | 33 | 30 | 52 | 53 | 57 |
| 151 | 28 | 30 | 27 | 32 | 30 | 28 | 30 | 28 | 33 | 26 | 32 | 26 | 54 | 53 | 56 |
| 152 | 33 | 22 | 26 | 20 | 21 | 25 | 20 | 27 | 21 | 22 | 27 | 34 | 46 | 41 | 51 |
| 153 | 23 | 34 | 30 | 27 | 22 | 23 | 26 | 23 | 31 | 21 | 28 | 29 | 45 | 44 | 42 |
| 154 | 21 | 36 | 23 | 34 | 22 | 22 | 32 | 25 | 29 | 23 | 24 | 30 | 32 | 47 | 38 |
| 155 | 20 | 35 | 25 | 25 | 22 | 22 | 38 | 27 | 27 | 24 | 22 | 30 | 38 | 44 | 46 |
| 156 | 25 | 23 | 25 | 22 | 20 | 18 | 18 | 22 | 19 | 19 | 24 | 23 | 44 | 31 | 42 |
| 157 | 21 | 21 | 16 | 22 | 16 | 16 | 25 | 19 | 18 | 21 | 14 | 26 | 32 | 45 | 40 |
| 158 | 23 | 29 | 19 | 25 | 19 | 23 | 24 | 19 | 24 | 19 | 24 | 30 | 36 | 40 | 46 |
| 159 | 21 | 30 | 26 | 27 | 23 | 28 | 24 | 27 | 34 | 25 | 28 | 28 | 42 | 42 | 54 |
| 160 | 26 | 36 | 26 | 32 | 27 | 22 | 30 | 23 | 25 | 27 | 24 | 32 | 29 | 38 | 51 |
| 161 | 21 | 24 | 23 | 27 | 35 | 28 | 29 | 29 | 24 | 25 | 19 | 25 | 39 | 37 | 45 |
| 162 | 25 | 29 | 20 | 20 | 24 | 29 | 22 | 25 | 21 | 19 | 24 | 32 | 27 | 42 | 51 |
| 163 | 24 | 28 | 21 | 21 | 34 | 21 | 21 | 25 | 28 | 22 | 18 | 43 | 32 | 33 | 43 |
| 164 | 37 | 31 | 25 | 32 | 26 | 23 | 27 | 24 | 23 | 23 | 32 | 23 | 36 | 45 | 49 |
| 165 | 22 | 24 | 38 | 26 | 23 | 28 | 28 | 28 | 23 | 39 | 26 | 26 | 48 | 50 | 46 |
| 166 | 22 | 22 | 42 | 22 | 31 | 28 | 36 | 21 | 21 | 32 | 23 | 26 | 39 | 54 | 46 |

Figure 3. Example of calculated approximation on the missing individual data cell.

### 3.2.3 Missing Daily Data

It was identified in some profiles that there were days, weeks, even a whole month, with no data recorded. Sources have acknowledged this and had stated the duration of the missing data – either within the original data file or on the website containing the data. Reasons for this include damage to the data storage medium, new monitoring system installed during the period of missing data etc. To overcome the problem with data missing for several days, the same calculated approximation used above was applied. The only difference was that the range of cells required to compute the average was expanded. Below, Figure 4 shows a demand profile for an Office in England with 3 days worth of data missing.

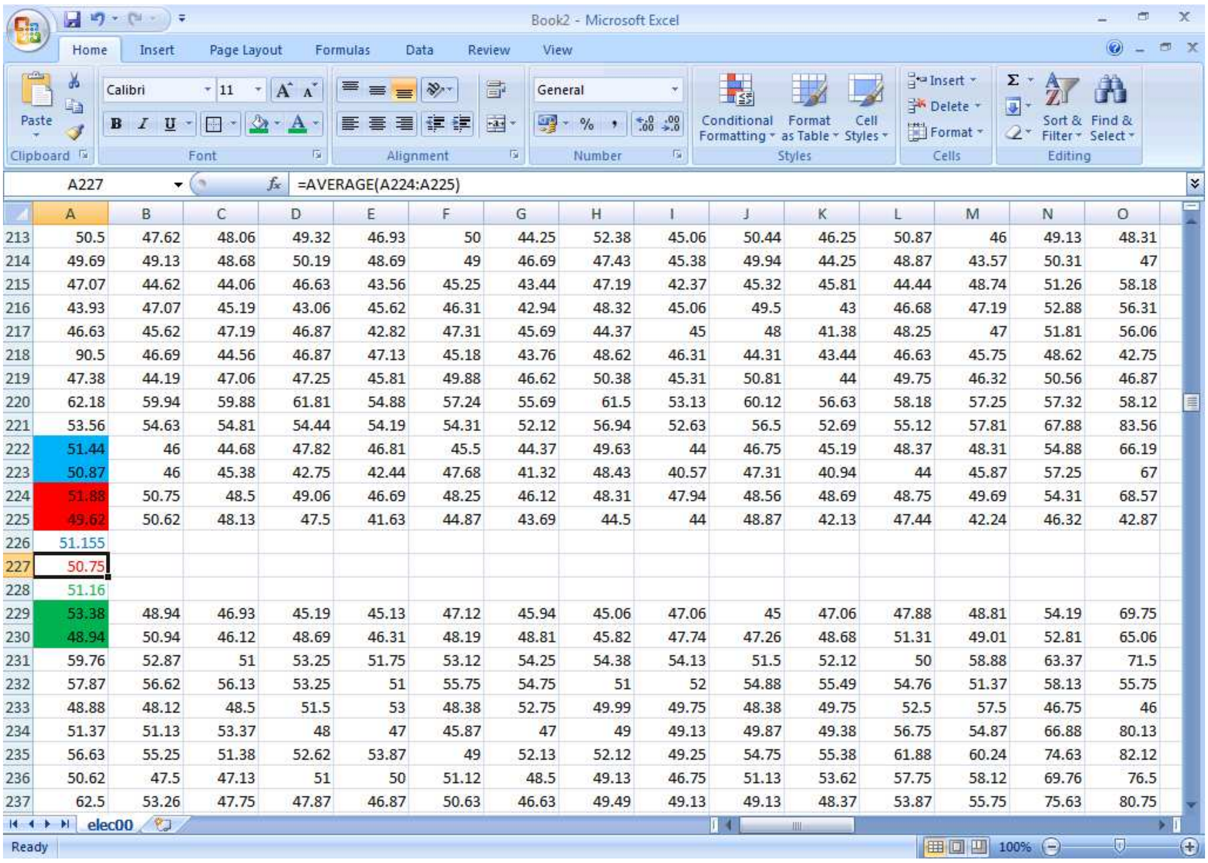



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 213 | 50.5 | 47.62 | 48.06 | 49.32 | 46.93 | 50 | 44.25 | 52.38 | 45.06 | 50.44 | 46.25 | 50.87 | 46 | 49.13 | 48.31 |
| 214 | 49.69 | 49.13 | 48.68 | 50.19 | 48.69 | 49 | 46.69 | 47.43 | 45.38 | 49.94 | 44.25 | 48.87 | 43.57 | 50.31 | 47 |
| 215 | 47.07 | 44.62 | 44.06 | 46.63 | 43.56 | 45.25 | 43.44 | 47.19 | 42.37 | 45.32 | 45.81 | 44.44 | 48.74 | 51.26 | 58.18 |
| 216 | 43.93 | 47.07 | 45.19 | 43.06 | 45.62 | 46.31 | 42.94 | 48.32 | 45.06 | 49.5 | 43 | 46.68 | 47.19 | 52.88 | 56.31 |
| 217 | 46.63 | 45.62 | 47.19 | 46.87 | 42.82 | 47.31 | 45.69 | 44.37 | 45 | 48 | 41.38 | 48.25 | 47 | 51.81 | 56.06 |
| 218 | 90.5 | 46.69 | 44.56 | 46.87 | 47.13 | 45.18 | 43.76 | 48.62 | 46.31 | 44.31 | 43.44 | 46.63 | 45.75 | 48.62 | 42.75 |
| 219 | 47.38 | 44.19 | 47.06 | 47.25 | 45.81 | 49.88 | 46.62 | 50.38 | 45.31 | 50.81 | 44 | 49.75 | 46.32 | 50.56 | 46.87 |
| 220 | 62.18 | 59.94 | 59.88 | 61.81 | 54.88 | 57.24 | 55.69 | 61.5 | 53.13 | 60.12 | 56.63 | 58.18 | 57.25 | 57.32 | 58.12 |
| 221 | 53.56 | 54.63 | 54.81 | 54.44 | 54.19 | 54.31 | 52.12 | 56.94 | 52.63 | 56.5 | 52.69 | 55.12 | 57.81 | 67.88 | 83.56 |
| 222 | 51.44 | 46 | 44.68 | 47.82 | 46.81 | 45.5 | 44.37 | 49.63 | 44 | 46.75 | 45.19 | 48.37 | 48.31 | 54.88 | 66.19 |
| 223 | 50.87 | 46 | 45.38 | 42.75 | 42.44 | 47.68 | 41.32 | 48.43 | 40.57 | 47.31 | 40.94 | 44 | 45.87 | 57.25 | 67 |
| 224 | 51.88 | 50.75 | 48.5 | 49.06 | 46.69 | 48.25 | 46.12 | 48.31 | 47.94 | 48.56 | 48.69 | 48.75 | 49.69 | 54.31 | 68.57 |
| 225 | 49.62 | 50.62 | 48.13 | 47.5 | 41.63 | 44.87 | 43.69 | 44.5 | 44 | 48.87 | 42.13 | 47.44 | 42.24 | 46.32 | 42.87 |
| 226 | | | | | | | | | | | | | | | |
| 227 | | | | | | | | | | | | | | | |
| 228 | | | | | | | | | | | | | | | |
| 229 | 53.38 | 48.94 | 46.93 | 45.19 | 45.13 | 47.12 | 45.94 | 45.06 | 47.06 | 45 | 47.06 | 47.88 | 48.81 | 54.19 | 69.75 |
| 230 | 48.94 | 50.94 | 46.12 | 48.69 | 46.31 | 48.19 | 48.81 | 45.82 | 47.74 | 47.26 | 48.68 | 51.31 | 49.01 | 52.81 | 65.06 |
| 231 | 59.76 | 52.87 | 51 | 53.25 | 51.75 | 53.12 | 54.25 | 54.38 | 54.13 | 51.5 | 52.12 | 50 | 58.88 | 63.37 | 71.5 |
| 232 | 57.87 | 56.62 | 56.13 | 53.25 | 51 | 55.75 | 54.75 | 51 | 52 | 54.88 | 55.49 | 54.76 | 51.37 | 58.13 | 55.75 |
| 233 | 48.88 | 48.12 | 48.5 | 51.5 | 53 | 48.38 | 52.75 | 49.99 | 49.75 | 48.38 | 49.75 | 52.5 | 57.5 | 46.75 | 46 |
| 234 | 51.37 | 51.13 | 53.37 | 48 | 47 | 45.87 | 47 | 49 | 49.13 | 49.87 | 49.38 | 56.75 | 54.87 | 66.88 | 80.13 |
| 235 | 56.63 | 55.25 | 51.38 | 52.62 | 53.87 | 49 | 52.13 | 52.12 | 49.25 | 54.75 | 55.38 | 61.88 | 60.24 | 74.63 | 82.12 |
| 236 | 50.62 | 47.5 | 47.13 | 51 | 50 | 51.12 | 48.5 | 49.13 | 46.75 | 51.13 | 53.62 | 57.75 | 58.12 | 69.76 | 76.5 |
| 237 | 62.5 | 53.26 | 47.75 | 47.87 | 46.87 | 50.63 | 46.63 | 49.49 | 49.13 | 49.13 | 48.37 | 53.87 | 55.75 | 75.63 | 80.75 |

Figure 4. Example of a missing data cluster.

To resolve this issue, 2 data cells of the same hour but on 2 different days would be used to estimate the individual missing cell. This can be seen more clearly in Figure 5 where the coloured NUMBERS represent the result of the calculated approximation; the coloured CELLS represent the data used to calculate the approximation. This process is then repeated for the remaining missing cells.

The accuracy of this technique can be justified by explaining that those 3 days worth of data, in a 365-days year, only accounts for 0.8 % of the annual data. Therefore, the accuracy of the data for the missing 3 days can be viewed as insignificant – provided that the data is reasonable and consistent with the data at the exact same time in the surrounding days.




| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 213 | 50.5 | 47.62 | 48.06 | 49.32 | 46.93 | 50 | 44.25 | 52.38 | 45.06 | 50.44 | 46.25 | 50.87 | 46 | 49.13 | 48.31 |
| 214 | 49.69 | 49.13 | 48.68 | 50.19 | 48.69 | 49 | 46.69 | 47.43 | 45.38 | 49.94 | 44.25 | 48.87 | 43.57 | 50.31 | 47 |
| 215 | 47.07 | 44.62 | 44.06 | 46.63 | 43.56 | 45.25 | 43.44 | 47.19 | 42.37 | 45.32 | 45.81 | 44.44 | 48.74 | 51.26 | 58.18 |
| 216 | 43.93 | 47.07 | 45.19 | 43.06 | 45.62 | 46.31 | 42.94 | 48.32 | 45.06 | 49.5 | 43 | 46.68 | 47.19 | 52.88 | 56.31 |
| 217 | 46.63 | 45.62 | 47.19 | 46.87 | 42.82 | 47.31 | 45.69 | 44.37 | 45 | 48 | 41.38 | 48.25 | 47 | 51.81 | 56.06 |
| 218 | 90.5 | 46.69 | 44.56 | 46.87 | 47.13 | 45.18 | 43.76 | 48.62 | 46.31 | 44.31 | 43.44 | 46.63 | 45.75 | 48.62 | 42.75 |
| 219 | 47.38 | 44.19 | 47.06 | 47.25 | 45.81 | 49.88 | 46.62 | 50.38 | 45.31 | 50.81 | 44 | 49.75 | 46.32 | 50.56 | 46.87 |
| 220 | 62.18 | 59.94 | 59.88 | 61.81 | 54.88 | 57.24 | 55.69 | 61.5 | 53.13 | 60.12 | 56.63 | 58.18 | 57.25 | 57.32 | 58.12 |
| 221 | 53.56 | 54.63 | 54.81 | 54.44 | 54.19 | 54.31 | 52.12 | 56.94 | 52.63 | 56.5 | 52.69 | 55.12 | 57.81 | 67.88 | 83.56 |
| 222 | 51.44 | 46 | 44.68 | 47.82 | 46.81 | 45.5 | 44.37 | 49.63 | 44 | 46.75 | 45.19 | 48.37 | 48.31 | 54.88 | 66.19 |
| 223 | 50.87 | 46 | 45.38 | 42.75 | 42.44 | 47.68 | 41.32 | 48.43 | 40.57 | 47.31 | 40.94 | 44 | 45.87 | 57.25 | 67 |
| 224 | 51.88 | 50.75 | 48.5 | 49.06 | 46.69 | 48.25 | 46.12 | 48.31 | 47.94 | 48.56 | 48.69 | 48.75 | 49.69 | 54.31 | 68.57 |
| 225 | 49.62 | 50.62 | 48.13 | 47.5 | 41.63 | 44.87 | 43.69 | 44.5 | 44 | 48.87 | 42.13 | 47.44 | 42.24 | 46.32 | 42.87 |
| 226 | 51.155 | | | | | | | | | | | | | | |
| 227 | 50.75 | | | | | | | | | | | | | | |
| 228 | 51.16 | | | | | | | | | | | | | | |
| 229 | 53.38 | 48.94 | 46.93 | 45.19 | 45.13 | 47.12 | 45.94 | 45.06 | 47.06 | 45 | 47.06 | 47.88 | 48.81 | 54.19 | 69.75 |
| 230 | 48.94 | 50.94 | 46.12 | 48.69 | 46.31 | 48.19 | 48.81 | 45.82 | 47.74 | 47.26 | 48.68 | 51.31 | 49.01 | 52.81 | 65.06 |
| 231 | 59.76 | 52.87 | 51 | 53.25 | 51.75 | 53.12 | 54.25 | 54.38 | 54.13 | 51.5 | 52.12 | 50 | 58.88 | 63.37 | 71.5 |
| 232 | 57.87 | 56.62 | 56.13 | 53.25 | 51 | 55.75 | 54.75 | 51 | 52 | 54.88 | 55.49 | 54.76 | 51.37 | 58.13 | 55.75 |
| 233 | 48.88 | 48.12 | 48.5 | 51.5 | 53 | 48.38 | 52.75 | 49.99 | 49.75 | 48.38 | 49.75 | 52.5 | 57.5 | 46.75 | 46 |
| 234 | 51.37 | 51.13 | 53.37 | 48 | 47 | 45.87 | 47 | 49 | 49.13 | 49.87 | 49.38 | 56.75 | 54.87 | 66.88 | 80.13 |
| 235 | 56.63 | 55.25 | 51.38 | 52.62 | 53.87 | 49 | 52.13 | 52.12 | 49.25 | 54.75 | 55.38 | 61.88 | 60.24 | 74.63 | 82.12 |
| 236 | 50.62 | 47.5 | 47.13 | 51 | 50 | 51.12 | 48.5 | 49.13 | 46.75 | 51.13 | 53.62 | 57.75 | 58.12 | 69.76 | 76.5 |
| 237 | 62.5 | 53.26 | 47.75 | 47.87 | 46.87 | 50.63 | 46.63 | 49.49 | 49.13 | 49.13 | 48.37 | 53.87 | 55.75 | 75.63 | 80.75 |

Figure 5. Example of calculated approximation on the missing data cluster.

3.2.4 Missing Weekly/Monthly Data

Unfortunately, there were several demand profiles with data missing between 4 weeks and a whole month – both of which accounts for 7.7 % and ~8.5 % respectively. These datasets were originally collected by the Buildings Research Establishment (BRE) and describe the hourly electrical and gas consumption rates of the houses which are examined in this project. The reason for the missing data is due to damage to the storage medium. An example of the problem is shown in Figure 6.

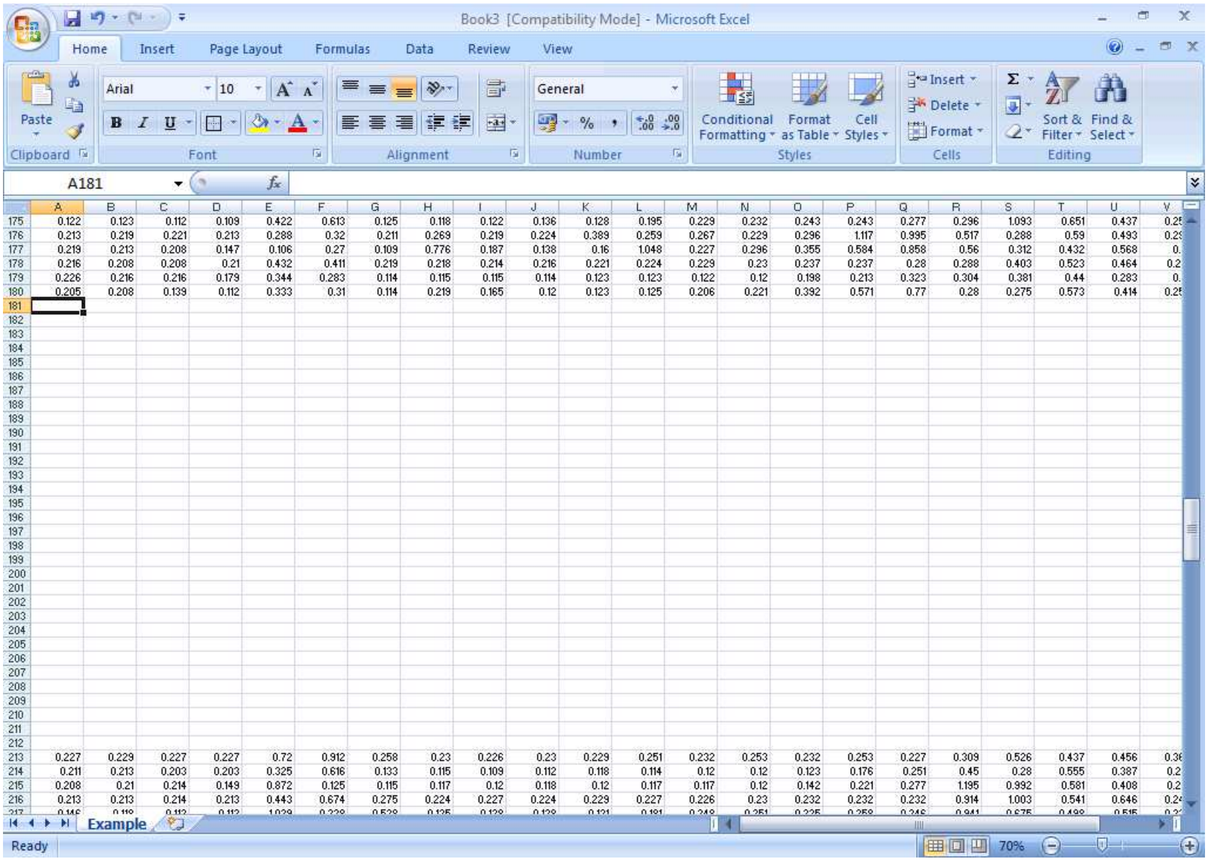
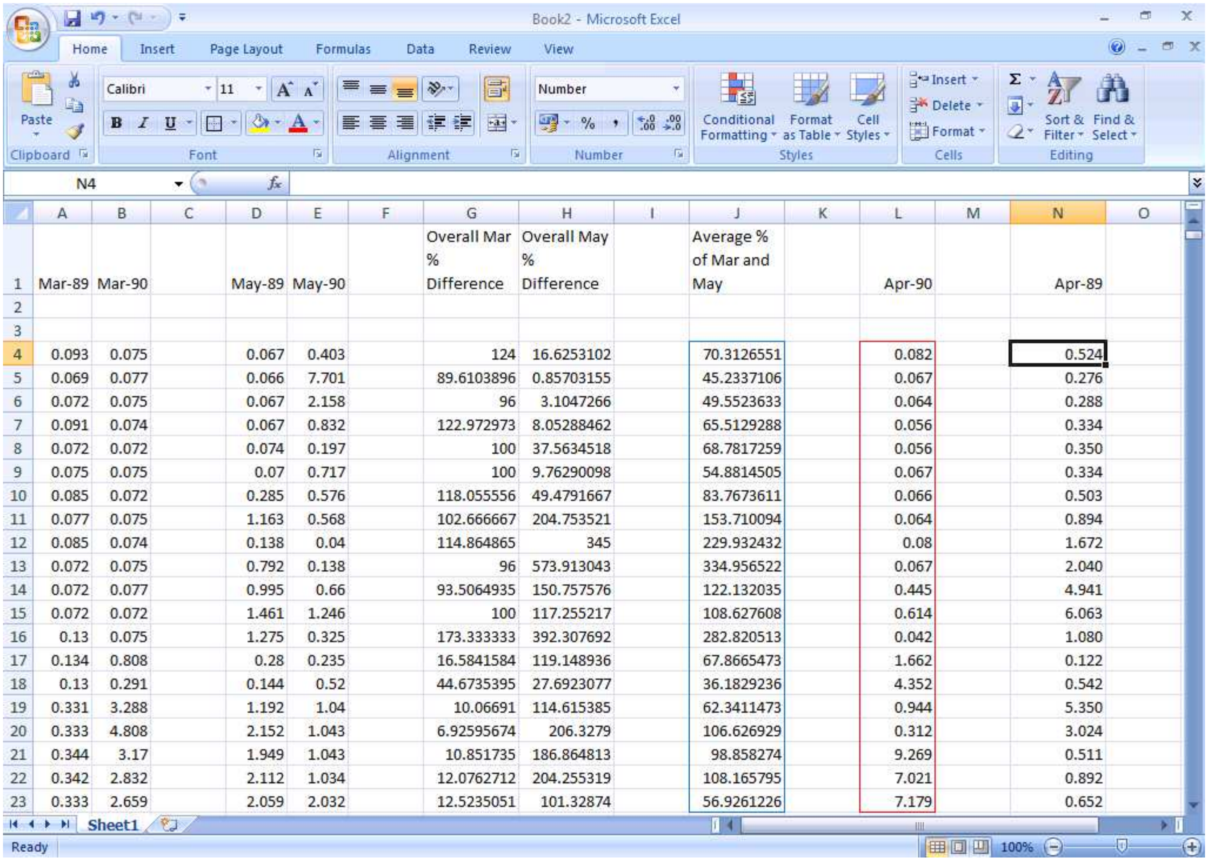



Figure 6. Example of missing weekly/monthly data.

No data is accessible for the month of April 1989; however, the original profile contained data over a 2-3 year period. To resolve this problem, data from March 1989 and May 1989 were compared to March 1990 and May 1990 respectively. An average percentage difference was calculated for each hour in March and May which was then applied to the hourly data in April 1990. This provided a reasonable estimate to what the data would have been in April 1989 as shown in Figure 7.



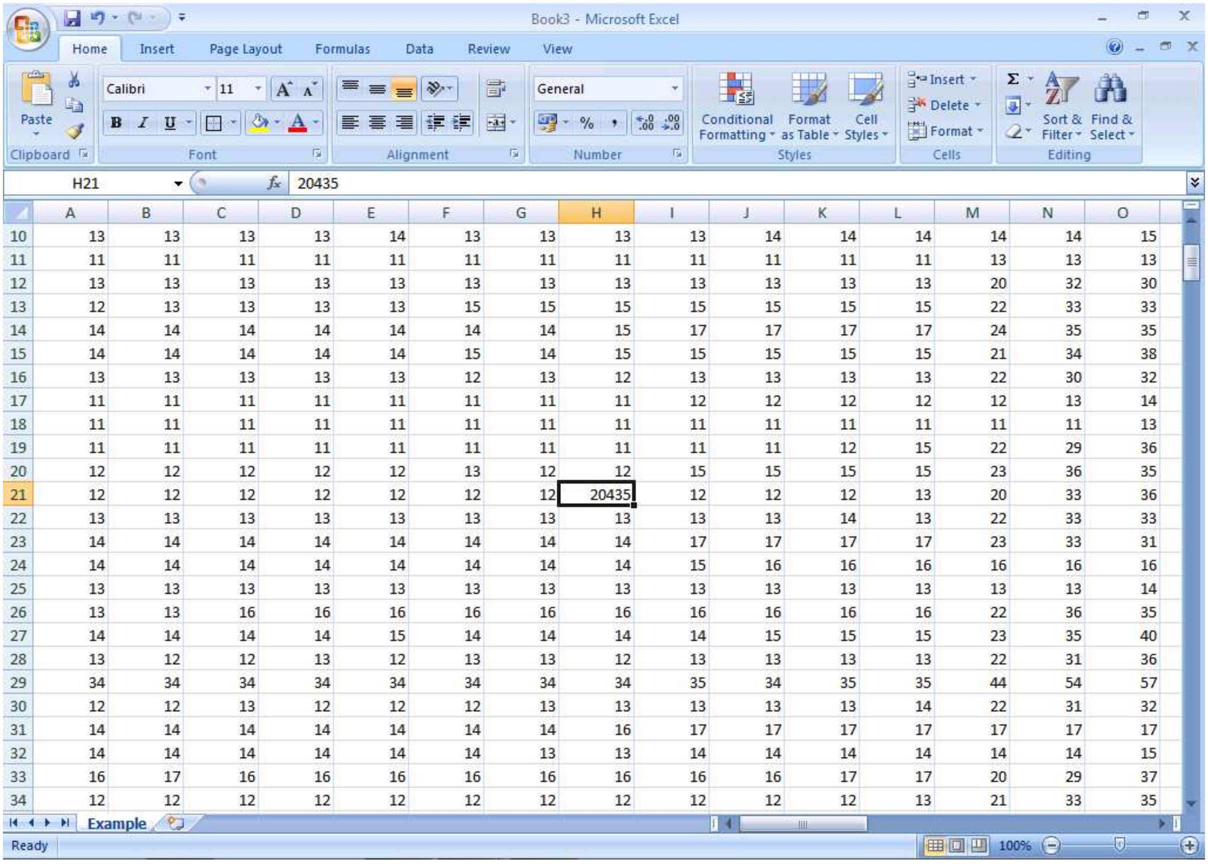
| | Mar-89 | Mar-90 | May-89 | May-90 | Overall Mar % Difference | Overall May % Difference | Average % of Mar and May | Apr-90 | Apr-89 |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 0.093 | 0.075 | 0.067 | 0.403 | 124 | 16.6253102 | 70.3126551 | 0.082 | 0.524 |
| 5 | 0.069 | 0.077 | 0.066 | 7.701 | 89.6103896 | 0.85703155 | 45.2337106 | 0.067 | 0.276 |
| 6 | 0.072 | 0.075 | 0.067 | 2.158 | 96 | 3.1047266 | 49.5523633 | 0.064 | 0.288 |
| 7 | 0.091 | 0.074 | 0.067 | 0.832 | 122.972973 | 8.05288462 | 65.5129288 | 0.056 | 0.334 |
| 8 | 0.072 | 0.072 | 0.074 | 0.197 | 100 | 37.5634518 | 68.7817259 | 0.056 | 0.350 |
| 9 | 0.075 | 0.075 | 0.07 | 0.717 | 100 | 9.76290098 | 54.8814505 | 0.067 | 0.334 |
| 10 | 0.085 | 0.072 | 0.285 | 0.576 | 118.055556 | 49.4791667 | 83.7673611 | 0.066 | 0.503 |
| 11 | 0.077 | 0.075 | 1.163 | 0.568 | 102.666667 | 204.753521 | 153.710094 | 0.064 | 0.894 |
| 12 | 0.085 | 0.074 | 0.138 | 0.04 | 114.864865 | 345 | 229.932432 | 0.08 | 1.672 |
| 13 | 0.072 | 0.075 | 0.792 | 0.138 | 96 | 573.913043 | 334.956522 | 0.067 | 2.040 |
| 14 | 0.072 | 0.077 | 0.995 | 0.66 | 93.5064935 | 150.757576 | 122.132035 | 0.445 | 4.941 |
| 15 | 0.072 | 0.072 | 1.461 | 1.246 | 100 | 117.255217 | 108.627608 | 0.614 | 6.063 |
| 16 | 0.13 | 0.075 | 1.275 | 0.325 | 173.333333 | 392.307692 | 282.820513 | 0.042 | 1.080 |
| 17 | 0.134 | 0.808 | 0.28 | 0.235 | 16.5841584 | 119.148936 | 67.8665473 | 1.662 | 0.122 |
| 18 | 0.13 | 0.291 | 0.144 | 0.52 | 44.6735395 | 27.6923077 | 36.1829236 | 4.352 | 0.542 |
| 19 | 0.331 | 3.288 | 1.192 | 1.04 | 10.06691 | 114.615385 | 62.3411473 | 0.944 | 5.350 |
| 20 | 0.333 | 4.808 | 2.152 | 1.043 | 6.92595674 | 206.3279 | 106.626929 | 0.312 | 3.024 |
| 21 | 0.344 | 3.17 | 1.949 | 1.043 | 10.851735 | 186.864813 | 98.858274 | 9.269 | 0.511 |
| 22 | 0.342 | 2.832 | 2.112 | 1.034 | 12.0762712 | 204.255319 | 108.165795 | 7.021 | 0.892 |
| 23 | 0.333 | 2.659 | 2.059 | 2.032 | 12.5235051 | 101.32874 | 56.9261226 | 7.179 | 0.652 |

Figure 7. Example of calculating the average percentage difference.

The calculated approximation of the data for April 1989 is then imported into the original demand profile where the real data would have been. This process was applied to a small number of demand profiles with several weeks of data missing.

### 3.2.5 Inaccurate or Unreliable Data

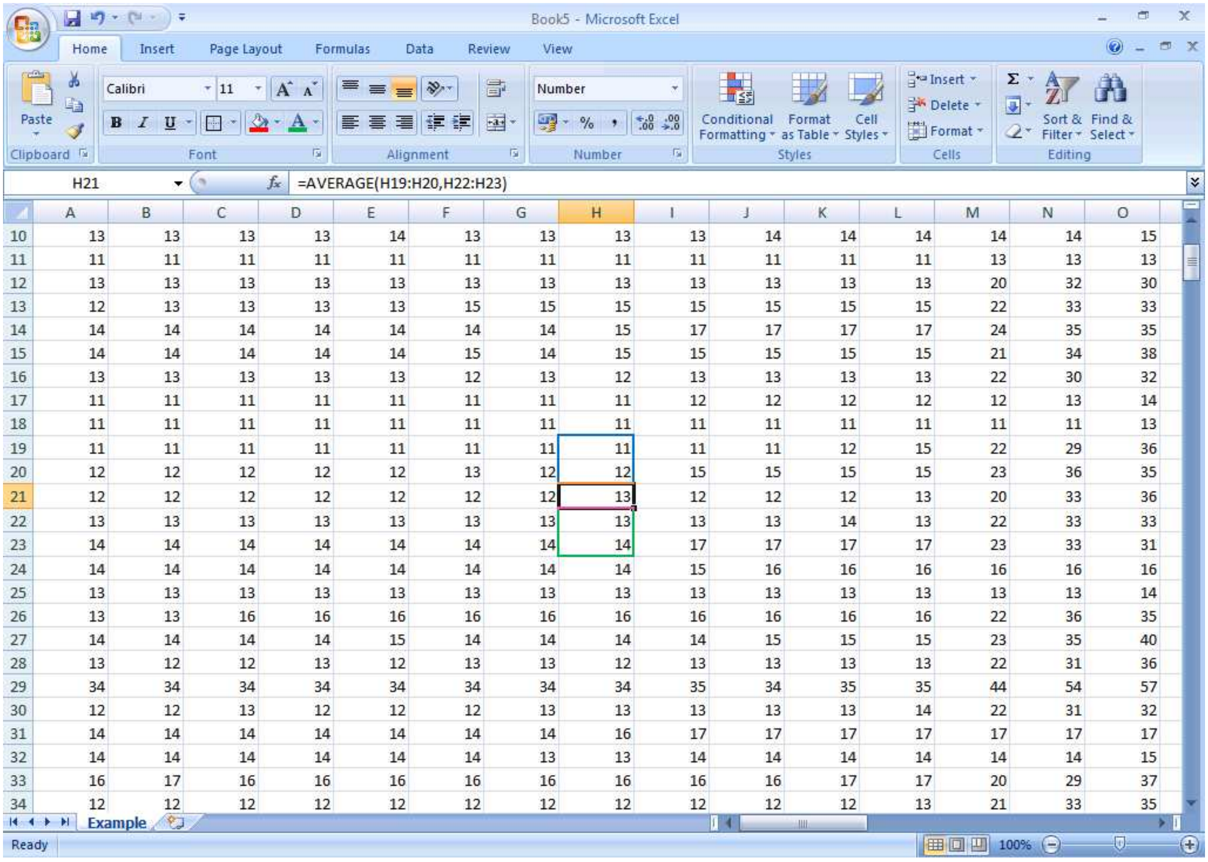
In few cases, there were data cells in which the data was found to be completely inaccurate and illogical. These usually contained values which were 10,000x greater than a typical demand value for that particular type of building. Figure 8 portrays a High School in Scotland with a half-hourly data resolution.




| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 13 | 13 | 13 | 13 | 14 | 13 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 13 | 13 | 13 |
| 12 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 20 | 32 | 30 |
| 13 | 12 | 13 | 13 | 13 | 13 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 22 | 33 | 33 |
| 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 15 | 17 | 17 | 17 | 17 | 24 | 35 | 35 |
| 15 | 14 | 14 | 14 | 14 | 14 | 15 | 14 | 15 | 15 | 15 | 15 | 15 | 21 | 34 | 38 |
| 16 | 13 | 13 | 13 | 13 | 13 | 12 | 13 | 12 | 13 | 13 | 13 | 13 | 22 | 30 | 32 |
| 17 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 12 | 13 | 14 |
| 18 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 13 |
| 19 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 12 | 15 | 22 | 29 | 36 |
| 20 | 12 | 12 | 12 | 12 | 12 | 13 | 12 | 12 | 15 | 15 | 15 | 15 | 23 | 36 | 35 |
| 21 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 20435 | 12 | 12 | 12 | 13 | 20 | 33 | 36 |
| 22 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 14 | 13 | 22 | 33 | 33 |
| 23 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 17 | 17 | 17 | 17 | 23 | 33 | 31 |
| 24 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 15 | 16 | 16 | 16 | 16 | 16 | 16 |
| 25 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 14 |
| 26 | 13 | 13 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 22 | 36 | 35 |
| 27 | 14 | 14 | 14 | 14 | 15 | 14 | 14 | 14 | 14 | 15 | 15 | 15 | 23 | 35 | 40 |
| 28 | 13 | 12 | 12 | 13 | 12 | 13 | 13 | 12 | 13 | 13 | 13 | 13 | 22 | 31 | 36 |
| 29 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 35 | 34 | 35 | 35 | 44 | 54 | 57 |
| 30 | 12 | 12 | 13 | 12 | 12 | 12 | 13 | 13 | 13 | 13 | 13 | 14 | 22 | 31 | 32 |
| 31 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 16 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| 32 | 14 | 14 | 14 | 14 | 14 | 14 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 15 |
| 33 | 16 | 17 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 17 | 17 | 20 | 29 | 37 |
| 34 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 13 | 21 | 33 | 35 |

Figure 8. Example of inaccurate data.

It is unclear whether or not this was a mistake when the data was recorded or imported into software. Regardless, the same calculated approximation process as used for the missing data was employed and is shown in Figure 9.

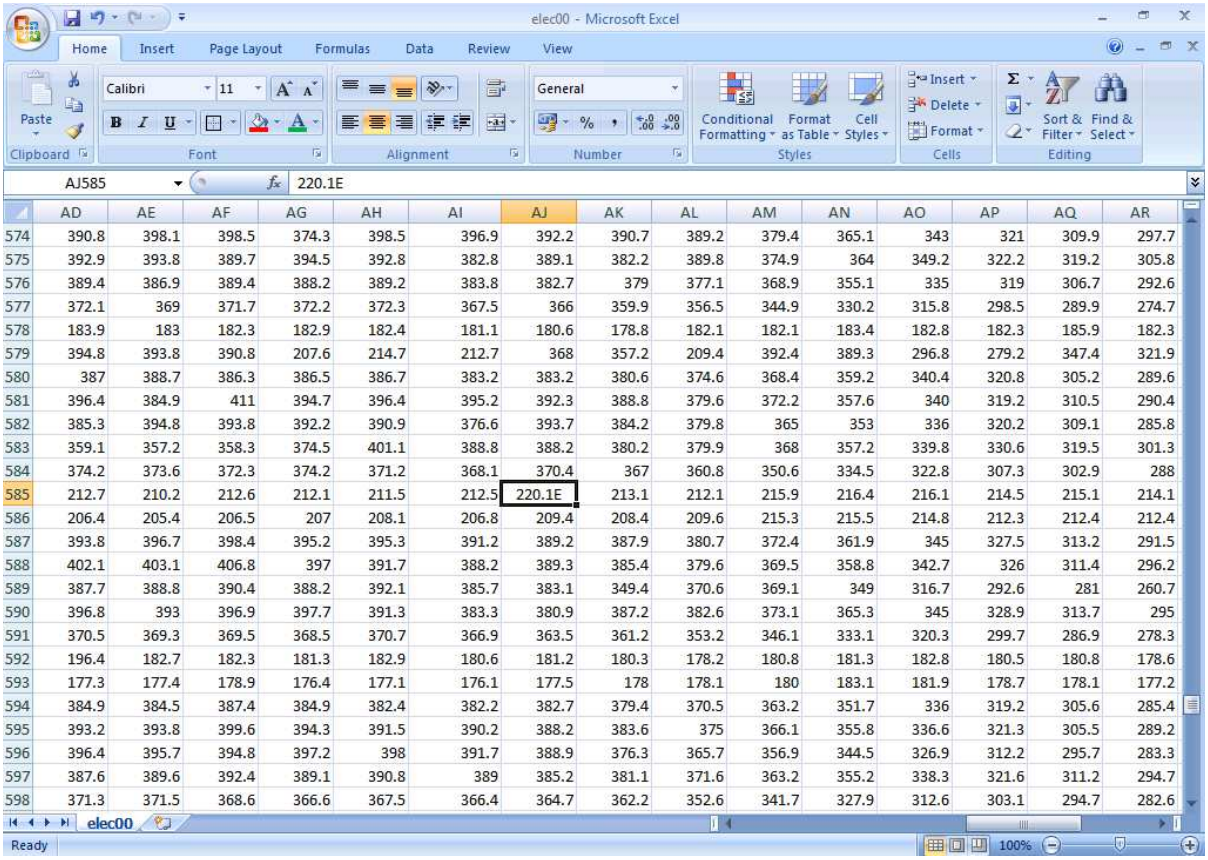


| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 13 | 13 | 13 | 13 | 14 | 13 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 15 |
| 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 13 | 13 | 13 |
| 12 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 20 | 32 | 30 |
| 13 | 12 | 13 | 13 | 13 | 13 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 22 | 33 | 33 |
| 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 15 | 17 | 17 | 17 | 17 | 24 | 35 | 35 |
| 15 | 14 | 14 | 14 | 14 | 14 | 15 | 14 | 15 | 15 | 15 | 15 | 15 | 21 | 34 | 38 |
| 16 | 13 | 13 | 13 | 13 | 13 | 12 | 13 | 12 | 13 | 13 | 13 | 13 | 22 | 30 | 32 |
| 17 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 12 | 12 | 12 | 12 | 12 | 13 | 14 |
| 18 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 13 |
| 19 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 12 | 15 | 22 | 29 | 36 |
| 20 | 12 | 12 | 12 | 12 | 12 | 13 | 12 | 12 | 15 | 15 | 15 | 15 | 23 | 36 | 35 |
| 21 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 13 | 12 | 12 | 12 | 13 | 20 | 33 | 36 |
| 22 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 14 | 13 | 22 | 33 | 33 |
| 23 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 17 | 17 | 17 | 17 | 23 | 33 | 31 |
| 24 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 15 | 16 | 16 | 16 | 16 | 16 | 16 |
| 25 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 14 |
| 26 | 13 | 13 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 22 | 36 | 35 |
| 27 | 14 | 14 | 14 | 14 | 15 | 14 | 14 | 14 | 14 | 15 | 15 | 15 | 23 | 35 | 40 |
| 28 | 13 | 12 | 12 | 13 | 12 | 13 | 13 | 12 | 13 | 13 | 13 | 13 | 22 | 31 | 36 |
| 29 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 35 | 34 | 35 | 35 | 44 | 54 | 57 |
| 30 | 12 | 12 | 13 | 12 | 12 | 12 | 13 | 13 | 13 | 13 | 13 | 14 | 22 | 31 | 32 |
| 31 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 16 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| 32 | 14 | 14 | 14 | 14 | 14 | 14 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 15 |
| 33 | 16 | 17 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 17 | 17 | 20 | 29 | 37 |
| 34 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 13 | 21 | 33 | 35 |



Figure 9. Example of calculated approximation on inaccurate data.

A small number of demand profiles also contained values which are considered defective. Again the reasons for this are unclear. The sources of such profiles mention a similar statement which basically reads the following: “numbers followed by an 'E' are unreliable numbers”. Figure 10 shows a cell with unreliable data, this too is solved by conducting a calculated approximation.




| | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM | AN | AO | AP | AQ | AR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 574 | 390.8 | 398.1 | 398.5 | 374.3 | 398.5 | 396.9 | 392.2 | 390.7 | 389.2 | 379.4 | 365.1 | 343 | 321 | 309.9 | 297.7 |
| 575 | 392.9 | 393.8 | 389.7 | 394.5 | 392.8 | 382.8 | 389.1 | 382.2 | 389.8 | 374.9 | 364 | 349.2 | 322.2 | 319.2 | 305.8 |
| 576 | 389.4 | 386.9 | 389.4 | 388.2 | 389.2 | 383.8 | 382.7 | 379 | 377.1 | 368.9 | 355.1 | 335 | 319 | 306.7 | 292.6 |
| 577 | 372.1 | 369 | 371.7 | 372.2 | 372.3 | 367.5 | 366 | 359.9 | 356.5 | 344.9 | 330.2 | 315.8 | 298.5 | 289.9 | 274.7 |
| 578 | 183.9 | 183 | 182.3 | 182.9 | 182.4 | 181.1 | 180.6 | 178.8 | 182.1 | 182.1 | 183.4 | 182.8 | 182.3 | 185.9 | 182.3 |
| 579 | 394.8 | 393.8 | 390.8 | 207.6 | 214.7 | 212.7 | 368 | 357.2 | 209.4 | 392.4 | 389.3 | 296.8 | 279.2 | 347.4 | 321.9 |
| 580 | 387 | 388.7 | 386.3 | 386.5 | 386.7 | 383.2 | 383.2 | 380.6 | 374.6 | 368.4 | 359.2 | 340.4 | 320.8 | 305.2 | 289.6 |
| 581 | 396.4 | 384.9 | 411 | 394.7 | 396.4 | 395.2 | 392.3 | 388.8 | 379.6 | 372.2 | 357.6 | 340 | 319.2 | 310.5 | 290.4 |
| 582 | 385.3 | 394.8 | 393.8 | 392.2 | 390.9 | 376.6 | 393.7 | 384.2 | 379.8 | 365 | 353 | 336 | 320.2 | 309.1 | 285.8 |
| 583 | 359.1 | 357.2 | 358.3 | 374.5 | 401.1 | 388.8 | 388.2 | 380.2 | 379.9 | 368 | 357.2 | 339.8 | 330.6 | 319.5 | 301.3 |
| 584 | 374.2 | 373.6 | 372.3 | 374.2 | 371.2 | 368.1 | 370.4 | 367 | 360.8 | 350.6 | 334.5 | 322.8 | 307.3 | 302.9 | 288 |
| 585 | 212.7 | 210.2 | 212.6 | 212.1 | 211.5 | 212.5 | 220.1E | 213.1 | 212.1 | 215.9 | 216.4 | 216.1 | 214.5 | 215.1 | 214.1 |
| 586 | 206.4 | 205.4 | 206.5 | 207 | 208.1 | 206.8 | 209.4 | 208.4 | 209.6 | 215.3 | 215.5 | 214.8 | 212.3 | 212.4 | 212.4 |
| 587 | 393.8 | 396.7 | 398.4 | 395.2 | 395.3 | 391.2 | 389.2 | 387.9 | 380.7 | 372.4 | 361.9 | 345 | 327.5 | 313.2 | 291.5 |
| 588 | 402.1 | 403.1 | 406.8 | 397 | 391.7 | 388.2 | 389.3 | 385.4 | 379.6 | 369.5 | 358.8 | 342.7 | 326 | 311.4 | 296.2 |
| 589 | 387.7 | 388.8 | 390.4 | 388.2 | 392.1 | 385.7 | 383.1 | 349.4 | 370.6 | 369.1 | 349 | 316.7 | 292.6 | 281 | 260.7 |
| 590 | 396.8 | 393 | 396.9 | 397.7 | 391.3 | 383.3 | 380.9 | 387.2 | 382.6 | 373.1 | 365.3 | 345 | 328.9 | 313.7 | 295 |
| 591 | 370.5 | 369.3 | 369.5 | 368.5 | 370.7 | 366.9 | 363.5 | 361.2 | 353.2 | 346.1 | 333.1 | 320.3 | 299.7 | 286.9 | 278.3 |
| 592 | 196.4 | 182.7 | 182.3 | 181.3 | 182.9 | 180.6 | 181.2 | 180.3 | 178.2 | 180.8 | 181.3 | 182.8 | 180.5 | 180.8 | 178.6 |
| 593 | 177.3 | 177.4 | 178.9 | 176.4 | 177.1 | 176.1 | 177.5 | 178 | 178.1 | 180 | 183.1 | 181.9 | 178.7 | 178.1 | 177.2 |
| 594 | 384.9 | 384.5 | 387.4 | 384.9 | 382.4 | 382.2 | 382.7 | 379.4 | 370.5 | 363.2 | 351.7 | 336 | 319.2 | 305.6 | 285.4 |
| 595 | 393.2 | 393.8 | 399.6 | 394.3 | 391.5 | 390.2 | 388.2 | 383.6 | 375 | 366.1 | 355.8 | 336.6 | 321.3 | 305.5 | 289.2 |
| 596 | 396.4 | 395.7 | 394.8 | 397.2 | 398 | 391.7 | 388.9 | 376.3 | 365.7 | 356.9 | 344.5 | 326.9 | 312.2 | 295.7 | 283.3 |
| 597 | 387.6 | 389.6 | 392.4 | 389.1 | 390.8 | 389 | 385.2 | 381.1 | 371.6 | 363.2 | 355.2 | 338.3 | 321.6 | 311.2 | 294.7 |
| 598 | 371.3 | 371.5 | 368.6 | 366.6 | 367.5 | 366.4 | 364.7 | 362.2 | 352.6 | 341.7 | 327.9 | 312.6 | 303.1 | 294.7 | 282.6 |

Figure 10. Example of unreliable data.

# Chapter 4: Generic Demand Profile Generation

Once all the demand profiles were categorised, as shown in ***Chapter 3; Table 5***, and refined, further analysis was conducted to determine vital pieces of information for the particular building. This included calculating and establishing the floor area, average daily occupancy, annual energy consumption rate, annual energy consumption rate per floor area etc. The next stage consisted of generating Generic Profiles – an electrical/thermal demand profile to convey a typical profile for a given building type. For this, various pieces of data such as the floor area, average daily occupancy, annual energy consumption per floor area etc were used to calculate an overall average.

It should be noted that when constructing the Generic Profiles, not all of the demand profiles were used for that particular building type. In order to achieve the highest accuracy possible with the data provided, the annual electrical consumption per floor area (AECFA) was used for Generic Profiling due to all buildings possessing electrical data. This was compared with other profiles for the same type of building and those which had a relatively similar value were utilised. However, the Generic Profile may also contain annual gas consumption per floor area (AGCFA) data if the associated buildings contained sufficient thermal data. Both Generic AECFA and Generic AGCFA were calculated by dividing the Generic annual electric/gas consumption with the Generic floor area for each building type – another method would have been to average the AECFA or AGCFA of the buildings to obtain a Generic value, however, this was not done as the entire process would no longer be consistent.

The analysis of the demand profiles for the various types of buildings will now be discussed in greater detail. Please note that only the information used for analysis and Generic Profiling are displayed in this section. For more detailed information such as the year of build, the councils which provided data, Energy Performance Certificate (EPC) or Display Energy Certificate (DEC) ratings etc, please check the Profile Library (described in ***Chapter 5***).

## 4.1 Care Home

Significant information for the 7 Care Homes, all of which were based in Scotland, is shown in Table 6, these profiles were provided by 5 Scottish Councils. The period of the data in which the demand profiles were recorded is 2011-2012. It is very clear that each Care Home has differing floor areas and average daily occupancy, the results of which could have considerable effects to energy consumption.

However, this is not always the case as can be seen with Bonnyton House Care Home from East Renfrewshire and Muirpark Care Home from North Lanarkshire. Both of these dwellings contain a floor area of 1,440 $m^2$ and 1,416 $m^2$ respectively; and an average daily occupancy of 34 and 40 respectively. Although both these buildings are similar in these respects, Bonnyton House consumes almost 4x more electricity (at 257,465 kWh/y) and 2x more gas (at 802,174 kWh/y) than does Muirpark. This can be due to a number of reasons such as the energy efficiency of the building, number and sophistication of equipment within the building etc.

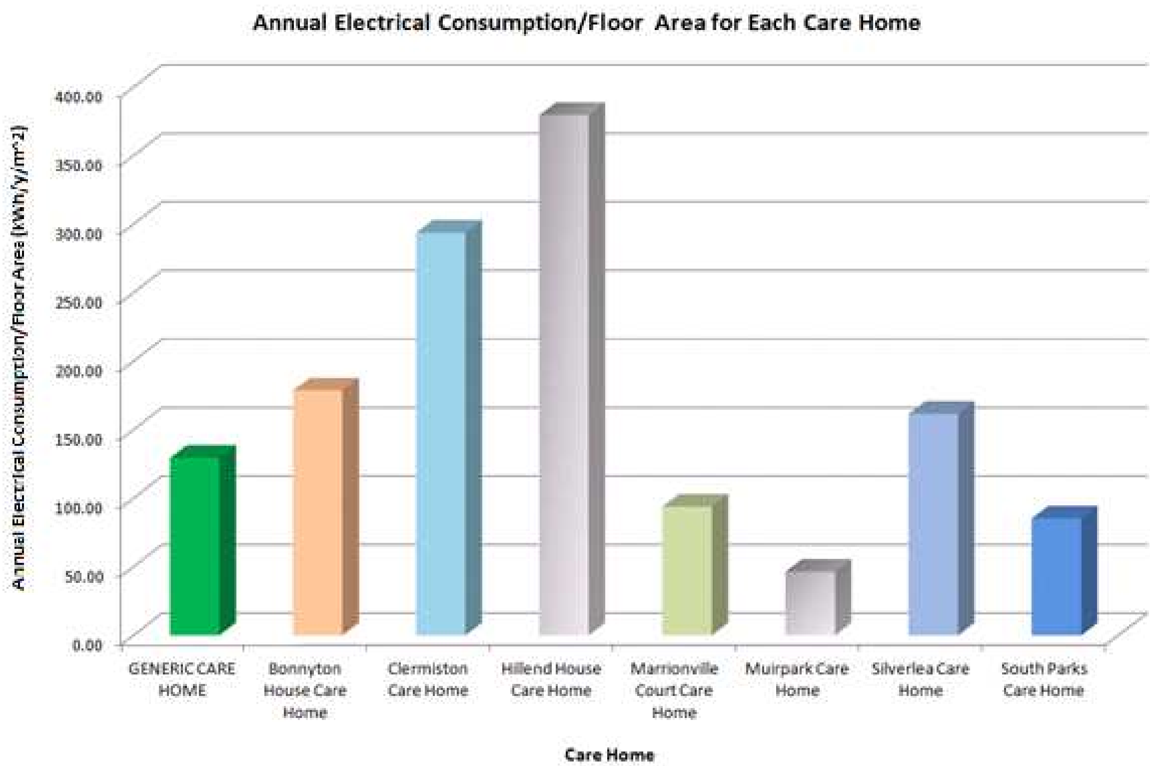
| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| GENERIC CARE HOME | 307,058.82 | 573,216.85 | 129.75 | 242.21 | 2,367 | 40 |
| Bonnyton House Care Home | 257,464.56 | 802,173.98 | 178.79 | 557.07 | 1,440 | 34 |
| Clermiston Care Home | 735,664.00 | - | 294.03 | - | 2,502 | 36 |
| Hillend House Care Home | 230,023.60 | - | 379.58 | - | 606 | 50 |
| Marrionville Court Care Home | 390,780.70 | - | 94.07 | - | 4,154 | 60 |
| Muirpark Care Home | 65,970.20 | 388,689.00 | 46.59 | 274.50 | 1,416 | 40 |
| Silverlea Care Home | 327,149.40 | - | 161.64 | - | 2,024 | 38 |
| South Parks Care Home | 146,336.11 | 528,787.56 | 85.43 | 308.69 | 1,713 | 32 |

Table 6. Care Home Data.

4.1.1 Generic Care Home

When generating the Generic Profile for the Care Home, 5 of the 7 buildings were used due to the major difference in the AECFA. Those that were excluded are Hillend House Care Home and Muirpark Care Home with the difference between them being 332.99 kWh/y/m$^2$; they possessed the maximum and minimum AECFA of 46.59 kWh/y/m$^2$ and 379.58 kWh/y/m$^2$ respectively.

The remaining buildings contained a more similar AECFA. The difference between the Care Homes with the next minimum and maximum AECFA was 208.60 kWh/y/m$^2$. It was then decided that these 5 Care Homes would be used to generate the Generic Profile as shown in Graph 4 which had an AECFA of 129.75 kWh/y/m$^2$. The lower the difference between the maximum and minimum AECFA and AGCFA, the more accurate the Generic Profile. The AGCFA was also found to be 242.21 kWh/y/m$^2$, although the accuracy for this factor is less than the AECFA due to only two annual gas consumption rates being observed compared to the 5 annual electric consumption rates.




Graph 4. Annual electrical consumption/floor area for each Care Home.

## 4.2 Community Centre

Five Community Centres were analysed, all of which were based in Scotland and provided by 3 Scottish Councils, the period in which these demand profiles were recorded was 2011-2012. Table 7 shows various pieces of important information concerning the Community Centres such as their corresponding floor areas: this varies greatly – from 272 $m^2$ for the Albertslund Community Centre to 1,885 $m^2$ for the Inch Community Education Centre. Unfortunately, the only annual gas consumption value recorded for these buildings was 54,000 kWh for the Albertslund Community Centre. This also held the lowest annual consumption rate for electricity which was 5,948 kWh/y compared to the highest value of 140,710 kWh/y held by Inch Community Education Centre.

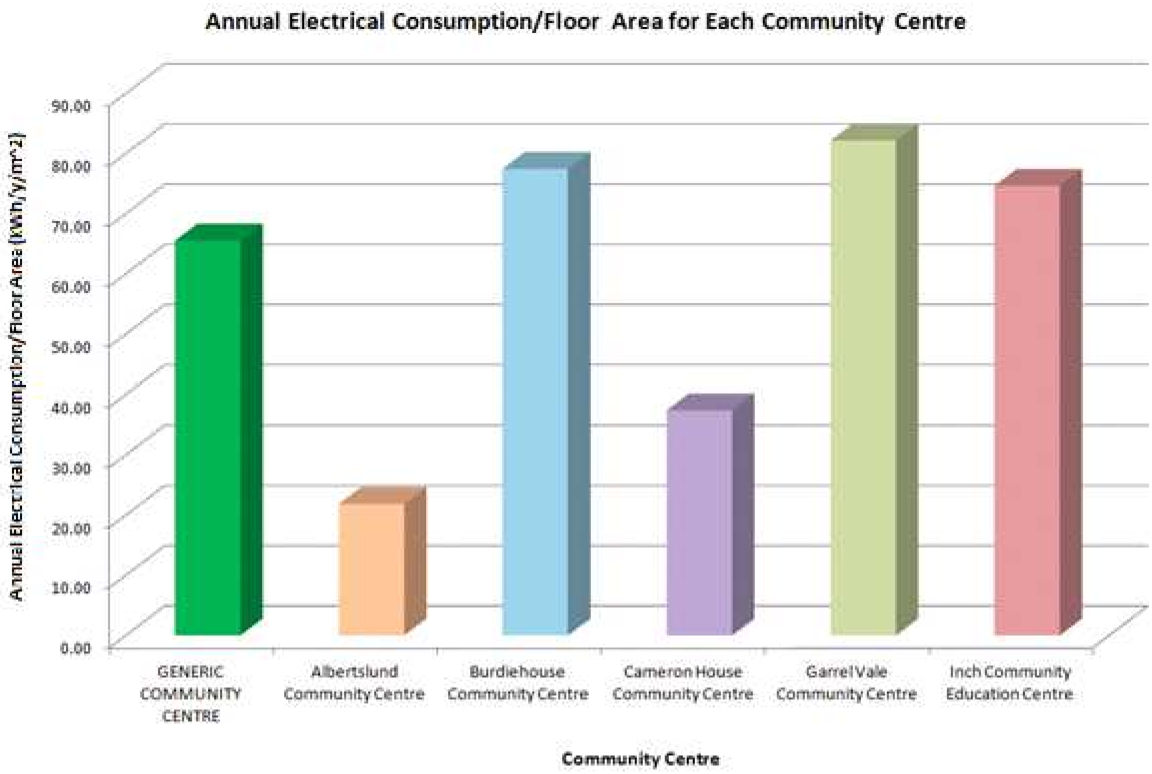
| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| **GENERIC COMMUNITY CENTRE** | **69,171.84** | **-** | **65.53** | **-** | **1,056** | **97** |
| **Albertslund Community Centre** | 5,948.00 | 54,000.00 | 21.87 | 198.53 | 272 | 80 |
| **Burdiehouse Community Centre** | 81,341.30 | - | 77.47 | - | 1,050 | 80 |
| **Cameron House Community Centre** | 44,580.70 | - | 37.43 | - | 1,191 | 150 |
| **Garrel Vale Community Centre** | 72,318.40 | - | 82.18 | - | 880 | 100 |
| **Inch Community Education Centre** | 140,709.60 | - | 74.65 | - | 1,885 | 75 |

Table 7. Community Centre Data.

4.2.1 Generic Community Centre

Producing the Generic Profiles for the Community Centres involved all 5 of the buildings due to the slight contrast of the AECFA. These would have little effect in reducing the overall accuracy. These 5 Centres utilised a very similar amount of electrical energy per floor area which contains a difference between the maximum and minimum of 60.31 kWh/y/$m^2$.

The Generic Profile as shown in Graph 5 was calculated to have an AECFA of 65.53 kWh/y/$m^2$.




Graph 5. Annual electrical consumption/floor area for each community centre.

## 4.3 Emergency Services

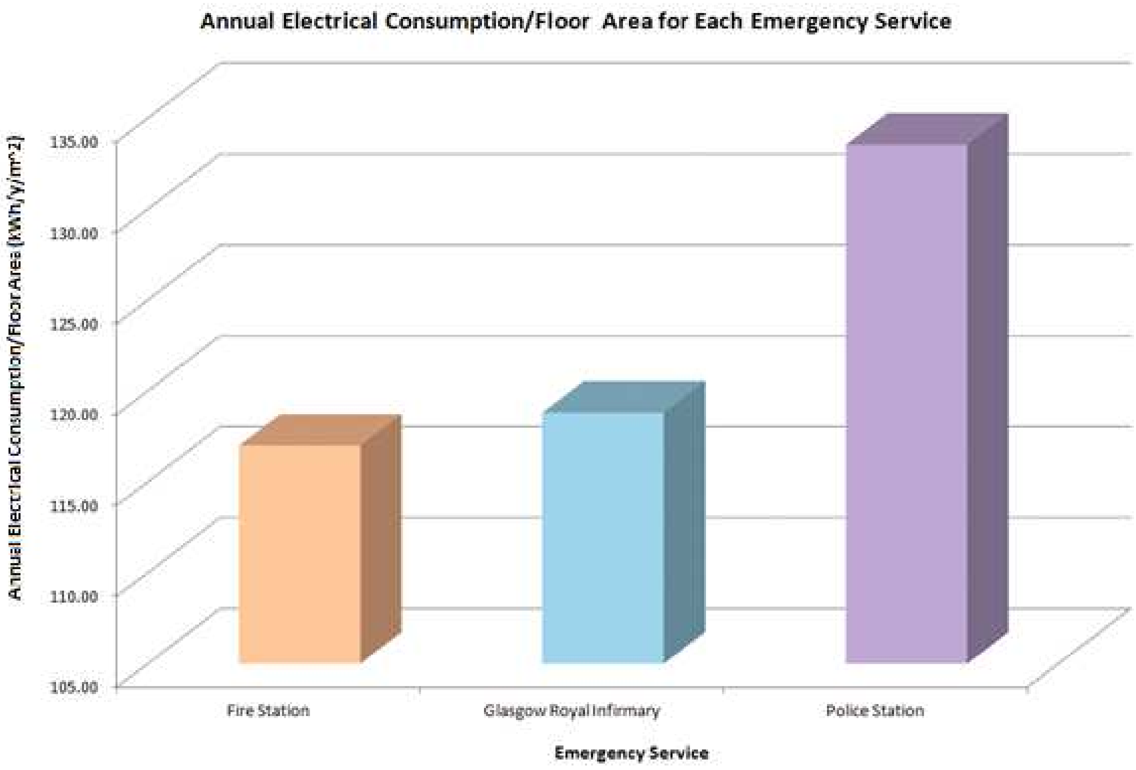
Demand profiles were obtained for only 3 Emergency Services, each one depicting a different service building: Fire, Hospital and Police. The data was based from April 2011 to March 2012. These buildings are situated in various parts of Scotland, all of which containing varying degrees of information as shown in Table 8. The floor area for Glasgow Royal Infirmary is 84x and 56x greater than the Fire Station and Police Station respectively. In terms of annual electrical consumption, the Hospital consumes 85x and 50x more than the Fire and Police stations respectively. It is interesting to note that although the range of factors is diverse; their AECFA is relatively similar – from 116.99 kWh/y/$m^2$ for the Fire Station, to 118.81 kWh/y/$m^2$ for Glasgow Royal Infirmary, and finally 133.54 kWh/y/$m^2$ for the Police Station.

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| Fire Station | 278,323.00 | 382,842.00 | 116.99 | 160.93 | 2,379 | 76 |
| Glasgow Royal Infirmary | 23,714,156.00 | - | 118.81 | - | 199,600 | 918 |
| Police Station | 476,990.00 | 908,208.00 | 133.54 | 254.26 | 3,572 | 253 |

Table 8. Emergency Services Data.

### 4.3.1 Generic Emergency Services

Due to the dissimilar type of Emergency Services, no Generic Profile could be made. Nevertheless, the demand profiles for these buildings were analysed and Graph 6 illustrates their respective AECFA.




Graph 6. Annual electrical consumption/floor area for each emergency service.

## 4.4 Hall/Venue

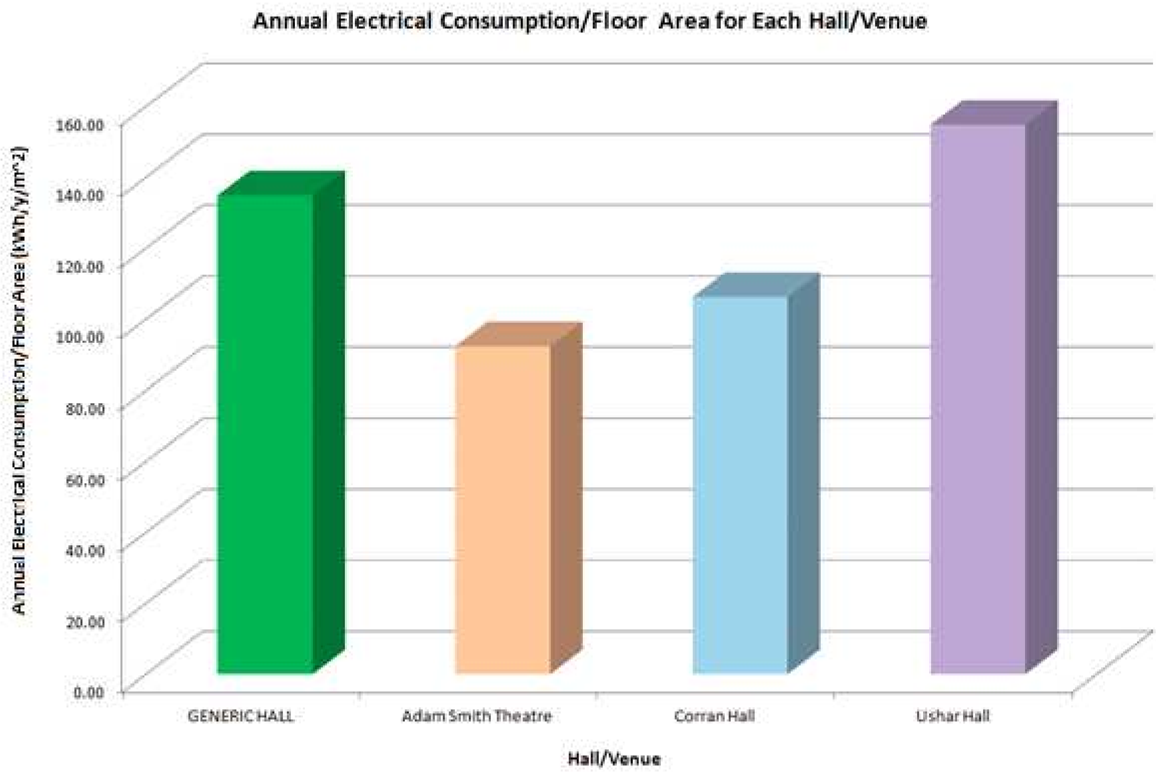
This section examines 3 Halls/Venues, all located in various regions of Scotland. Examining the annual electrical consumption rate, the Corran Hall consumes the least with a value of 199,744 kWh/y and a floor area of 1,880 $m^2$. Secondly, the Adam Smith Theatre makes use of 267,418 kWh/y with a corresponding floor area of 2,895 $m^2$. Finally, the largest of the 3 Halls studied is the Ushar Hall which contains a floor area of 8,861 $m^2$ in conjunction with the most annual electrical consumption of $1.37 \times 10^6$ kWh/y – all of which are shown below. The period for the demand profiles was between 2011 and 2012.

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m²) | Annual Gas Consumption per Floor Area (kWh/y/m²) | Floor Area (m²) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| GENERIC HALL | 613,066.09 | - | 134.88 | - | 4,545 | 858 |
| Adam Smith Theatre | 267,417.86 | 629,891.66 | 92.37 | 217.58 | 2,895 | 475 |
| Corran Hall | 199,744.40 | - | 106.25 | - | 1,880 | 600 |
| Ushar Hall | 1,371,909.80 | - | 154.83 | - | 8,861 | 1,500 |

Table 9. Hall/Venue Data.

## 4.4.1 Generic Hall/Venue

The Generic Profiles generated for the Hall/Venue consisted of using all 3 of the buildings as there were no major distinctions in the AECFA. The difference between the maximum and minimum values of the AECFA is 62.46 kWh/y/m$^2$. The Generic Profile was computed to have an AECFA rate of 134.88 kWh/y/m$^2$ and is shown in Graph 7.




Graph 7. Annual electrical consumption/floor area for each Hall/Venue.

## 4.5 High/Secondary School

A large number of demand profiles for 24 High Schools (from 2011 to 2012) were obtained, all based in Scotland with most located in Edinburgh. Although there is a large variety of data provided, there are also similarities between several schools for numerous factors such as AECFA and floor area. These schools range from smaller schools such as Tiree School, with a 2,160 $m^2$ floor area and average daily occupancy of 83, to a much larger school such as Forrester & St Augustines High School, with a 27,865 $m^2$ floor area and average daily occupancy of 1,352. The annual electrical consumption rates also vary from as little as 56,090 kWh/y (Mearns Academy) to as much as 1.7 x $10^6$ kWh/y (Forrester & St Augustines High School). Table 10 does not provide the complete list of schools but it does quite clearly show that buildings with a larger floor area do not necessarily consume more energy than those with a smaller floor area (Broughton High School and Ellon Academy are two such examples).

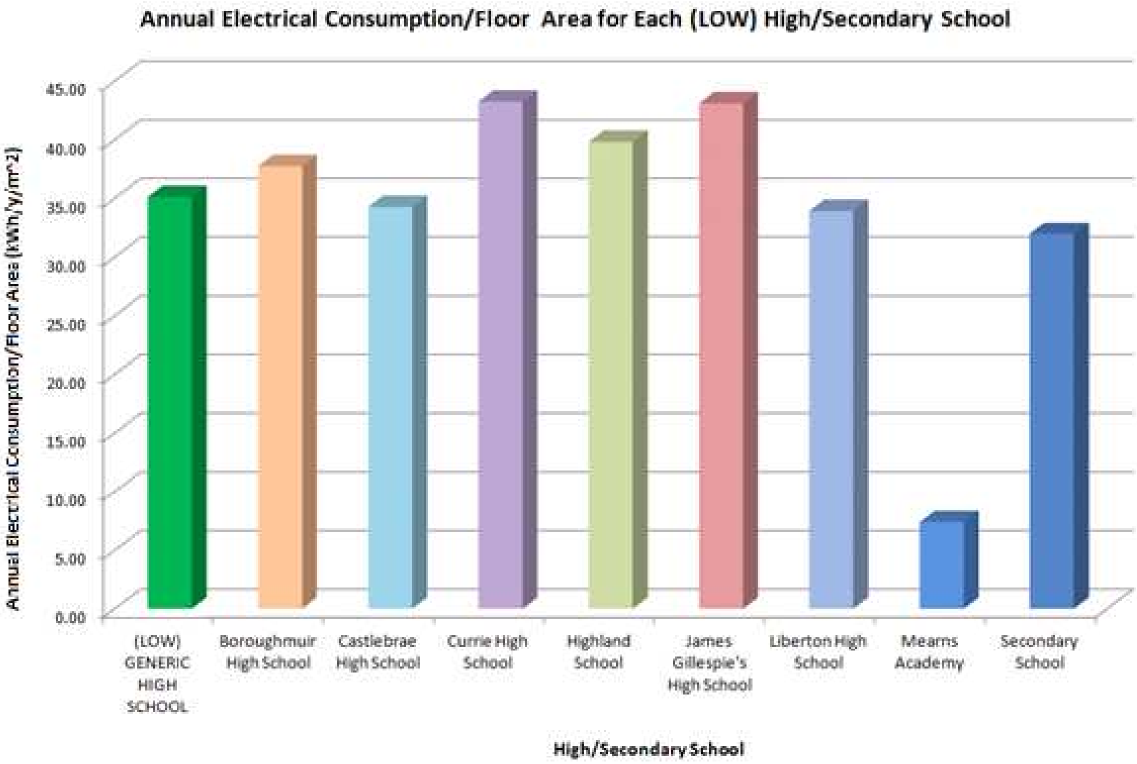
| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| **(LOW) GENERIC HIGH SCHOOL** | **393,956.19** | **-** | **35.13** | **-** | **11,215** | **742** |
| **Currie High School** | 526,484.70 | - | 43.27 | - | 12,167 | 921 |
| **James Gillespie's High School** | 492,974.80 | - | 43.13 | - | 11,430 | 1,129 |
| **Liberton High School** | 446,282.50 | - | 33.95 | - | 13,145 | 697 |
| **Mearns Academy** | 56,090.10 | 1,710.93 | 7.42 | 0.23 | 7,562 | 603 |
| **(MEDIUM) GENERIC HIGH SCHOOL** | **709,971.84** | **-** | **52.56** | **-** | **13,508** | **983** |
| **Broughton High School** | 974,471.70 | - | 53.91 | - | 18,076 | 895 |
| **Portobello High School** | 702,475.70 | - | 45.71 | - | 15,368 | 1,421 |
| **South Queensferry High School** | 562,916.00 | - | 48.80 | - | 11,535 | 786 |
| **Trinity Academy** | 554,530.40 | - | 47.23 | - | 11,742 | 905 |
| **(HIGH) GENERIC HIGH SCHOOL** | **996,083.60** | **-** | **71.08** | **-** | **14,014** | **747** |
| **Ellon Academy** | 1,225,027.60 | 38,686.08 | 74.15 | 2.34 | 16,520 | 1,061 |
| **Forrester & St Augustines High School** | 1,732,354.20 | - | 62.17 | - | 27,865 | 1,352 |
| **Tiree School** | 399,164.60 | - | 184.80 | - | 2,160 | 83 |
| **Tynecastle High School** | 825,032.40 | - | 63.06 | - | 13,084 | 576 |

Table 10. High/Secondary School Data.

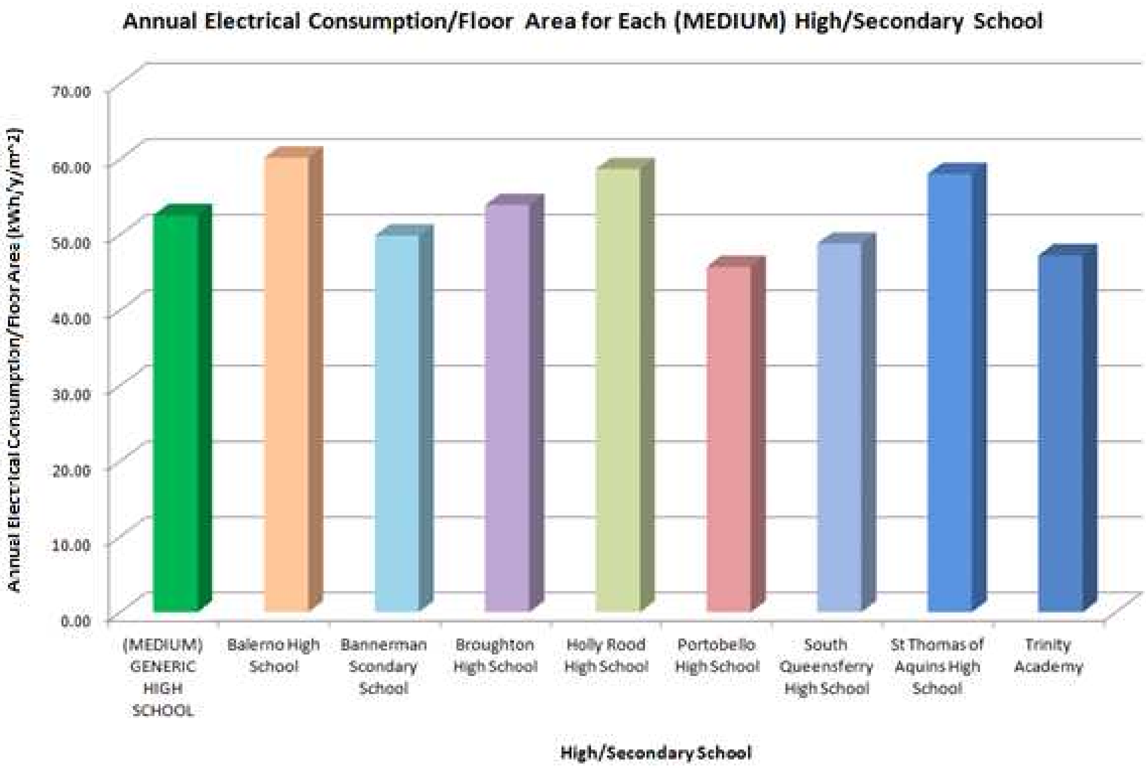
4.5.1 Generic High/Secondary School

As a result of this many profiles and a vast range of data (regarding consumption rates, floor areas and average daily occupancy), it was decided to categorise the schools in terms of the AECFA in order to produce an effective and accurate Generic Profile. Therefore, 3 groups of High Schools, each containing 8 schools, were created. To clarify: all schools are sorted from largest to smallest in terms of their AECFA; the first 8 schools would be brought together to create a HIGH Group; the next 8 schools would represent the MEDIUM Group; finally, the remaining 8 with the lowest AECFA would depict the LOW Group.

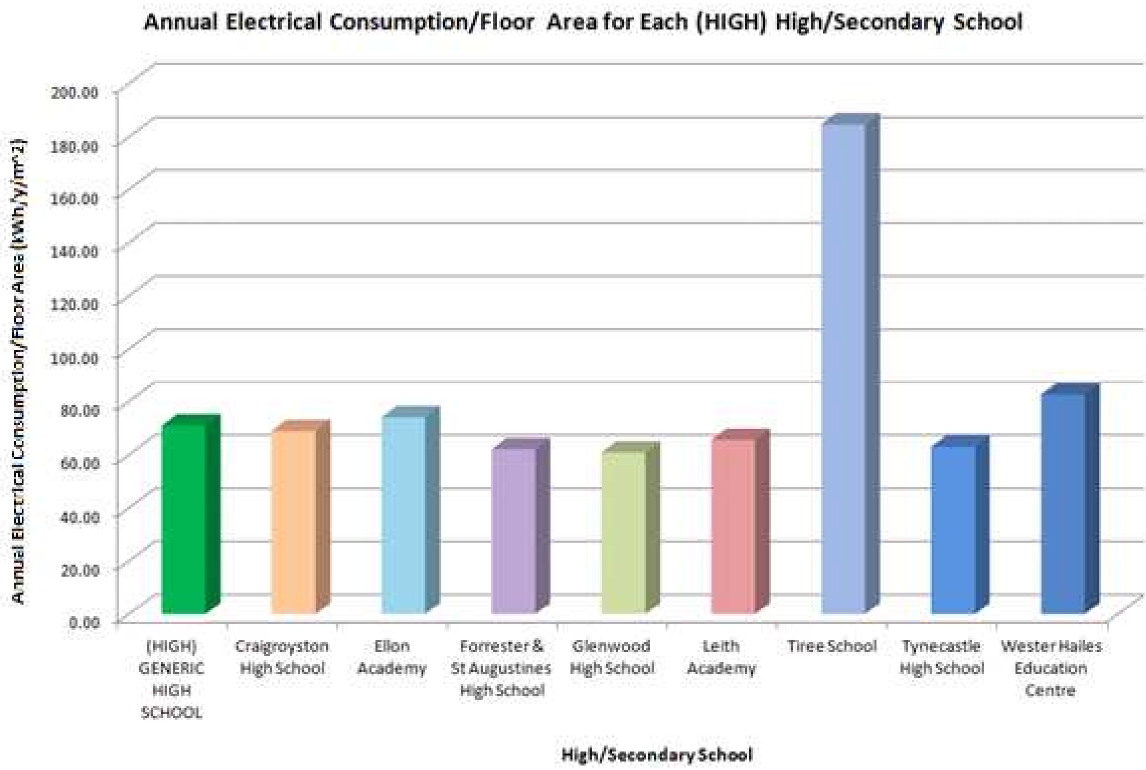
As a result, 3 Generic Profiles were produced and shown below with their associated Group. The LOW, MEDIUM and HIGH Groups have an AECFA of 35.13 kWh/y/$m^2$, 52.56 kWh/y/$m^2$ and 71.08 kWh/y/$m^2$ respectively.




Graph 8. (LOW) annual electrical consumption/floor area for each High School.




Graph 9. (MEDIUM) annual electrical consumption/floor area for each High School.




Graph 10. (HIGH) annual electrical consumption/floor area for each High School.

## 4.6 Houses

Demand profiles for an assortment of 79 houses were scrutinised and classified according to their type, some of which are tabulated below. The data for these houses were part of the 'Milton Keynes Energy Park Dwellings 1990', originally collected by the Building Research Establishment (BRE) and provided by the UK Energy Research Centre. These dwellings were constructed with the aim to be highly energy efficient. The name of each individual house contains the letters 'MK' followed by a set of numbers to distinguish it from the other houses.

Those of a particular dwelling-type consisting of (A) and (B) were further classed according to their structural characteristics such as the depth of floor insulation, the U-Value of the floor, roof, external walls etc. These characteristics can be fully viewed in the Profile Library. The period of the data selected was based between 1989 and 1990. Although the data is somewhat outdated, the process of analysis and Generic Profiling would still apply to data of any period.

| Dwelling Type | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Maximum Occupancy |
|---|---|---|---|---|---|---|
| **2-BED MID-TERRACE:** | | | | | | |
| MK0822 | 1,572.19 | 9,114.80 | 26.07 | 151.16 | 60.3 | 4 |
| MK0825 | 3,042.76 | 10,533.98 | 50.46 | 174.69 | 60.3 | 4 |
| **2-BED SEMI-DETACHED (A):** | | | | | | |
| MK0819 | 43,475.65 | 8,537.97 | 692.29 | 135.95 | 62.8 | 4 |
| MK0820 | 3,335.11 | 12,864.18 | 53.11 | 204.84 | 62.8 | 4 |
| **2-BED SEMI-DETACHED (B):** | | | | | | |
| MK0805 | 1,928.19 | 13,449.86 | 29.76 | 207.56 | 64.8 | 4 |
| MK0811 | 1,261.23 | 4,255.10 | 19.46 | 65.67 | 64.8 | 4 |
| **3-BED DETACHED (A):** | | | | | | |
| MK0883 | 5,567.86 | 18,267.14 | 73.07 | 239.73 | 76.2 | 5 |
| MK0884 | 2,731.97 | 9,451.13 | 35.85 | 124.03 | 76.2 | 5 |
| **3-BED DETACHED (B):** | | | | | | |
| MK0750 | 14,275.69 | - | 136.48 | - | 104.6 | 5 |
| MK0754 | 14,278.38 | - | 136.50 | - | 104.6 | 5 |
| **3-BED END-TERRACE:** | | | | | | |
| MK0751 | 6,705.16 | - | 84.45 | - | 79.4 | 5 |
| MK0753 | 7,830.90 | - | 98.63 | - | 79.4 | 5 |
| **3-BED SEMI-DETACHED (A):** | | | | | | |
| MK0802 | 2,971.62 | 10,514.14 | 39.99 | 141.51 | 74.3 | 5 |
| MK0803 | 3,407.42 | 11,993.75 | 45.86 | 161.42 | 74.3 | 5 |
| **3-BED SEMI-DETACHED (B):** | | | | | | |
| MK0758 | 7,553.87 | - | 86.43 | - | 87.4 | 5 |
| MK0761 | 12,195.08 | - | 139.53 | - | 87.4 | 5 |
| **4-BED DETACHED:** | | | | | | |
| MK0890 | 6,519.37 | 19,413.77 | 46.87 | 139.57 | 139.1 | 6 |
| MK0892 | 4,562.85 | 13,016.17 | 32.80 | 93.57 | 139.1 | 6 |

Table 11. House Data.

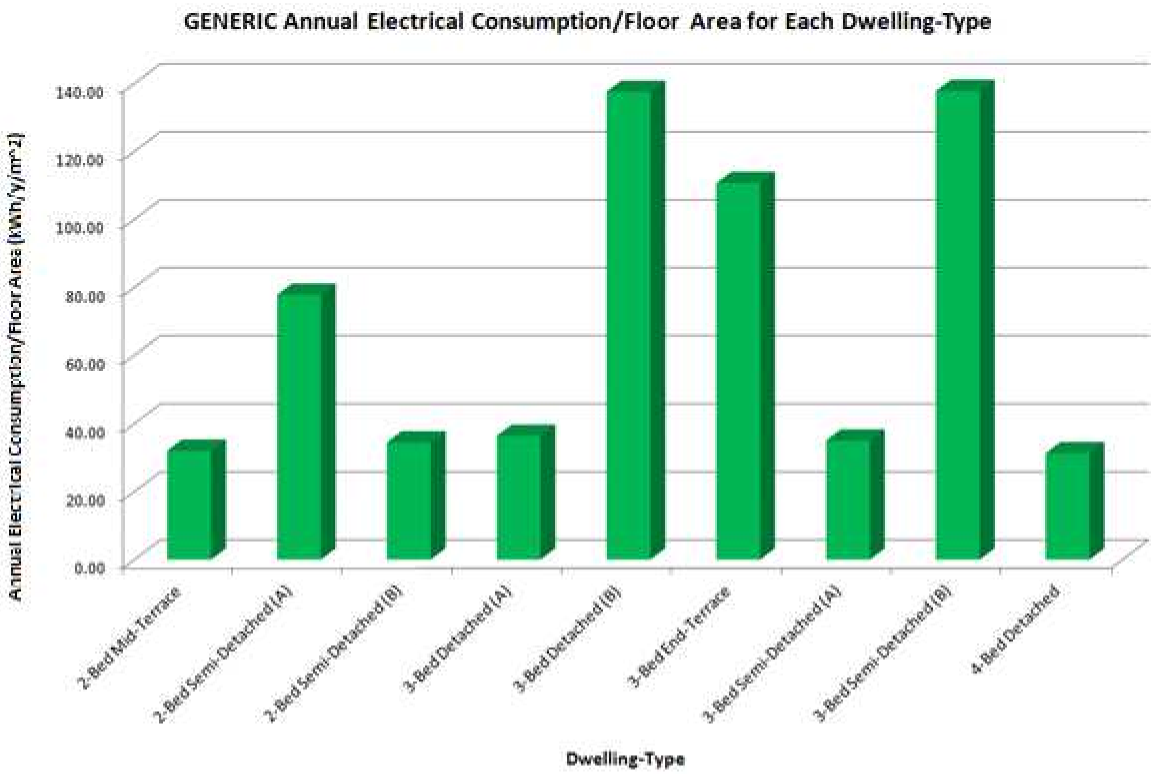
### 4.6.1 Generic Houses

With an extensive amount of data for each type of dwelling and those classed as (A) and (B), Generic Profiles with some of the significant information shown in below in Table 12 and illustrated in Graph 11. It can be seen from the different type of houses with a very similar floor area such as the 2-Bed Mid-Terrace and the 2-Bed Semi-Detached, the AECFA contrasts greatly – 32.11 kWh/y/m$^2$ and 77.82 kWh/y/m$^2$ respectively.

Conversely, houses belonging to the same type but with alternative structural features produce a large difference in AECFA. Taking the 3-Bed Detached (A) and (B) as an example, (B) consumes 4x more annual electricity per floor area than (A). This is likely due to the differing structural differences such as the houses in (B) containing 100 mm of floor insulation compared to the 50 mm for most of the houses in (A).

| GENERIC Dwelling | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Maximum Occupancy |
|---|---|---|---|---|---|---|
| 2-BED MID-TERRACE | 1,936.41 | 9,350.20 | 32.11 | 155.06 | 60.3 | 4 |
| 2-BED SEMI-DETACHED (A) | 4,887.35 | 10,879.01 | 77.82 | 173.23 | 62.8 | 4 |
| 2-BED SEMI-DETACHED (B) | 2,237.72 | 9,325.66 | 34.53 | 143.91 | 64.8 | 4 |
| 3-BED DETACHED (A) | 3,120.96 | 13,006.17 | 36.42 | 151.76 | 85.7 | 5 |
| 3-BED DETACHED (B) | 14,397.18 | - | 137.64 | - | 104.6 | 5 |
| 3-BED END-TERRACE | 8,792.65 | - | 110.74 | - | 79.4 | 5 |
| 3-BED SEMI-DETACHED (A) | 2,607.77 | 11,297.19 | 35.10 | 152.05 | 74.3 | 5 |
| 3-BED SEMI-DETACHED (B) | 12,050.32 | - | 137.88 | - | 87.4 | 5 |
| 4-BED DETACHED | 4,019.47 | 16,393.62 | 31.35 | 127.88 | 128.2 | 6 |

Table 12. Generic House Data.




Graph 11. Generic annual electrical consumption/floor area for each dwelling-type.

## 4.7 Leisure Centre

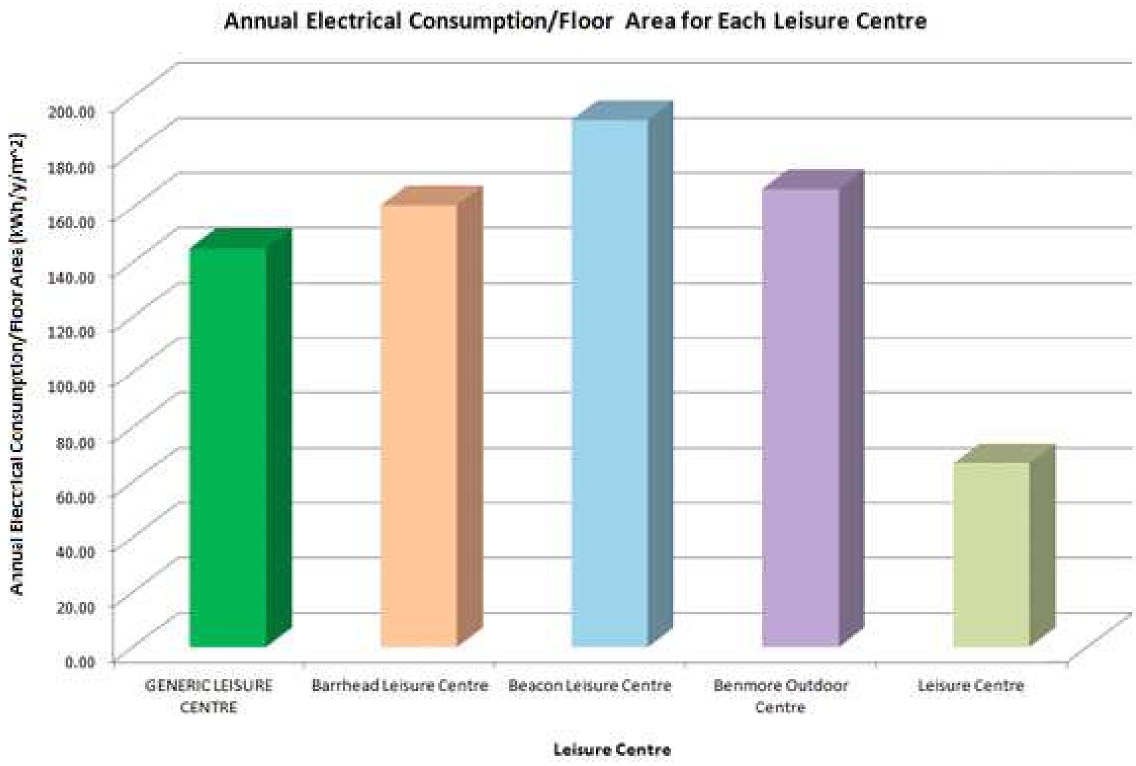
Profiles for four Leisure Centres were provided by 4 Scottish Councils, all of which are between 2011 and 2012. There are discrepancies in terms of the annual electrical consumption with Barrhead Leisure Centre making use of 805,844 kWh/y and an AECFA of 160.82 kWh/y/m$^2$ compared to a Leisure Centre from the Angus region which annually consumes 233,161 kWh/y with an AECFA of 66.94 kWh/y/m$^2$.

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| **GENERIC LEISURE CENTRE** | **508,991.93** | **1,587,156.08** | **145.12** | **452.50** | **3,508** | **503** |
| **Barrhead Leisure Centre** | 805,844.00 | 2,837,415.00 | 160.82 | 566.24 | 5,011 | 1,000 |
| **Beacon Leisure Centre** | 561,097.13 | 1,513,026.65 | 191.76 | 517.10 | 2,926 | 400 |
| **Benmore Outdoor Centre** | 435,181.50 | - | 166.74 | - | 2,610 | 110 |
| **Leisure Centre** | 233,160.78 | 407,257.02 | 66.94 | 116.93 | 3,483 | - |

Table 13. Leisure Centre Data.

### 4.7.1 Generic Leisure Centre

When producing the Generic Profile for a Leisure Centre in Scotland, evaluation of the profiles revealed that the annual electrical consumption would be approximately 508,992 kWh/y combined with an AECFA of 145.12 kWh/y/m$^2$. The difference between the maximum and minimum AECFA equates to 124.82 kWh/y/m$^2$ which is within a reasonable limit. Had more data been provided, the Generic Profile would have been more accurate. Fortunately, 4 of the 5 Leisure Centre Profiles contained thermal data and the AGCFA was calculated to be 452.50 kWh/y/m$^2$.




Graph 12. Annual electrical consumption/floor area for each Leisure Centre.

## 4.8 Library

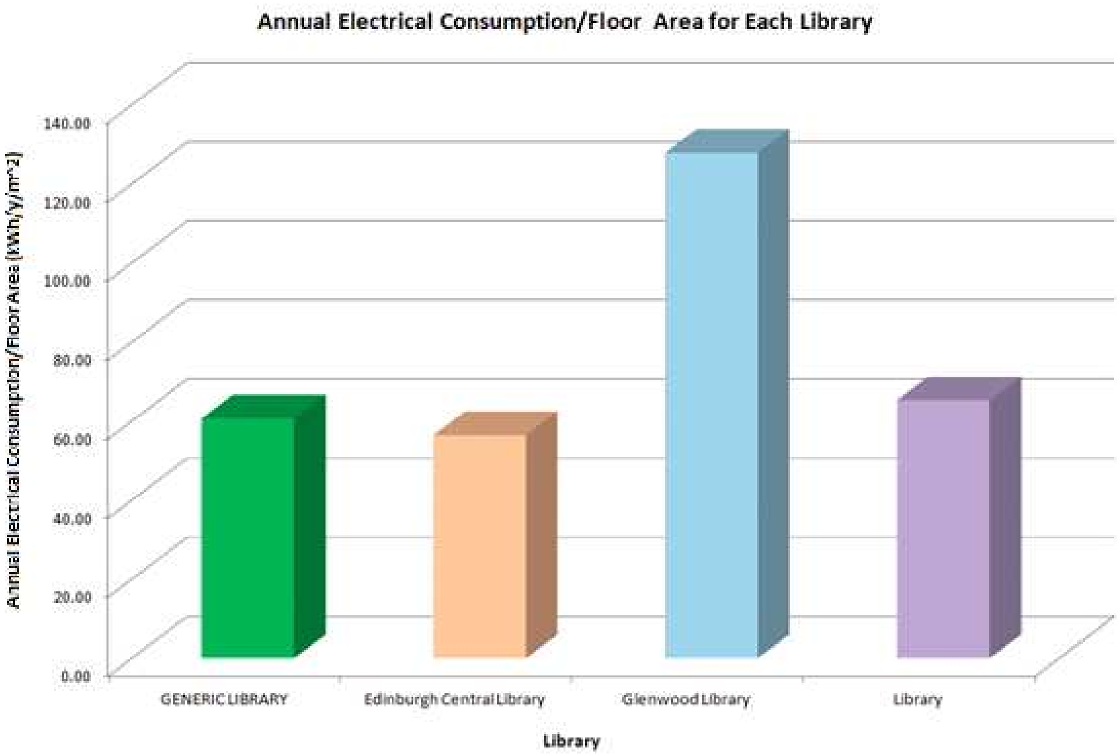
Data from only 3 Scottish Libraries were obtained and evaluated. The period for these demand profiles was 2011. By far the largest of the 3 libraries is the Edinburgh Central Library which encompasses a floor area of 6,500 $m^2$; Glenwood Library and a library from Angus both possessed a floor area of 349 $m^2$ and 827 $m^2$ respectively. Edinburgh Central Library also consumes the most electricity annually at 366, 412 kWh/y compared to only 44,623 kWh/y for Glenwood Library. Interestingly, the smallest Library, Glenwood, has the highest AECFA (127.86 kWh/y/$m^2$) with the largest Library, Edinburgh Central, having the lowest (56.37 kWh/y/$m^2$).

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| GENERIC LIBRARY | 155,111.26 | - | 60.62 | - | 2,559 | 558 |
| Edinburgh Central Library | 366,411.60 | - | 56.37 | - | 6,500 | 875 |
| Glenwood Library | 44,623.32 | - | 127.86 | - | 349 | 240 |
| Library | 53,968.78 | 118,450.61 | 65.26 | 143.23 | 827 | - |

Table 14. Library Data.

## 4.8.1 Generic Library

Unfortunately with demand profiles for only 3 libraries, the accuracy for the Generic Profile is not as high as it would have been with more profiles. Nevertheless, the difference between the maximum and minimum AECFA was found to be 71.49 kWh/y/m$^2$ which is fairly high compared to 60.62 kWh/y/m$^2$ for the Generic Profile. In other words, the error margin for this is significantly higher than it would have been if more profiles were taken into account.




Graph 13. Annual electrical consumption/floor area for each Library.

## 4.9 Maintenance Services

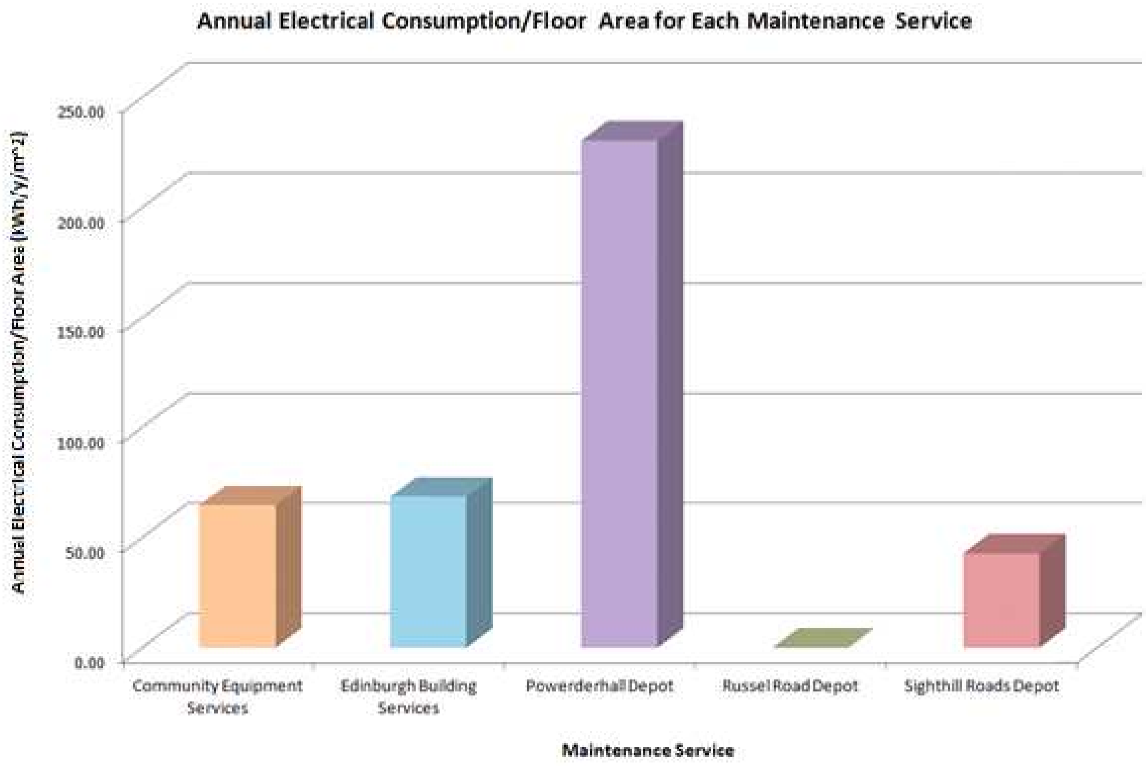
These buildings incorporate a range of equipment and building maintenance services alongside a number of depots. These were situated in Edinburgh with varying annual electrical consumption rates: from a low 0.19 x $10^6$ kWh/y for the Community Equipment Services to as high as 1.06 x $10^6$ kWh/y. No thermal or average daily occupancy data were available for analysis, the demand profiles were all based in 2011. The AECFA also ranges from as little as 42.94 kWh/y/$m^2$ (Sighthill Roads Depot) compared to 230.47 kWh/y/$m^2$ (Powerderhall Depot), more than 5x difference.

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| Community Equipment Services | 189,938.00 | - | 64.74 | - | 2,934 | - |
| Edinburgh Building Services | 725,032.30 | - | 68.70 | - | 10,553 | - |
| Powerderhall Depot | 1,062,922.40 | - | 230.47 | - | 4,612 | - |
| Russel Road Depot | 530,520.60 | - | - | - | - | - |
| Sighthill Roads Depot | 294,630.80 | - | 42.94 | - | 6,861 | - |

Table 15. Maintenance Services Data.

### 4.9.1 Generic Maintenance Services

Due to the dissimilar type of Maintenance Services, no Generic Profile could be made. Nevertheless, the demand profiles for these buildings were analysed and Graph 14 illustrates their respective AECFA.




Graph 14. Annual electrical consumption/floor area for each Maintenance Service.

## 4.10 Museum/Art Gallery

Edinburgh City Council provided the only demand profile (electrical) for this type of building. The City Arts Centre, encompassing 2,584 $m^2$ consumed 506,632 kWh/y in 2011 with an AECFA of 196.07 kWh/y/$m^2$.

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| City Arts Centre | 506,632.00 | - | 196.07 | - | 2,584 | - |

Table 16. Museum/Art Gallery Data.

4.10.1 Generic Museum/Art Gallery

With only one demand profile, it was not possible to create a Generic Profile for this type of building.

## 4.11 Nursery/Primary School

A large number of demand profiles for 22 Nursery/Primary Schools (from 2011 to 2012) were obtained, all based in Scotland with most located in Edinburgh. With a large quantity of statistics, similarities were distinguished in terms of AECFA. These schools range from a small floor area of 615 $m^2$ (Pikeman Nursery) to a large floor area of 6,980 $m^2$ (Niddrie/St Francis Primary School).

The Niddrie/St Francis Primary School is an example of a joint campus in which both nursery and primary school students attend. It should be noted that both Carricknowe Nursery and Carricknowe Primary are part of the same building and only the Nursery is shown in Table 17. The statistics for both these Schools in the Profile Library are shown to be exactly the same due to the summation of data, however, their individual demand profiles differ greatly.

The annual electrical consumption rates also vary from as little as 36,531 kWh/y (Pikeman Nursery) to as much as 532,080 kWh/y (Blackfriars Primary School). It can be seen from Table 17, which does not show the complete list of schools, that a Nursery/Primary School with larger floor area does not necessarily consume more energy than those with a smaller floor area (Ashpark Primary School and Gylemuir Primary School are an example).

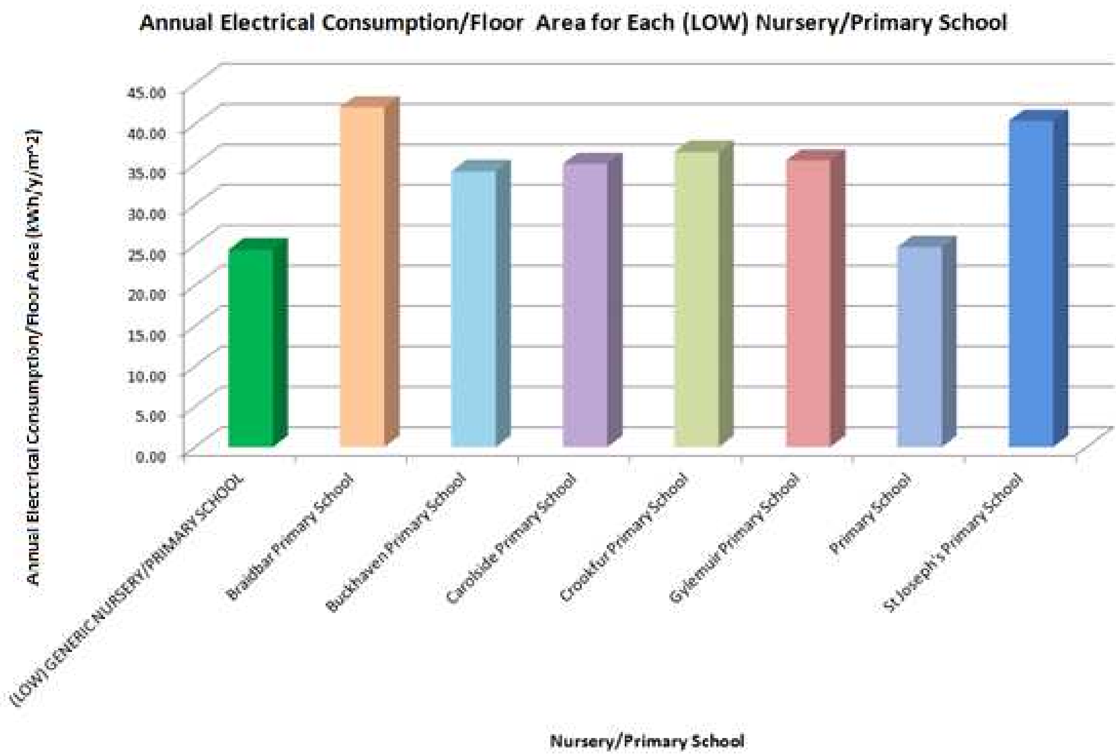
| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| **(LOW) GENERIC NURSERY/PRIMARY SCHOOL** | **79,921.19** | **499,826.63** | **24.45** | **152.93** | **3,268** | **395** |
| **Carolside Primary School** | 202,890.00 | 845,619.00 | 35.08 | 146.22 | 5,783 | 751 |
| **Crookfur Primary School** | 85,140.00 | 469,816.00 | 36.56 | 201.72 | 2,329 | 246 |
| **Gylemuir Primary School** | 141,959.50 | - | 35.48 | - | 4,001 | 383 |
| **St Joseph's Primary School** | 94,905.00 | 372,240.00 | 40.40 | 158.47 | 2,349 | 357 |
| **(MEDIUM) GENERIC NURSERY/PRIMARY SCHOOL** | **169,714.82** | **-** | **44.65** | **-** | **3,801** | **422** |
| **Canal View Primary School** | 159,621.80 | - | 44.88 | - | 3,557 | 229 |
| **Carricknowe Nursery** | 208,222.20 | - | 49.04 | - | 4,246 | 504 |
| **Mearns Primary School** | 311,572.00 | 828,826.00 | 49.64 | 132.06 | 6,276 | 808 |
| **Pentland Primary School** | 166,057.70 | - | 46.09 | - | 3,603 | 330 |
| **(HIGH) GENERIC NURSERY/PRIMARY SCHOOL** | **295,853.59** | **-** | **106.28** | **-** | **2,784** | **275** |
| **Ashpark Primary School** | 270,007.70 | - | 90.00 | - | 3,000 | 287 |
| **Blackfriars Primary School** | 532,080.10 | - | 224.51 | - | 2,370 | 225 |
| **Niddrie/St Francis Primary School** | 387,233.20 | - | 55.48 | - | 6,980 | 780 |
| **Parsons Primary School** | 422,628.00 | - | 168.04 | - | 2,515 | 288 |
| **Pikeman Nursery** | 36,531.10 | - | 59.40 | - | 615 | 115 |

Table 17. Nursery/Primary School Data.

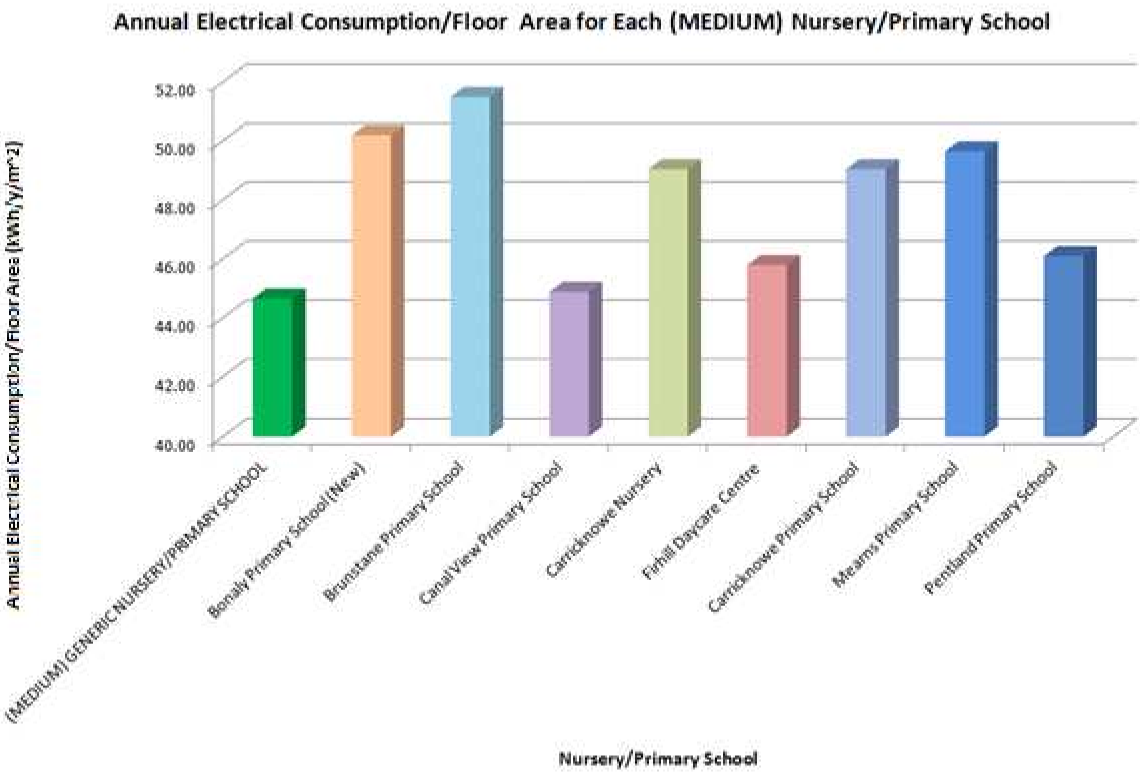
### 4.11.1 Generic Nursery/Primary School

As a result of the number of profiles and a wide range of data (concerning consumption rates, floor areas, average daily occupancy etc), it was decided to utilise the same Generic process as conducted with High/Secondary Schools. Therefore, the Nursery/Primary Schools were categorised in terms of their AECFA in order to produce 3 effective and accurate Generic Profiles: LOW, MEDIUM and HIGH.

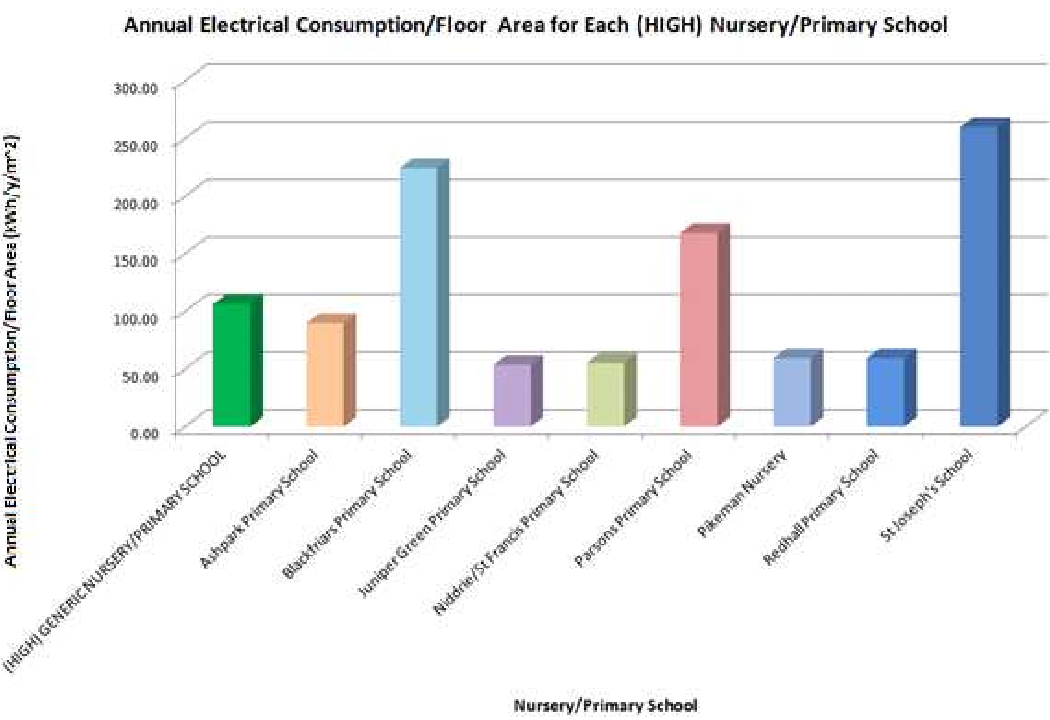
The LOW, MEDIUM and HIGH groups contain 7, 8 and 7 Nursery/Primary Schools respectively according to their AECFA rate of 24.45 kWh/y/$m^2$, 44.65 kWh/y/$m^2$ and 106.28 kWh/y/$m^2$ respectively. The LOW group also contained thermal data – 6 of the 7 schools – in which it was possible to calculate the AGCFA, this was found to be 152.93 kWh/y/$m^2$.




Graph 15. (LOW) annual electrical consumption/floor area for each Nursery/Primary School.




Graph 16. (MEDIUM) annual electrical consumption/floor area for each Nursery/Primary School.




Graph 17. (HIGH) annual electrical consumption/floor area for each Nursery/Primary School.

## 4.12 Office

Nineteen demand profiles for an Office were obtained, 8 based in Westminster, England, and the remainder located around Scotland. These datasets, from between 2011 and 2012, belong to both Government and private offices, some of which are tabulated below. Examining the floor area, there is a massive difference between the smallest and largest: 1,106 $m^2$ from the Finance Office, Campbeltown to 76,203 $m^2$ from the Foreign and Commonwealth Office. There are also major variations in the annual electrical consumption rate: the North Edinburgh Local Office observed 0.26 x $10^6$ kWh/y, the lowest of all Offices; the HM Treasury possessed the most with 5.74 x $10^6$ kWh/y, 22x greater than the North Edinburgh Local Office. There are also a number of annual gas consumption data with HM Revenue & Customs consuming the most at 1.86 x $10^6$ kWh/y and the Foreign and Commonwealth Office consuming 7x least at 0.26 x $10^6$ kWh/y.

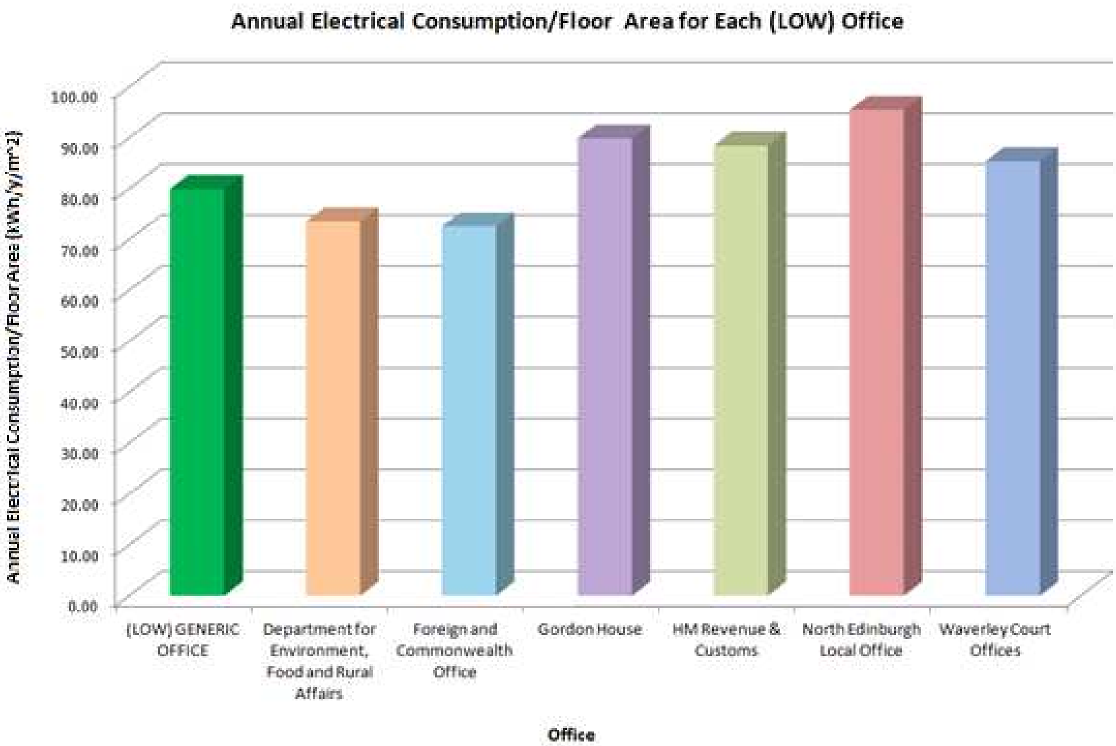
| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/$m^2$) | Annual Gas Consumption per Floor Area (kWh/y/$m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| **(LOW) GENERIC OFFICE** | **2,485,850.92** | **-** | **79.99** | **-** | **31,076** | **1,205** |
| Foreign and Commonwealth Office | 5,531,964.20 | 25,545.27 | 72.60 | 0.34 | 76,203 | 1,815 |
| HM Revenue & Customs | 4,332,264.60 | 1,858,346.00 | 88.48 | - | 48,965 | 2,000 |
| North Edinburgh Local Office | 263,156.20 | - | 95.48 | - | 2,756 | 160 |
| Waverley Court Offices | 3,114,083.40 | - | 85.44 | - | 36,448 | 1,800 |
| **(MEDIUM) GENERIC OFFICE** | **1,664,246.40** | **261,060.30** | **123.25** | **19.33** | **13,503** | **616** |
| Department of Energy & Climate Change | 1,304,643.97 | 138,397.29 | 115.77 | 12.28 | 11,269 | 924 |
| Edinburgh City Chambers | 1,878,321.20 | - | 101.82 | - | 18,447 | 500 |
| HM Treasury | 5,737,682.00 | 59,168.17 | 139.58 | 1.44 | 41,106 | 1,670 |
| Kirkcaldy Town House | 350,182.22 | 519,519.02 | 113.47 | 168.35 | 3,086 | 180 |
| Westwood House | 457,759.70 | - | 113.17 | - | 4,045 | 220 |
| **(HIGH) GENERIC OFFICE** | **1,947,870.60** | **-** | **184.82** | **-** | **10,540** | **598** |
| Cabinet Office | 2,060,506.00 | 433,403.00 | 142.30 | 29.93 | 14,480 | 430 |
| Department for Culture, Media & Sport | 1,856,606.50 | 408,618.19 | 146.87 | 32.32 | 12,641 | 611 |
| Finance Office, Campbeltown | 301,997.00 | - | 273.05 | - | 1,106 | 71 |
| PM's Office - 10 Downing Street | 1,050,946.10 | 400,069.30 | 155.81 | - | 6,745 | - |

Table 18. Office Data.

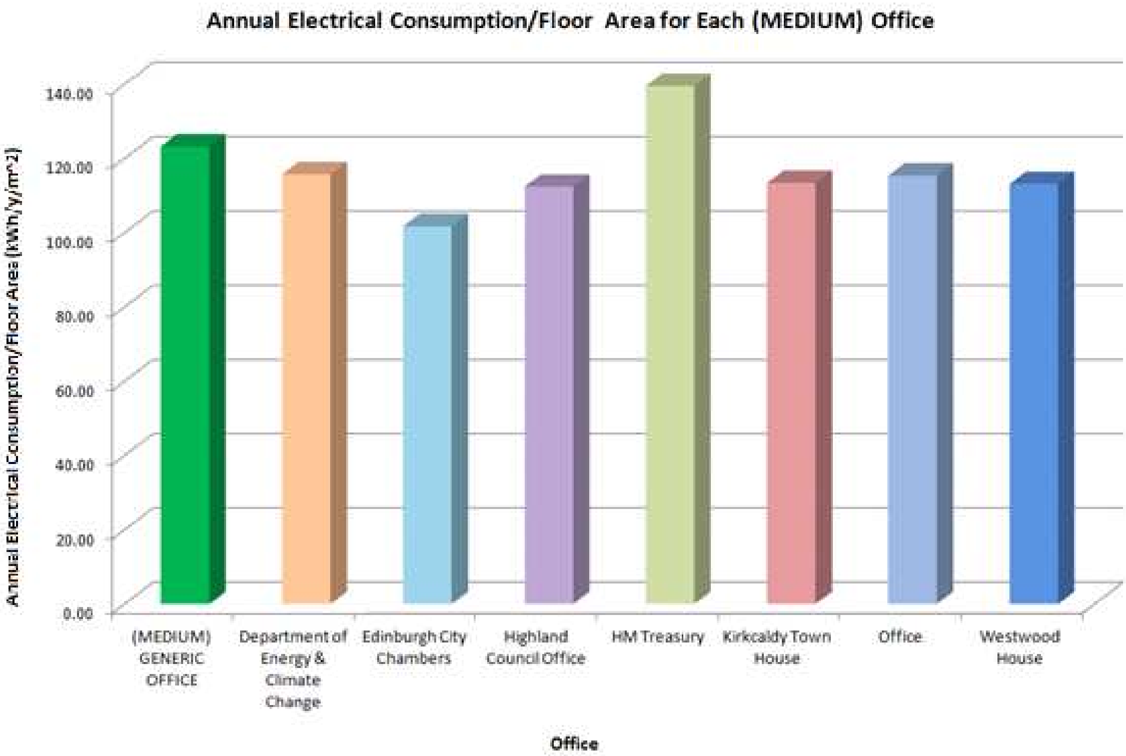
4.12.1 Generic Office

As 19 demand profiles were collected, the same Generic Process used for High/Secondary Schools and Nursery/Primary Schools was applied for Offices. The 3 Generic groups – LOW, MEDIUM and HIGH – all contained 6, 7 and 6 Offices respectively and were sorted by their AECFA. The LOW group boasted an AECFA of 79.99 kWh/y/$m^2$; 123.25 kWh/y/$m^2$ for MEDIUM; and 184.82 for HIGH.

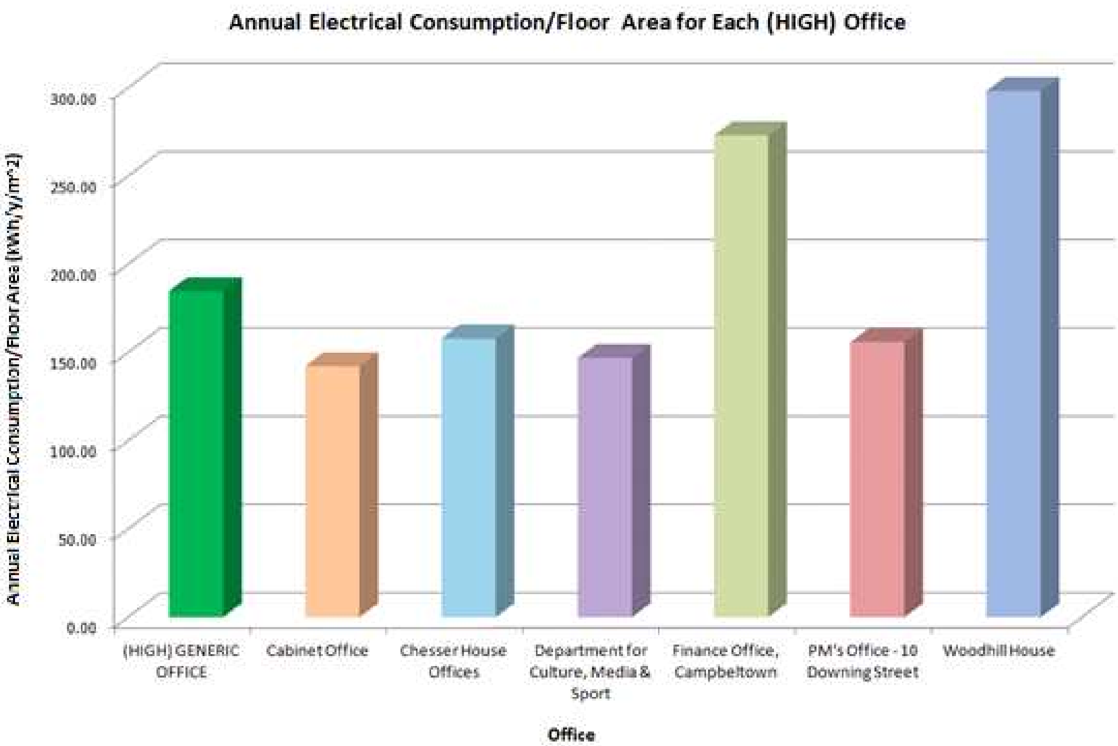
Surprisingly, when scrutinising the floor area for the Generic Profiles, the LOW group with the lowest AECFA was calculated to have the highest floor area at 31, 076 $m^2$; MEDIUM had a median floor area 13, 503 $m^2$; HIGH was computed to have the lowest floor area of 10,540 $m^2$.




Graph 18. (LOW) annual electrical consumption/floor area for each Office.




Graph 19. (MEDIUM) annual electrical consumption/floor area for each Office.




Graph 20. (HIGH) annual electrical consumption/floor area for each Office.

## 4.13 Specialist School

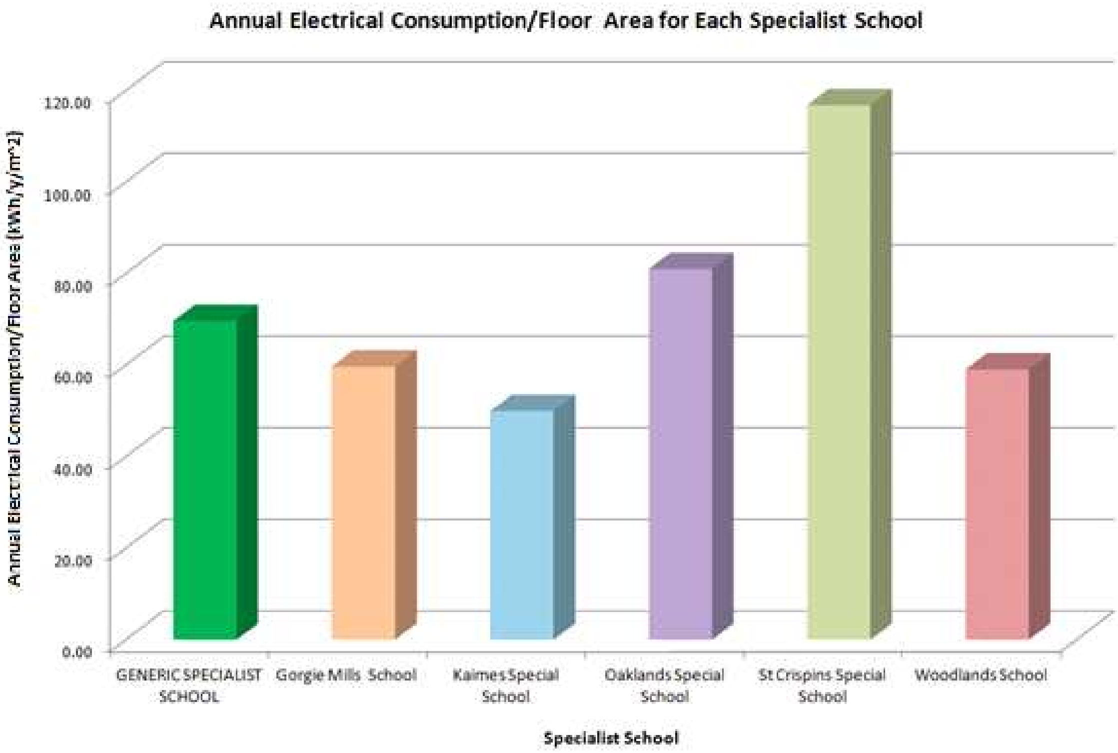
Based in Edinburgh, 5 Specialist Schools were investigated and their corresponding data from 2011 is shown in Table 19. No thermal data were available; however, the annual electrical consumption rates vary from the lowest of 136,097 kWh/y (Woodlands School) to as high as 298,716 kWh/y (Oaklands Special School).

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| **GENERIC SPECIALIST SCHOOL** | **182,077.58** | **-** | **69.65** | **-** | **2,614** | **65** |
| **Gorgie Mills School** | 164,542.30 | - | 59.70 | - | 2,756 | 54 |
| **Kaimes Special School** | 145,748.30 | - | 49.97 | - | 2,917 | 98 |
| **Oaklands Special School** | 298,716.30 | - | 81.00 | - | 3,688 | 44 |
| **St Crispins Special School** | 164,150.30 | - | 116.83 | - | 1,405 | 50 |
| **Woodlands School** | 136,097.70 | - | 59.07 | - | 2,304 | 78 |

Table 19. Specialist School Data.

### 4.13.1 Generic Specialist School

A Generic Profile was created by exploiting the datasets for all 5 Specialist Schools. It was determined that the difference between the minimum and maximum AECFA was 66.86 kWh/y/m$^2$; the minimum of 49.97 kWh/y/m$^2$ belonging to Kaimes Special School and the maximum of 116.83 kWh/y/m$^2$ belonging to St Crispins Special School. The Generic annual electrical consumption was then found to be 182,078 kWh/y with an AECFA of 69.65 kWh/y/m$^2$ as exemplified below in Graph 21.




Graph 21. Annual electrical consumption/floor area for each Specialist School.

## 4.14 Transport

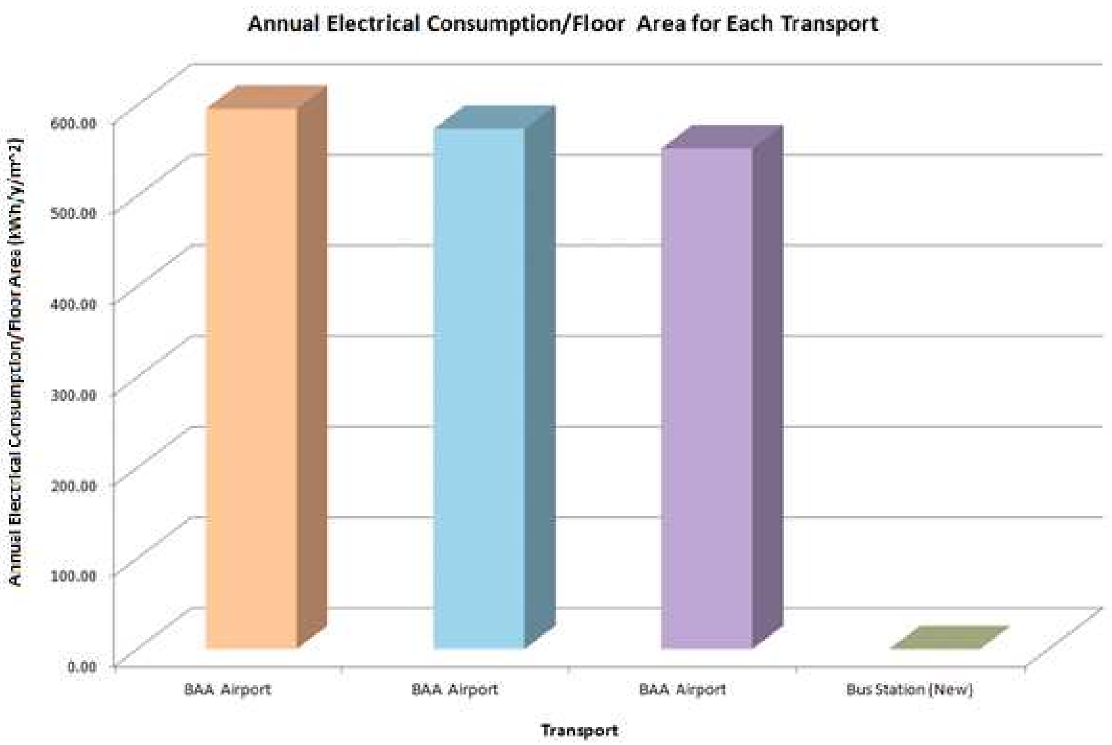
Demand profiles were obtained for 2 different types of Transport buildings: a BAA Airport based in the UK (which will not be identified), and a Bus Station sited in Edinburgh. Only the electrical consumption rate and floor area for both these buildings were obtained – however, 3 years worth of data for the BAA Airport was included, from 2009 to 2011, which clearly shows a constant reduction in annual electrical consumption and AECFA. The main cause for this may be due to improved energy efficiency methods employed within the Airport and increased investment in renewable technologies such as Solar PV Panels.

| Building | Period of Data | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area (kWh/y/m$^2$) | Annual Gas Consumption per Floor Area (kWh/y/m$^2$) | Floor Area (m$^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|---|
| BAA Airport | 2009 | 32,410,265.20 | - | 595.99 | - | 54,381 | - |
| BAA Airport | 2010 | 31,205,064.50 | - | 573.82 | - | 54,381 | - |
| BAA Airport | 2011 | 30,039,622.20 | - | 552.39 | - | 54,381 | - |
| Bus Station (New) | 2011 | 836,816.50 | - | - | - | - | - |

Table 20. Transport Data.

### 4.14.1 Generic Transport

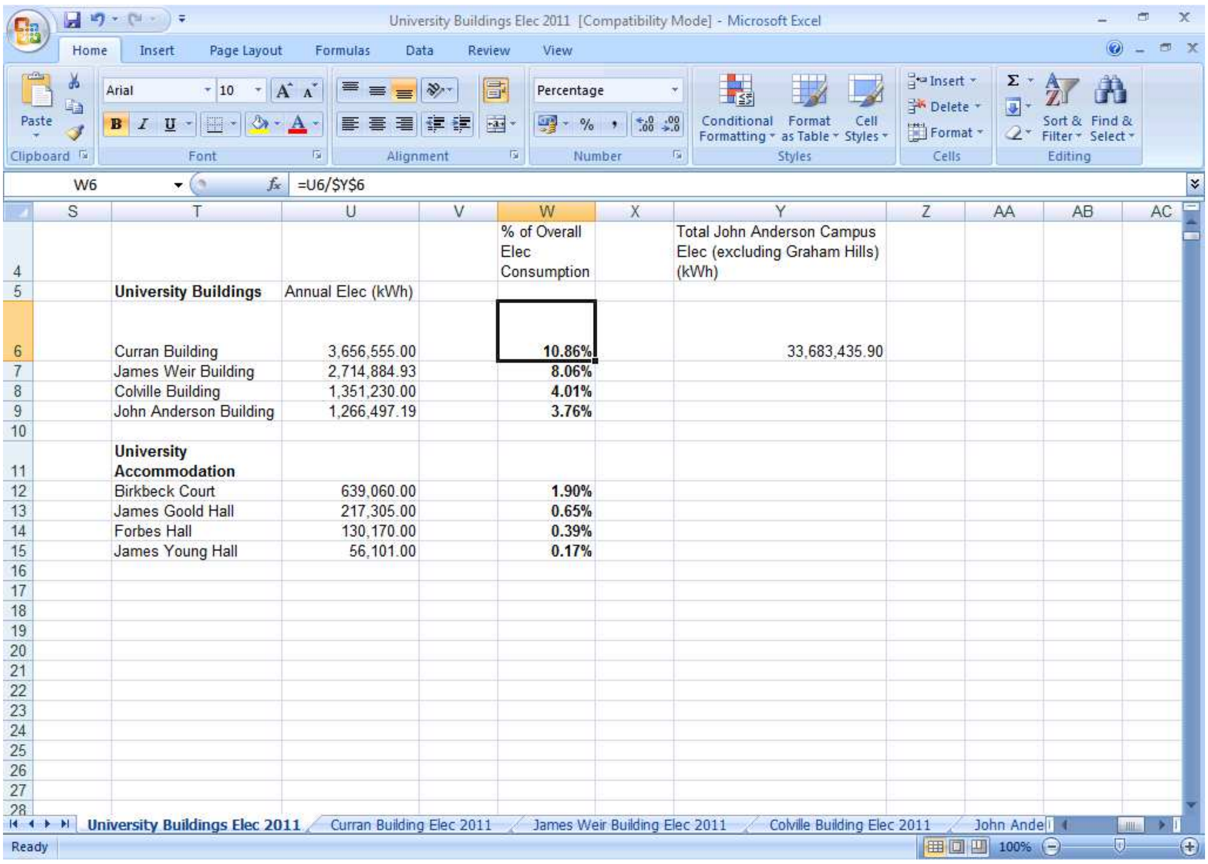
As there were only 2 types of Transport buildings, no Generic Profile could be established. Although 3 years worth of data for the Airport was collected, a specific Generic Profile for that particular Airport could not be ascertained due to a steady decline in annual electrical consumption, and therefore, the AECFA. This reduction from 595.99 kWh/y/m$^2$ to 552.39 kWh/y/m$^2$ equates to a drop of 7.3 %.




Graph 22. Annual electrical consumption/floor area for each Transport.

## 4.15 University of Strathclyde

The University of Strathclyde boasts 2 campuses: Jordanhill and John Anderson. Half-hourly demand profiles for 2011 were collected for both campuses equipped with a list of University buildings with their total monthly consumption rates. By summing up the half-hourly demand for each campus and totalling the monthly demand for each selected building, a percentage value for each University building could be calculated. This can then be used to identify how much electrical demand each chosen building consumes from the overall campus demand at each half-hour as shown in Figure 11 – thus, providing high-resolution demand data for a number of University buildings. Table 21 shows data for the selected buildings: 4 of which are used for teaching and research; the remaining 4 buildings used for student accommodation. All these buildings are part of the John Anderson Campus.



| University Buildings | Annual Elec (kWh) | % of Overall Elec Consumption | Total John Anderson Campus Elec (excluding Graham Hills) (kWh) |
|---|---|---|---|
| Curran Building | 3,656,555.00 | 10.86% | 33,683,435.90 |
| James Weir Building | 2,714,884.93 | 8.06% | |
| Colville Building | 1,351,230.00 | 4.01% | |
| John Anderson Building | 1,266,497.19 | 3.76% | |
| **University Accommodation** | | | |
| Birkbeck Court | 639,060.00 | 1.90% | |
| James Goold Hall | 217,305.00 | 0.65% | |
| Forbes Hall | 130,170.00 | 0.39% | |
| James Young Hall | 56,101.00 | 0.17% | |

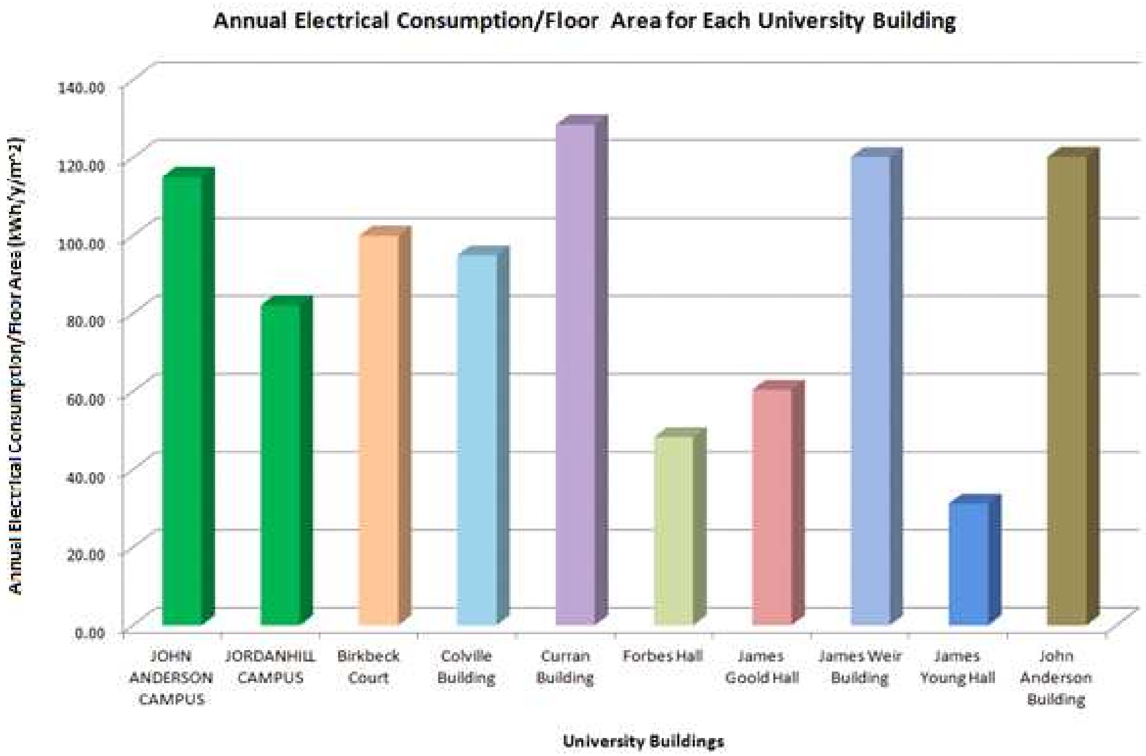
Figure 11. Percentage consumption for University buildings of overall campus demand.

| Building | Annual Electrical Consumption (kWh/y) | Annual Gas Consumption (kWh/y) | Annual Electrical Consumption per Floor Area ($kWh/y/m^2$) | Annual Gas Consumption per Floor Area ($kWh/y/m^2$) | Floor Area ($m^2$) | Average Daily Occupancy |
|---|---|---|---|---|---|---|
| JOHN ANDERSON CAMPUS | 33,683,435.90 | 35,886,288.32 | 115.14 | 122.67 | 292,536 | 26,188 |
| JORDANHILL CAMPUS | 3,964,814.40 | 11,697,015.55 | 82.13 | 242.29 | 48,277 | 6,088 |
| Birkbeck Court | 639,060.00 | - | 100.01 | - | 6,390 | 384 |
| Colville Building | 1,351,230.00 | - | 95.01 | - | 14,222 | 1,499 |
| Curran Building | 3,656,555.00 | - | 128.51 | - | 28,454 | 882 |
| Forbes Hall | 130,170.00 | - | 48.30 | - | 2,695 | 104 |
| James Goold Hall | 217,305.00 | - | 60.45 | - | 3,595 | 66 |
| James Weir Building | 2,714,884.93 | - | 120.20 | - | 22,587 | 3,357 |
| James Young Hall | 56,101.00 | - | 31.24 | - | 1,796 | 66 |
| John Anderson Building | 1,266,497.19 | - | 120.22 | - | 10,535 | 1,544 |

Table 21. University of Strathclyde Data.

The John Anderson Campus encompasses a floor area of 292, 536 $m^2$ (0.11 square miles), this equates to an annual electrical and gas consumption rate of 33.7 x 10 $^6$ kWh/y and 35.9 x $10^6$ kWh/y respectively. The AECFA and AGCFA are computed to be 115.14 $kWh/y/m^2$ and 122.67 $kWh/y/m^2$ respectively. Jordanhill Campus being smaller than John Anderson with only a floor area of 48,277 $m^2$, possesses an AECFA and AGCFA of 82.13 $kWh/y/m^2$ and 242.29 $kWh/y/m^2$ respectively.

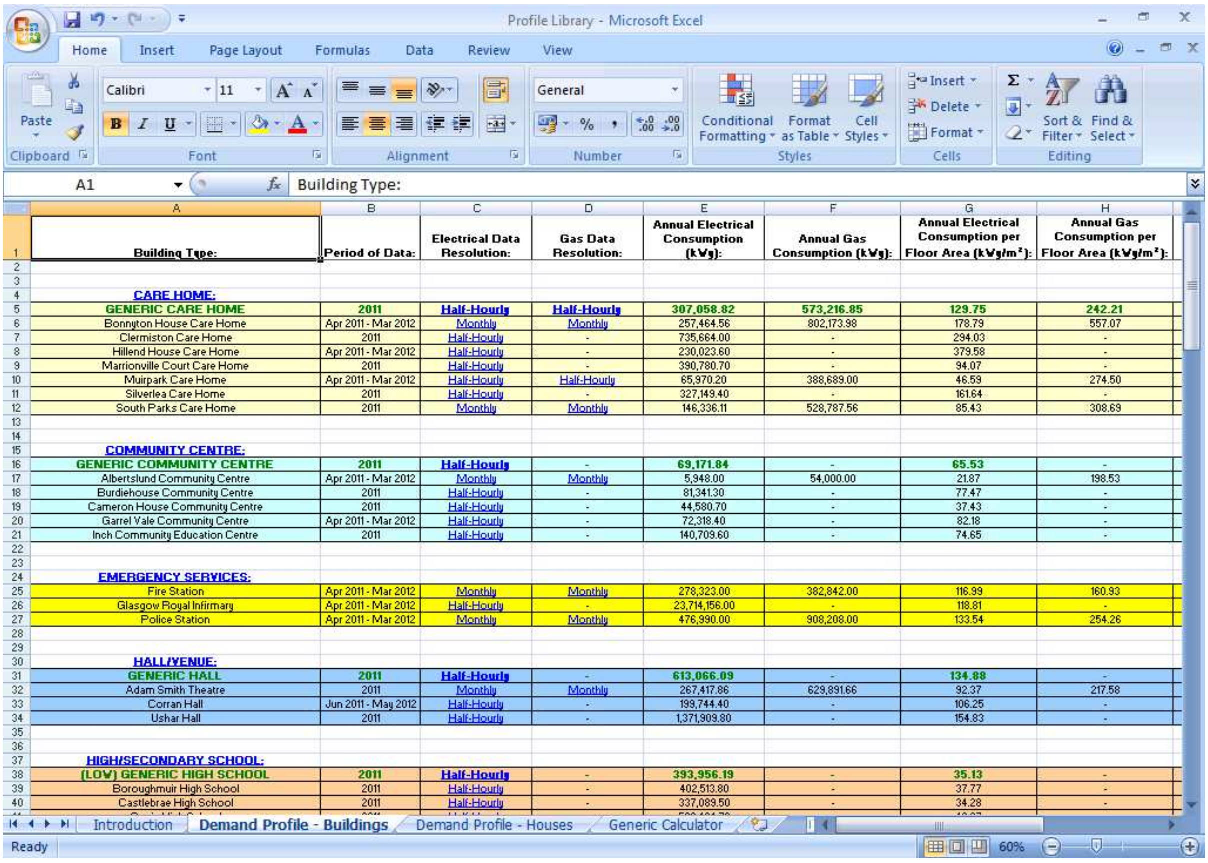
The University buildings used for teaching and research comprises of a larger floor area and larger electrical/thermal consumption rates than those used for student accommodation. Excluding the Colville Building, the remaining 3 teaching buildings contain a higher AECFA than the student accommodations – Birbeck Court has an AECFA of 100.01 $kWh/y/m^2$ compared to 95.01 $kWh/y/m^2$ for Colville Building.




Graph 23. Annual electrical consumption/floor area for each University building.

# Chapter 5: Profile Library

The Profile Library is a database constructed to contain and provide information on all available demand profiles and their associated buildings. The library categorises the demand profiles depending on the type of building – this categorisation is shown in ***Chapter 3; Table 5***. One of the key aspects of this database is to allow the exportation of demand data which can then be immediately imported into the energy-matching tool, Merit. Figure 12 provides a snapshot of the Profile Library; the Library itself can be downloaded from the following link: http://www.strath.ac.uk/esru/degrees/renewablenrg/reseindividualtheses/.



| Building Type: | Period of Data: | Electrical Data Resolution: | Gas Data Resolution: | Annual Electrical Consumption (kWh): | Annual Gas Consumption (kWh): | Annual Electrical Consumption per Floor Area (kWh/m²): | Annual Gas Consumption per Floor Area (kWh/m²): |
|---|---|---|---|---|---|---|---|
| **CARE HOME:** | | | | | | | |
| **GENERIC CARE HOME** | **2011** | **Half-Hourly** | **Half-Hourly** | **307,058.82** | **573,216.85** | **129.75** | **242.21** |
| Bonnyton House Care Home | Apr 2011 - Mar 2012 | Monthly | Monthly | 257,464.56 | 802,173.98 | 178.79 | 557.07 |
| Clermiston Care Home | 2011 | Half-Hourly | - | 735,664.00 | - | 294.03 | - |
| Hillend House Care Home | Apr 2011 - Mar 2012 | Half-Hourly | - | 230,023.60 | - | 379.58 | - |
| Marrionville Court Care Home | 2011 | Half-Hourly | - | 390,780.70 | - | 94.07 | - |
| Muirpark Care Home | Apr 2011 - Mar 2012 | Half-Hourly | Half-Hourly | 65,970.20 | 388,689.00 | 46.59 | 274.50 |
| Silverlea Care Home | 2011 | Half-Hourly | - | 327,149.40 | - | 161.64 | - |
| South Parks Care Home | 2011 | Monthly | Monthly | 146,336.11 | 528,787.56 | 85.43 | 308.69 |
| **COMMUNITY CENTRE:** | | | | | | | |
| **GENERIC COMMUNITY CENTRE** | **2011** | **Half-Hourly** | - | **69,171.84** | - | **65.53** | - |
| Albertslund Community Centre | Apr 2011 - Mar 2012 | Monthly | Monthly | 5,948.00 | 54,000.00 | 21.87 | 198.53 |
| Burdiehouse Community Centre | 2011 | Half-Hourly | - | 81,341.30 | - | 77.47 | - |
| Cameron House Community Centre | 2011 | Half-Hourly | - | 44,580.70 | - | 37.43 | - |
| Garrel Vale Community Centre | Apr 2011 - Mar 2012 | Half-Hourly | - | 72,318.40 | - | 82.18 | - |
| Inch Community Education Centre | 2011 | Half-Hourly | - | 140,709.60 | - | 74.65 | - |
| **EMERGENCY SERVICES:** | | | | | | | |
| Fire Station | Apr 2011 - Mar 2012 | Monthly | Monthly | 278,323.00 | 382,842.00 | 116.99 | 160.93 |
| Glasgow Royal Infirmary | Apr 2011 - Mar 2012 | Half-Hourly | - | 23,714,156.00 | - | 118.81 | - |
| Police Station | Apr 2011 - Mar 2012 | Monthly | Monthly | 476,990.00 | 908,208.00 | 133.54 | 254.26 |
| **HALL/VENUE:** | | | | | | | |
| **GENERIC HALL** | **2011** | **Half-Hourly** | - | **613,066.09** | - | **134.88** | - |
| Adam Smith Theatre | 2011 | Monthly | Monthly | 267,417.86 | 629,891.66 | 92.37 | 217.58 |
| Corran Hall | Jun 2011 - May 2012 | Half-Hourly | - | 199,744.40 | - | 106.25 | - |
| Ushar Hall | 2011 | Half-Hourly | - | 1,371,909.80 | - | 154.83 | - |
| **HIGH/SECONDARY SCHOOL:** | | | | | | | |
| **(LOW) GENERIC HIGH SCHOOL** | **2011** | **Half-Hourly** | - | **393,956.19** | - | **35.13** | - |
| Boroughmuir High School | 2011 | Half-Hourly | - | 402,513.80 | - | 37.77 | - |
| Castlebrae High School | 2011 | Half-Hourly | - | 337,089.50 | - | 34.28 | - |

Figure 12. Snapshot of the Demand Profile – Buildings Worksheet in the Profile Library.

## 5.1 Introduction Worksheet

The Profile Library contains an Introduction Worksheet which briefly explains what the Profile Library is, what it contains and instructions on how to navigate and export the Demand Profiles in order for them to be imported into Merit. A list of acknowledgments is also included.

## 5.2 Demand Profile Worksheets

There are two Worksheets in the Profile Library; one contains information on general buildings, the other on a number of houses. For each Demand Profile Worksheet, various pieces of information are shown in a table. Clicking on each building type link (such as Care Home, Community Centre etc) will take you to the corresponding Excel file within the database where the user can view a chart depicting the daily average energy consumption over an annual period for each building type. Each building type Excel file contains charts and the demand profiles for their associated buildings. These demand profiles are easier to access through the Demand Profile Worksheets by clicking on the various Data Resolution links. Please note that all links are highlighted in blue.

## 5.3 Supply Profile Worksheet

These supply profiles were generated for the demonstration of Merit (which is discussed in ***Chapter** 7*). Similarly to the Demand Profiles, a small database contains relevant information regarding the renewable technologies such as annual supply generation, wind turbine nominal power, solar cell voltage at maximum power point etc. These profiles can also be viewed by clicking on their corresponding Supply Data Resolution.

## 5.4 Taxonomy

A Generic Profile Taxonomy was created via the website - https://bubbl.us/. This taxonomy illustrates the Demand Profiles contained within the Profile Library. Due to its size as shown in Figure 13, it was not possible to fit the entire contents of the taxonomy into this dissertation without compromising clarity. However, the following read-only link has been provided by the website to allow users to view the taxonomy as clearly as possible: https://bubbl.us/?h=108917/1f6e31/10omU/w7jxZsM.

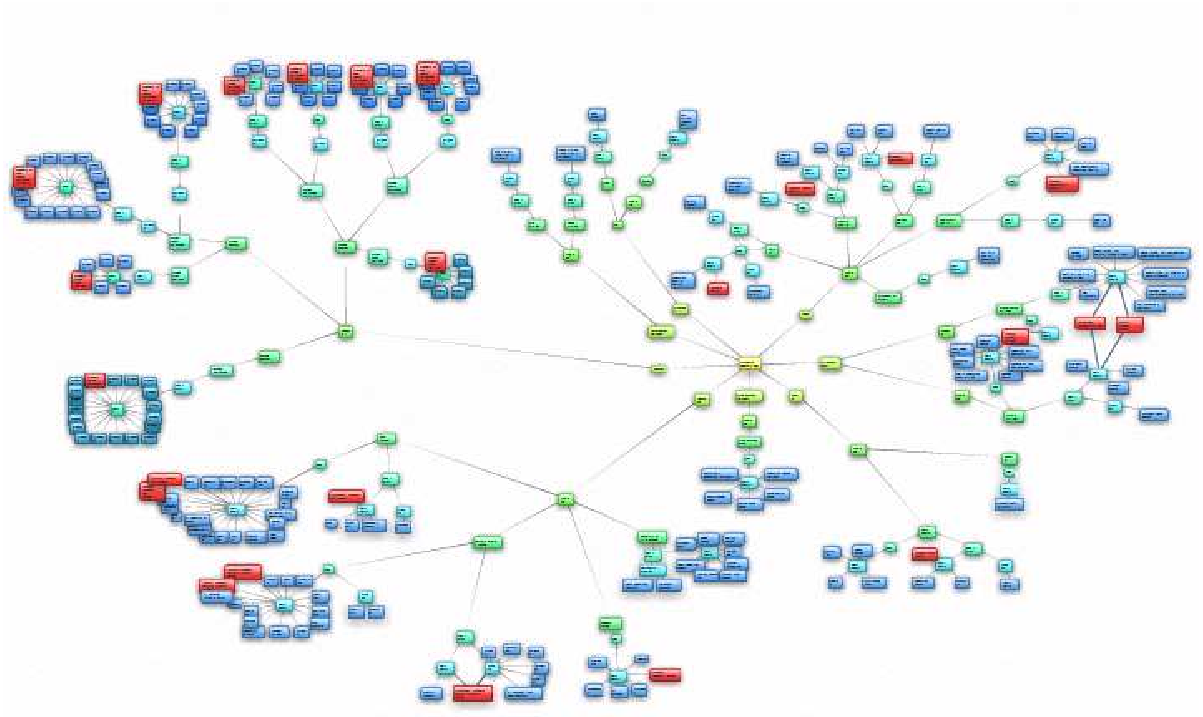


Figure 13. Snapshot of the Generic Profile Taxonomy.

# Chapter 6: Generic Electricity Consumption Calculator

A Generic Electricity Consumption Calculator was developed once all the Generic Demand Profiles were created and analysed. The calculator, as shown in Figure 14 below, allows the user to calculate the overall annual electrical consumption for a specific Generic-type of building (Hall/Venue, Office etc).

Firstly, the user selects the type of building they wish to utilise from a list. Once a building type is selected, the Generic AECFA and Generic daily occupancy for that building type are shown in the next two cells, replacing the hyphen. The user can then enter the floor area and average daily occupancy in the following two cells which would allow an estimated annual electrical consumption to be calculated.

**IMPORTANT**: This calculator is based ONLY on the data for the Generic Demand Profiles and as such, may not accurately match specific buildings (i.e. entering details for Bonnyton House Care Home from the Profile Library can result in the calculator estimating a dissimilar value).

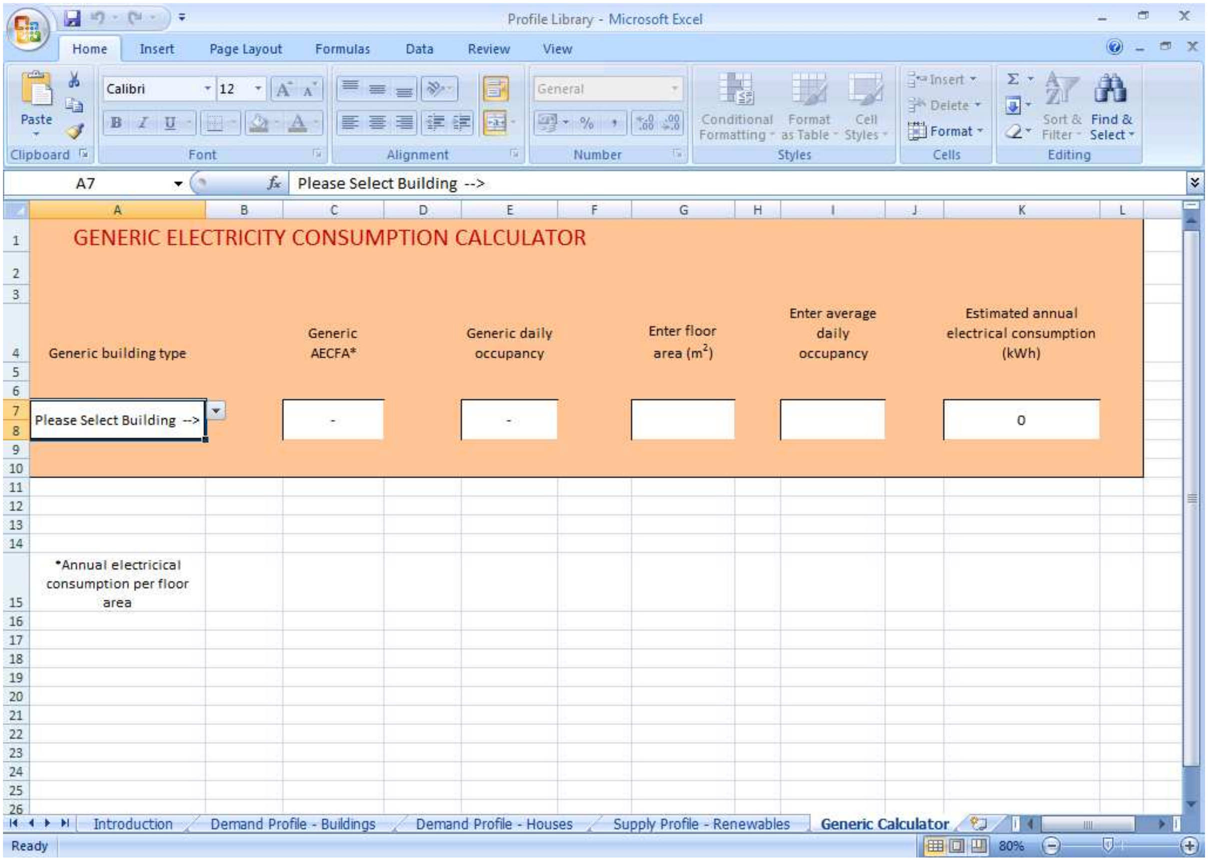



Figure 14. Snapshot of the Generic Electricity Consumption Calculator in the Profile Library.

Although the Generic Electricity Consumption Calculator is in a very early development stage, the process in which it operates is still valid and more refinement and demand data are required in order to expand and improve the accuracy of the calculator.

# Chapter 7: Analysing the University of Strathclyde with Merit

To better show how the latest version of Merit can be exploited and the effectiveness of such a DCMT, an example will be used – in this case, the University of Strathclyde.

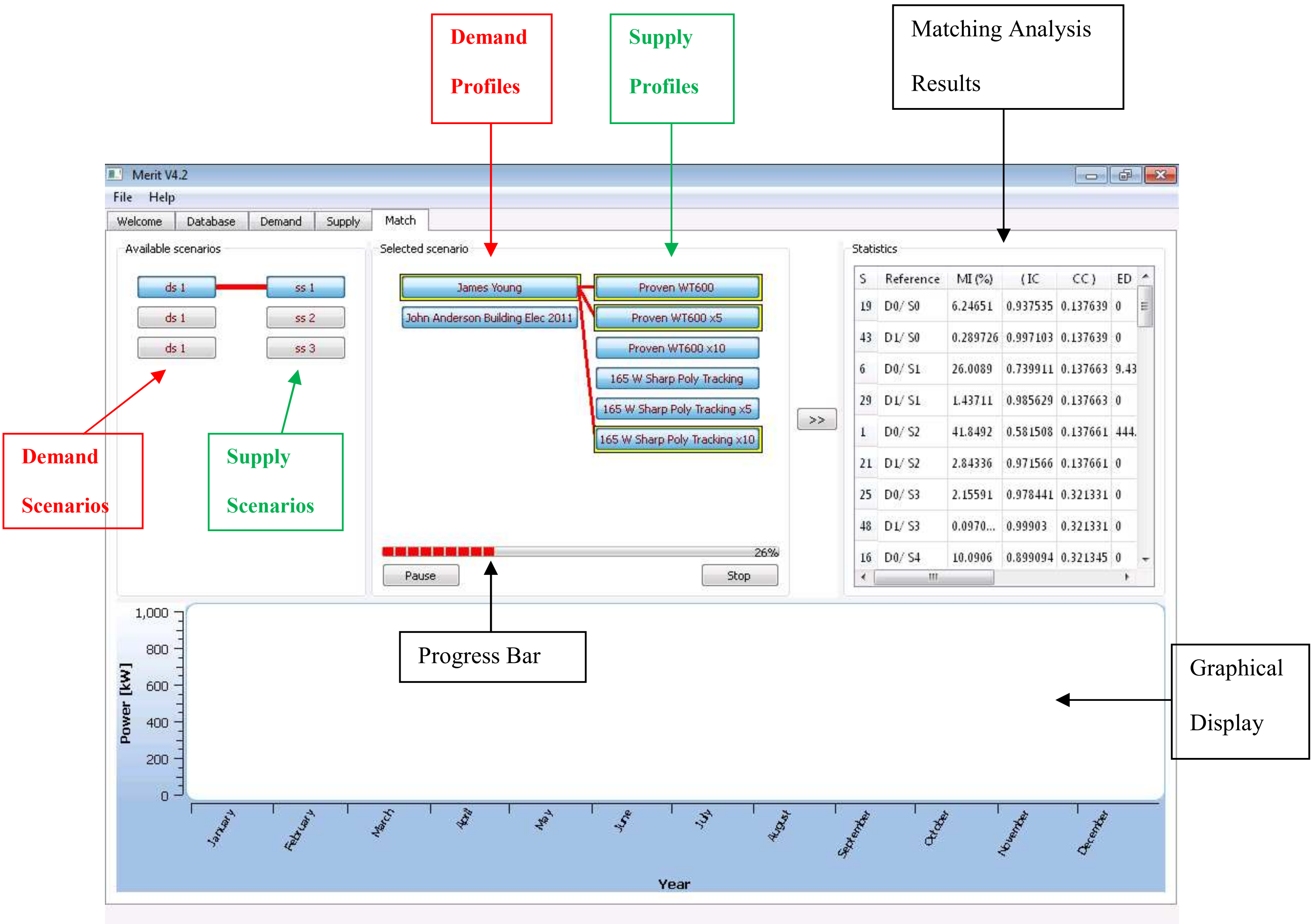
**Please note that the version of Merit used during this dissertation is NOT the final product and the images of the interface shown below may differ to the latest version.**

Two buildings with an electric-demand profile will be used to showcase the supply/demand matching tool of Merit: James Young, a student accommodation building; and John Anderson, a teaching and research building. Both buildings consumed contrasting overall amounts of electricity in 2011 – James Young (56,101 kWh/y) and John Anderson (1,266,497 kWh/y).

A number of supply profiles were generated using renewable technologies such as Proven Wind Turbines and Sharp Poly Solar PV Panels. Only 3 profiles for each technology were utilised in Merit, although there were 30 supply profiles created in total. The reason for only 6 profiles used is mainly to demonstrate the execution of Merit. The 6 profiles included supply data for 1, 5 and 10 Proven WT600 Wind Turbines; 1, 5 and 10 Sharp Poly Solar Panels.

These profiles were created using weather data from Glasgow in 1972. It is assumed that the weather for Glasgow from 1972 to 2012 has not changed drastically to affect the results of Merit.

Once the profiles were imported into Merit, the James Young and John Anderson Demand Profiles were selected for the Demand Scenario; equally, the same was applied to the supply profiles for the Supply Scenario. The Matching analysis could now be conducted and is shown in Figure 15. When this is completed, a list of matches is shown and the optimal matches for the two Demand Profiles are shown in both Figure 16 and 17.




| S | Reference | MI (%) | (IC | CC) | ED |
|---|---|---|---|---|---|
| 19 | D0/ S0 | 6.24651 | 0.937535 | 0.137639 | 0 |
| 43 | D1/ S0 | 0.289726 | 0.997103 | 0.137639 | 0 |
| 6 | D0/ S1 | 26.0089 | 0.739911 | 0.137663 | 9.43 |
| 29 | D1/ S1 | 1.43711 | 0.985629 | 0.137663 | 0 |
| 1 | D0/ S2 | 41.8492 | 0.581508 | 0.137661 | 444. |
| 21 | D1/ S2 | 2.84336 | 0.971566 | 0.137661 | 0 |
| 25 | D0/ S3 | 2.15591 | 0.978441 | 0.321331 | 0 |
| 48 | D1/ S3 | 0.0970... | 0.99903 | 0.321331 | 0 |
| 16 | D0/ S4 | 10.0906 | 0.899094 | 0.321345 | 0 |

Figure 15. Annotated snapshot of matching interface in Merit.

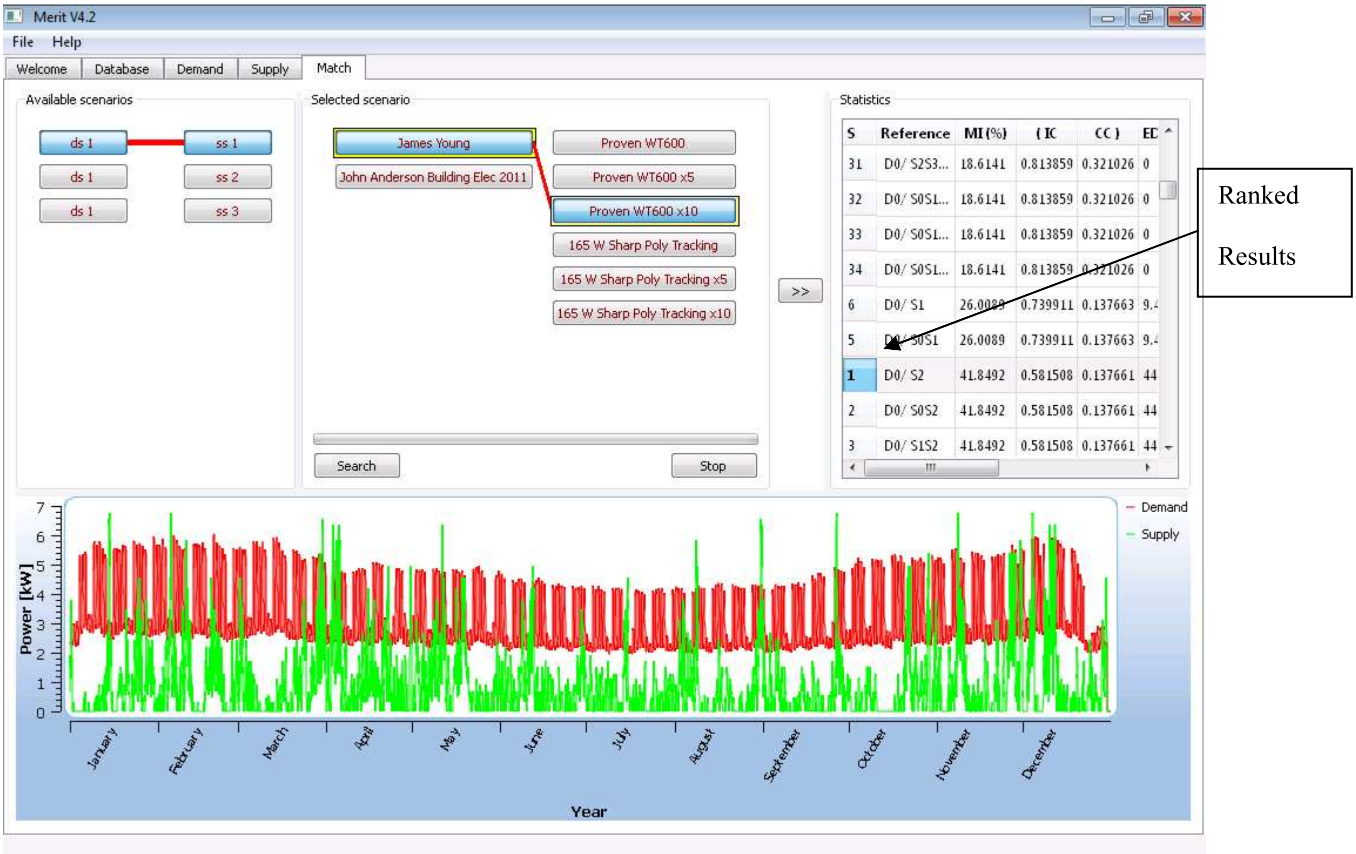



Figure 16. Optimal match found for James Young.

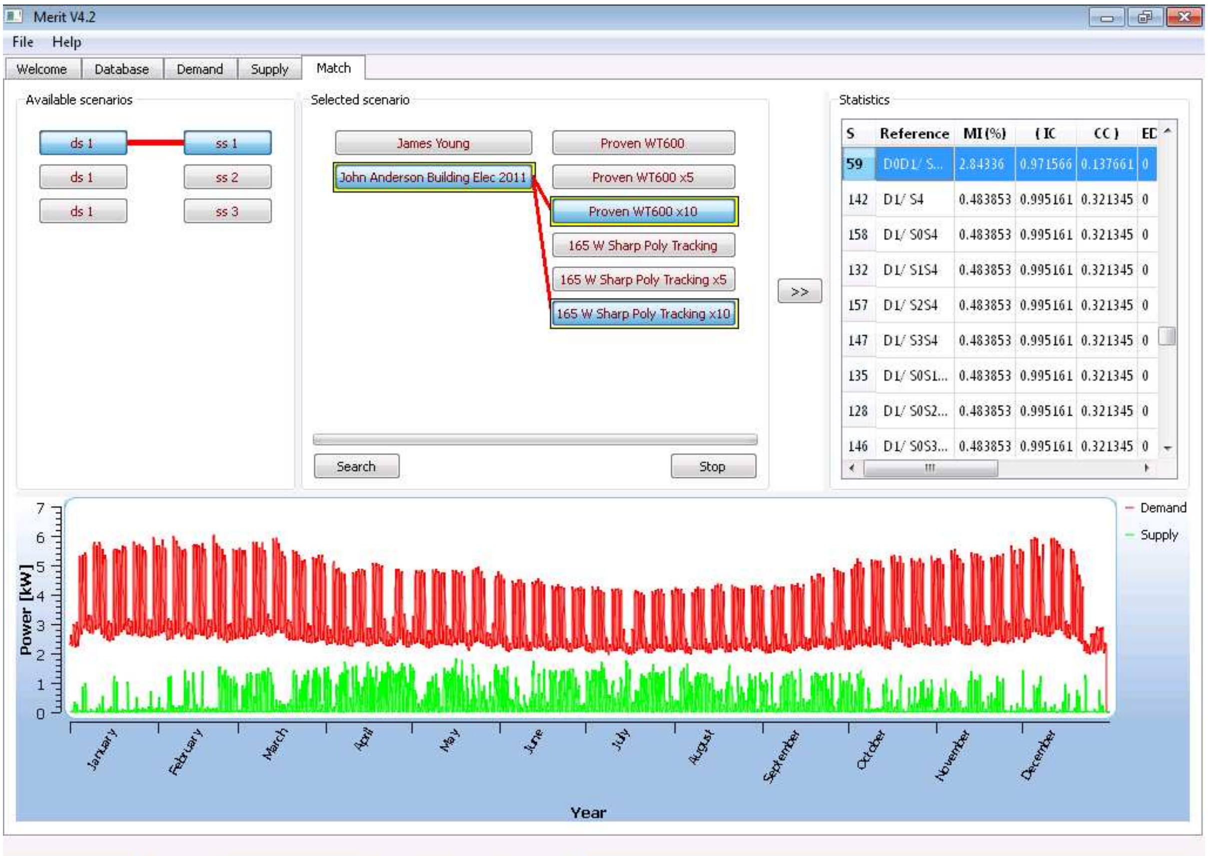



Figure 17. Optimal match found for John Anderson.

The results of Merit have shown that the optimal match for the James Young building with the renewable technologies corresponded to 10 Proven WT600 wind turbines. The Match Rate was calculated to be 41.85 %.

In terms of the John Anderson building, the optimal match corresponded to 10 Proven WT600 wind turbines and 10 165 W Sharp Poly Solar Panels. However, the Match Rate for this was computed to be only 2.84 %.

This demonstration has shown how Merit can be used to conduct a supply/demand matching analysis. Those combinations with a significantly high Match Rate could benefit from the proposed renewable technology.

# Chapter 8: Conclusions and Future Work

## 8.1 Conclusion

Over 300 electrical/thermal demand profiles were obtained for various buildings from a range of sources. These profiles were categorised, refined and analysed with their AECFA, and AGCFA if applicable, calculated. This allowed Generic Profiles to be developed for a number of building types such as Schools, Offices, and Houses etc. A Profile Library was developed which contained relevant information and demand profiles regarding all buildings used in this project. This database also allows the immediate exportation of demand data for each individual building which can then be readily imported into a DCMT such as Merit.

Once the Generic Profiles were acquired, a Generic Electricity Consumption Calculator was developed. This calculator, which is purely based on the data from the Generic Profiles, can be used to estimate the annual electrical consumption of a specific type of building by scaling the floor area and average daily occupancy.

A taxonomy was designed to illustrate the demand profiles contained within the Profile Library and has been categorised to allow clear understanding.

Finally, demand profiles from buildings James Young and John Anderson, part of the University of Strathclyde, were used with the supply/demand energy matching tool – Merit. The supply profiles used in collaboration with these demand profiles comprised of data generation from Wind Turbines and Solar PV Cells. It was found that, with the generated supply profiles, James Young received an optimal Match Rate of 44.11 % when combined with 10 Proven WT600 Wind Turbines. John Anderson received an optimal Match Rate of 2.83 % with 10 Proven WT600 Wind Turbines and 10 165 W Sharp Poly Solar Panels.

## 8.2 Future Work

To increase accuracy and effectiveness of the Generic Profiles, more demand profiles could be collected and analysed. Therefore, those buildings with similar AECFA or AGCFA could be grouped together just as those done for Offices and Schools.

A more in-depth study could be conducted to not only collect demand profiles for electrical/thermal consumption but also take into account the electrical appliances in buildings and how much energy each of those actually consumes, such as lighting, computers, air-conditioning systems etc. These added factors can then be used to determine a more accurate Generic Profile which could then be added and exploited in the Generic Electricity Consumption Calculator where the user can define what type and how many electrical appliances there are in a specific type of building.

By doing so, it could potentially diminish the need of creating and simulating virtual models in order to see how much energy a building consumes – thus saving time, money and resources.

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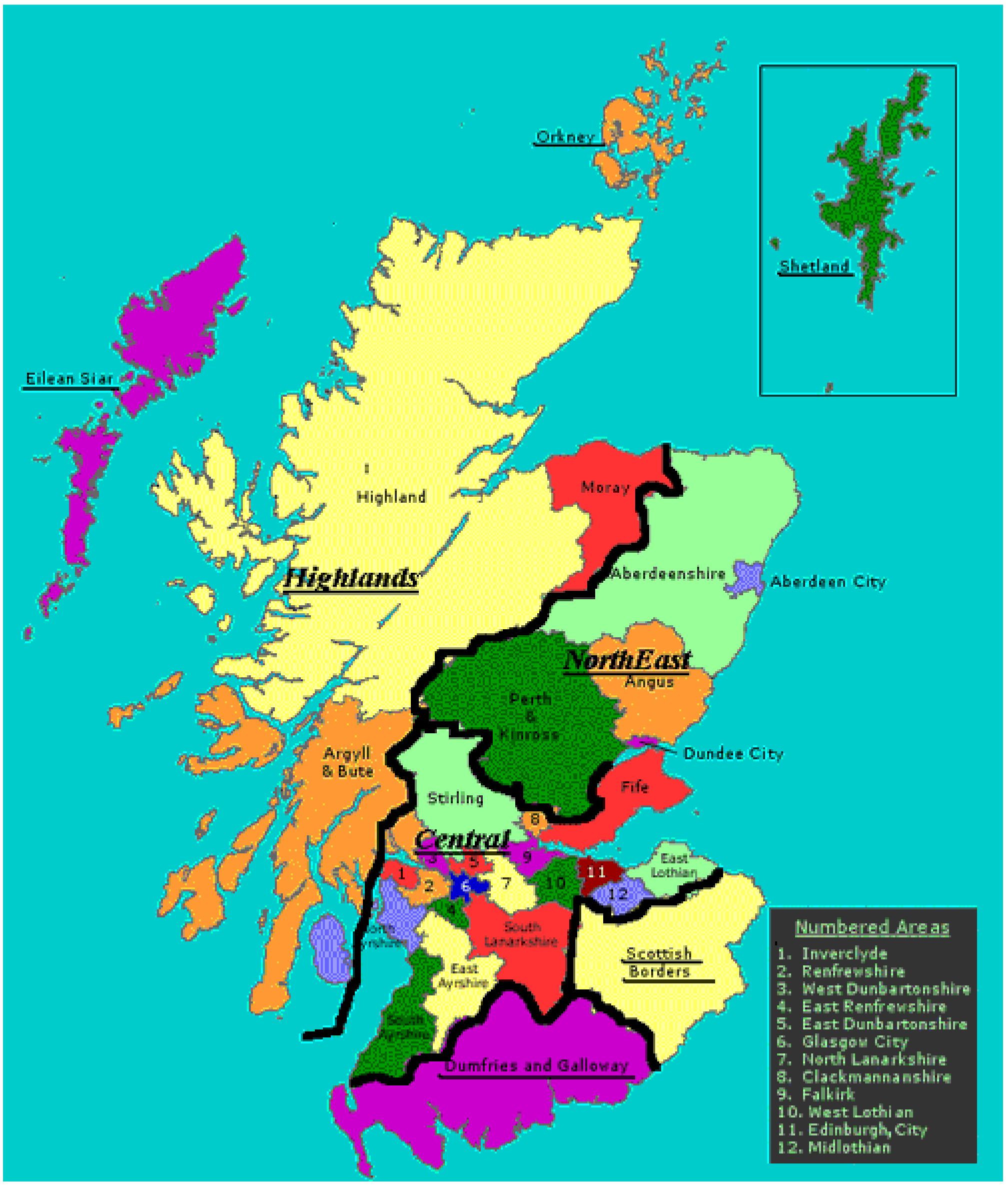
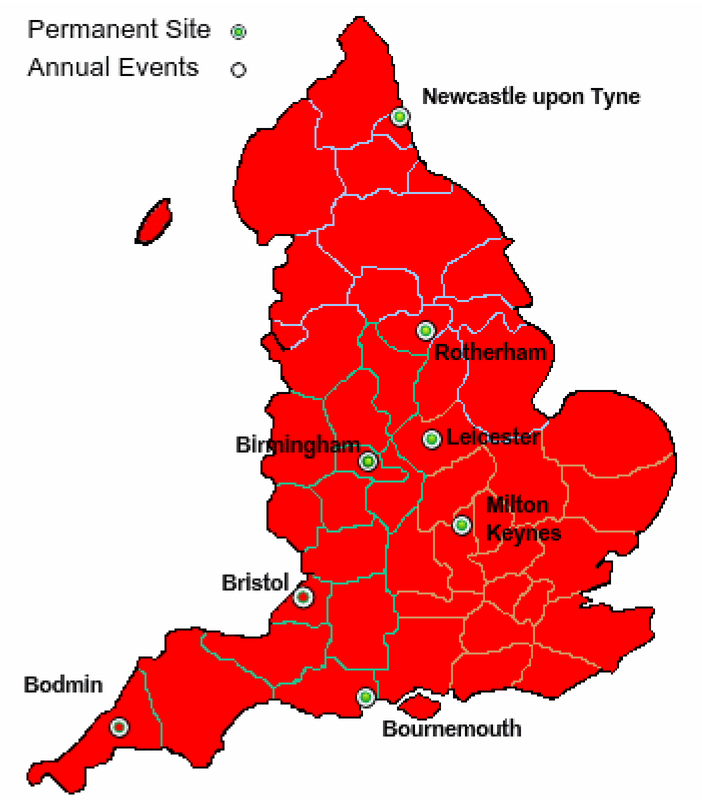
# Appendices

## Appendix 1: Map of Scottish Regions




Source: http://www.scotland.gov.uk/Publications/2004/06/19506/38901.

Appendix 2: Location of Milton Keynes, England




Source: http://www.lasersafety.org.uk/archived-website/schemes/england/index.htm.