Department of Mechanical and Aerospace Engineering

Distributed Energy Resources: Feasibility Study for the Dundee Central Waterfront

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Abstract

As energy security is brought to the forefront of policy in Scotland to help mitigate emissions to the atmosphere from human energy consumption and production, its reflection is being seen in redevelopment projects such as the Dundee Central Waterfront redevelopment project. Scottish policies are discussed, and the concept of small scale generation and distribution to lower carbon emissions is introduced and discussed. This feasibility study addresses approaching the Dundee Central Waterfront as a Distributed Energy Resource (DER) System to maximise carbon emissions savings through the use of integrated renewable energy and storage technologies and efficient building design. First, demand profiles are derived for the three buildings in the system. The match of simulated renewable supply to demand is then generated using a programme created by ESRU called Merit. A hand calculation method is also used to derive a match over a period of 11 months for which simulation data exists. The optimal combination of renewable energy supply and storage systems is determined for Plot 5, Plot 6, and the V&A Museum (when building to BREEAM Outstanding standards) to be 1814 YL245P solar modules to cover the three roofs, 12 WS110 turbines for along the Waterfront, 22 WS138 turbines at a site nearby, 40 iMiEV batteries from electric vehicles, one WSHP beneath the V&A Museum, and one AKVA 5,000 litre thermal buffer tank. When considering these three buildings as a part of the Central Waterfront, it is recommended to go forward with the systematic approach if the benefits outweigh the monetary costs. Additionally, it is recommended to increase the contribution of electrical supply delivered to the system or add substantial electrical storage to maximise return from the DERs in the system.

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1 Introduction

Energy security is becoming of utmost importance for our future as fossil fuel supplies are depleted at a staggering rate. Total world energy consumption in 2010 was 153.6 PWh (picowatt hours) and is expected to increase by 56% by 2040 (United States Energy Information Administration, 2013). Scotland has an abundance of natural resources including wind, wave, and tidal power that could provide a significant portion of the nation's total energy consumption, so planning for the future now is key if energy security is to be maintained or improved. One method of potentially increasing the overall amount of renewable energy used is to approach the problem on a community level rather than building-by-building and treat the community as a system, with each building as an individual demand component connected to a local electrical and heating 'district' with renewable energy generation, or distributed energy resource (DER), technology.

World carbon dioxide levels peaked over 400 ppm in May 2013, and to keep current levels from rising, the world would need to immediately reduce fossil fuel use by 55-60%, according to Ralph Keeling, Scripps Carbon Dioxide Programme. He points out that the atmosphere does fluctuate over thousands of years, but it has been somewhere around 3 million years since the carbon dioxide levels in the air were this high (Montaigne, 2013). Action must be taken now to replace fossil fuels with renewable resources for energy generation to mitigate the impact of human consumption by reducing greenhouse gas emissions to the atmosphere.

One project for which the design process will have a great effect on greenhouse gas emissions to the environment is the Dundee Central Waterfront redevelopment project, a £1 billion, 30-year investment that will reconnect the city centre to the waterfront, is aiming to put the city of Dundee at Scotland's forefront of sustainable design and business (Dundee City Council, 2013). This report aims to determine whether approaching the Dundee Central Waterfront redevelopment project as a DER system from the design phase (with local renewable generation and storage) will be of benefit in decreasing the city's carbon footprint and providing a reliable energy supply system from renewable resources.

Scotland's current energy situation including the Government's ambitious policies, generous feed in tariffs, and strict obligations are introduced in this section to provide justification for pressing this potential renewable energy system design. A distributed energy resource system is also defined in Section 1.4, and the case study along the Dundee Central Waterfront is explained in detail in Section 1.5.

1.1 Energy Generation and Demand in Scotland

Scotland's energy situation has become an important topic within Government politics of late, for potential in the country for wind, wave, and tidal power, for example, is much higher than in other countries and the markets are growing at a rapid pace. The Digest of UK Energy Statistics (DUKES) is therefore released annually to summarise Scotland's energy statistics, and the Scottish Government releases reports using the data collected by the DECC to document changes while predicting the uptake of renewables in Scotland.

Energy generation in Scotland since 2000 can be seen in Figure 1.1 below, which is extrapolated from a 2012 Scottish energy statistics report (Scottish Government, 2012). In 2011, energy generation was approximately 50.2 TWh, and total energy consumption was 32.1 TWh (Scottish Government, 2012).

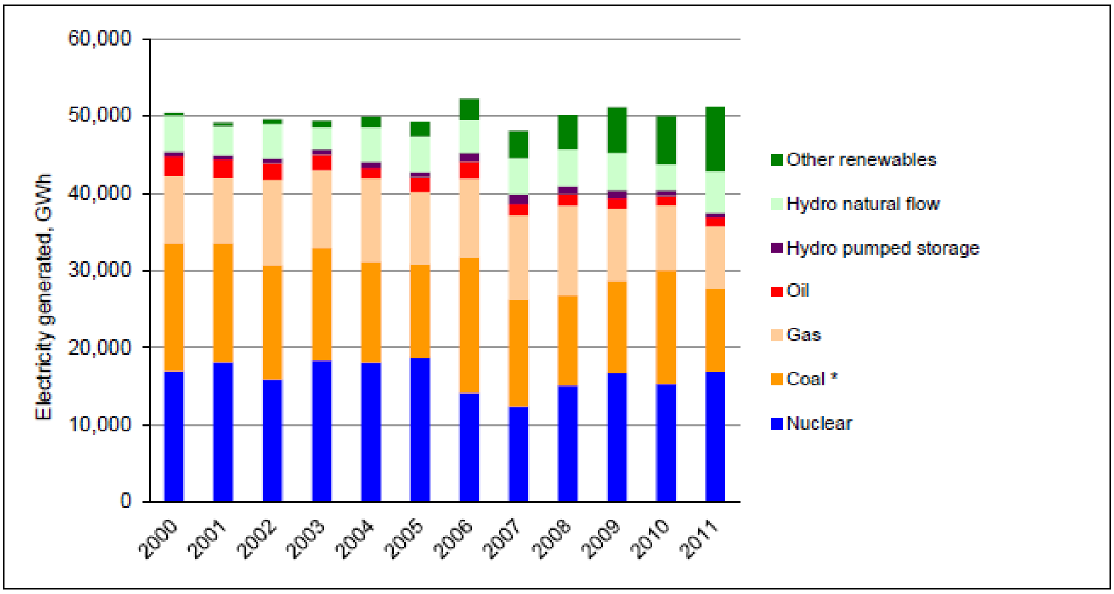


Figure 1.1- Energy Generation in Scotland 2000-2011

Although the UK is a net importer of electricity, Scotland is currently (and has been for some time) a net exporter of electricity, as is explained further in the following section on renewable energy (Department of Energy and Climate Change, 2013). It should also be noted that Scotland has seen a decrease in energy demand since 2009, which is possibly due to the global recession that began that year (Milner, 2009). It is predicted to take beyond 2015 to recover from pre-recession levels (Social Research, 2011). The data for the following, Figure 1.2, was extrapolated from a paper on Scottish generation scenarios.

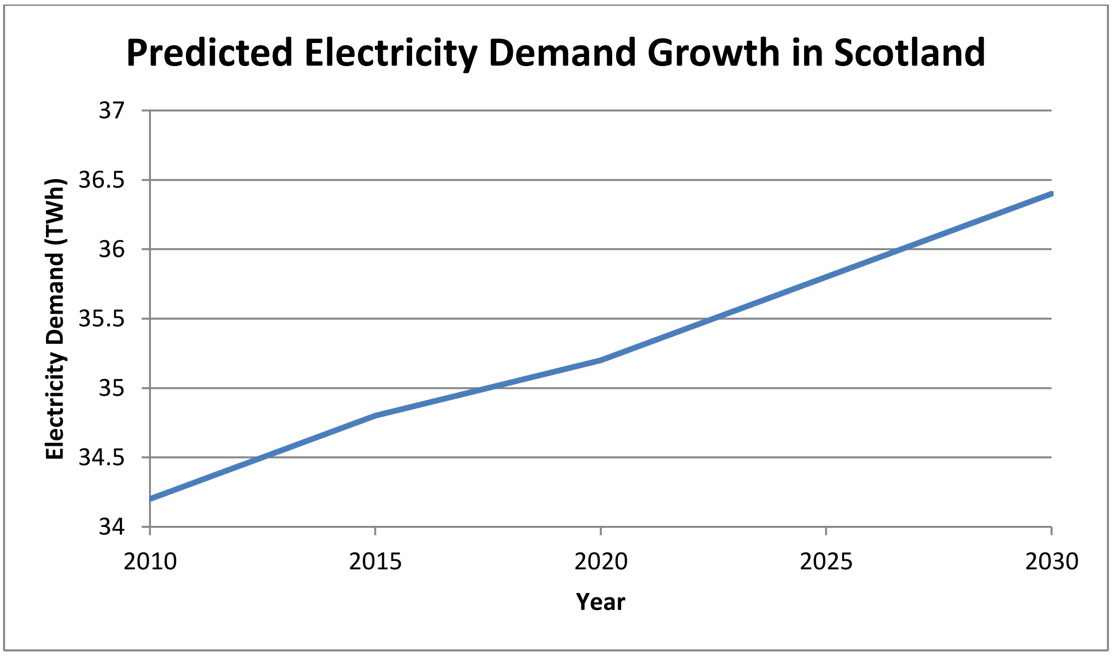


Figure 1.2- Predicted Electricity Demand Growth in Scotland

Despite energy efficiency measures, demand is predicted to continue to increase, largely due to population growth and immigration, but also due to an increase in industry in Scotland (Office for National Statistics, 2011; Social Research, 2011). Therefore, the Government has set targets and schemes to help promote the uptake of renewable energy generation to support energy security and sustainable development in the future.

1.2 Scotland's Future Targets

The Scottish Government realises the impact our current energy production and consumption is having on the environment and has chosen to mitigate this through setting ambitious targets and implementing multiple energy-related policies to decrease demand and increase the percentage of energy generation from renewable resources. Scotland has set a target of 12% reduction in final energy consumption by 2020 to encourage energy efficiency, for example (Scottish Government, 2012). Multiple policies exist to require carbon dioxide emissions reduction as well, so use of renewable sources is promoted.

It has been estimated that the average household bill in 2020 can be reduced by approximately 7% through implementation of Government policies that encourage energy efficiency and production of renewable energy as a percentage of total energy production. That is an average savings of nearly £100 per year.

Energy-related policies not covered in this report include the Green Deal, for it applies only to existing buildings. Fuel poverty is also assumed not to be an issue, for the project will likely attract many customers not in fuel poverty (Dundee City Council, 2013). Additionally, the Renewable Heat Premium Payment (RHPP) programme is for existing customers switching to renewable heat (Department of Energy and Climate Change, 2013).

1.2.1 Emissions Reduction

In 2012, the ‘basket 6’ greenhouse gas emissions (CO_2, CH_4, N_{20}, HFC, PFC, and SF_6) totalled a staggering 571.6 million tonnes of carbon dioxide equivalent, up 3.5% from 2011. 83% of those 2011 emissions were carbon dioxide, and that figure is estimated to have increased by 14.5% since then. It is estimated that emissions have risen since 2011 primarily due to the increased use of coal rather than natural gas and the increased use of residential gas during the coldest months of 2012 (Department of Energy and Climate Change, 2013).

Because greenhouse gas emissions in our atmosphere are still rising and the climate is changing due to anthropogenic global warming, reducing the emissions produced every day can potentially benefit the earth’s ecosystem while providing energy security for the future. The Scottish Government is choosing to take action through policies as detailed below.

1.2.1.1 Climate Change (Scotland) Act

Scotland’s Climate Change Act was set in 2009 with a target to reduce 80% of greenhouse gas emissions (on 1990 levels) by 2050 and an interim target of 42% emissions reduction by 2020 (Scottish Government, 2012)

1.2.1.2 Scottish Building Emissions Regulations

Section 6 (Energy) Building Regulations up to 2030 regarding emissions reduction will require 100% of carbon dioxide reduction (from 2007 values) from regulated energy by 2017, and 100% of carbon dioxide reduction from total energy by 2030 (Scottish Enterprise, 2013).

1.2.2 European Union Eco-Design Framework Directive

The Eco-design Framework Directive (2009) regards ecological requirements for energy-related products in the European Union, a large portion of electricity demand. The Directive encourages carbon emissions reduction through energy-efficiency.

There are currently no minimum ecological requirements set through this directive; rather they have been adopted to encourage continuous improvement on environmentally friendly design for energy, emissions, water, materials use and recyclability (European Union, 2009).

1.2.3 Renewable Energy Use

To combat rising fossil fuel prices and provide energy security for the future, Scotland has set a target to produce 30% of total energy consumed from renewable sources by 2020 (Scottish Government, 2012).

A target of 11% of heating in Scotland from renewable sources has also been set for 2020. That is 6.4 terawatt hours of renewable heating generation, or 2.1 gigawatts of installed capacity (Scottish Government, 2012).

Additionally, a target was set for 2015 for 50% of gross annual electricity consumption to come from renewables, stretching to 100% by 2020. Gross annual consumption is measured as ‘electricity generated minus net exports (but including losses)’ (Scottish Government, 2012). It is predicted that 39% of Scotland’s electricity in 2012 came from renewable sources, so the target is well within an achievable range given that renewable supply continues to grow at an exponential rate (Scottish Government, 2013).

The Scottish Government has estimated that 6.2 GW of renewable energy capacity is currently installed in Scotland, with a total of approximately 19.2 GW in the planning stages, under construction, or in operation, as is shown in Figure 1.3 (Scottish Government, 2013).

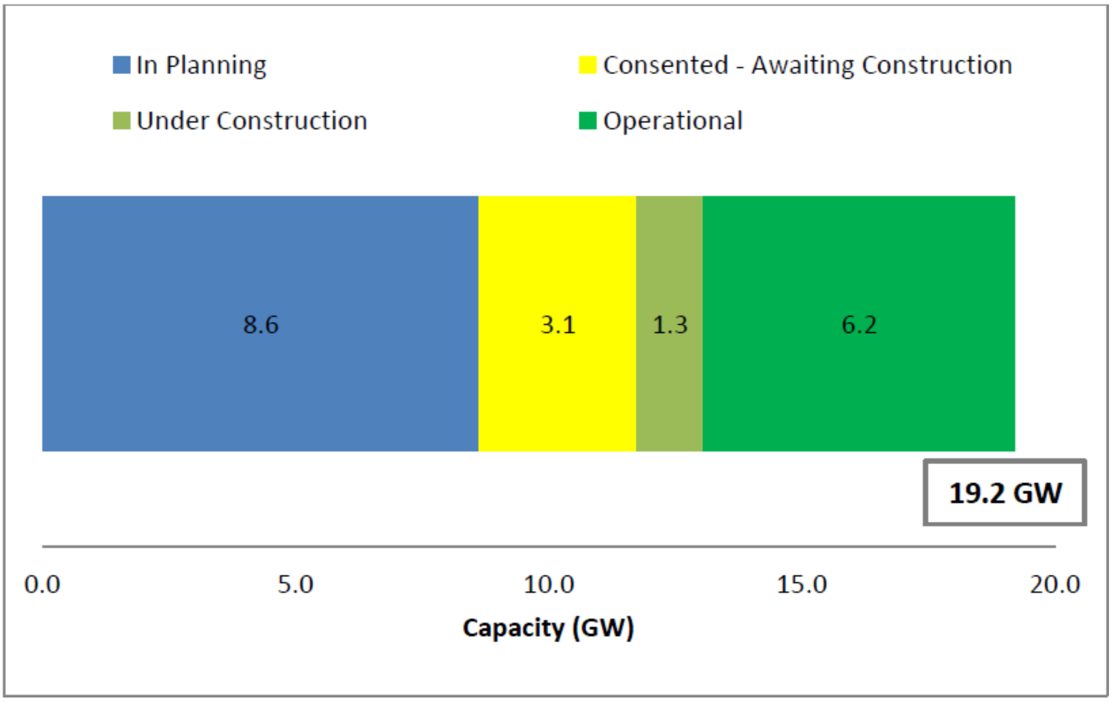


Figure 1.3- RE Capacity in Scotland (March 2013)

To maximise contribution of renewable energy systems in addition to energy efficiency improvement, the Environmental Assessment (Scotland) Act was passed in 2005 (Scottish Government, 2012). Energy storage is also encouraged as part of a whole distributed system.

Carbon emissions reductions targets are one motivator for producing renewable electricity, and energy exports are another, for the potential for net profit exists. With countries including the European Union's largest energy consumer, Germany (European Commission, 2012), phasing out nuclear power completely by 2022, Scotland will have a great opportunity to export electricity to Europe, which boosts the chance of becoming the 'green energy powerhouse of Europe' (Currie, 2011). According to the Government, Scotland has been a net exporter of electricity for some time, with net exports in 2010 to England and Northern Ireland at 19.1% of total annual generation, and 'renewable electricity generation [in Scotland is continuing] to grow, with onshore wind capacity set to expand and enormous offshore wind, wave, and tidal resources ready to be harnessed' (Scottish Government, 2012). Offshore wind capacity is up a staggering 63% from 2011, and wave and tidal supply could deliver between 40-50 and 20-30 TWh/yr, respectively (Department of Energy and Climate Change, 2013). So exports could easily increase to allow for the renewable market to expand.

Figure 1.4 below is extrapolated from the DECC (2012) (Department of Energy and Climate Change, 2012) illustrates Scotland's historic electricity exports and consumption. Electricity generation has exceeded consumption for at least 10 years, so if enough interest is spurred in generating additional renewable electricity (and the current fossil fuel generation plants remain in operation) exports could increase further (Scottish Government, 2012).

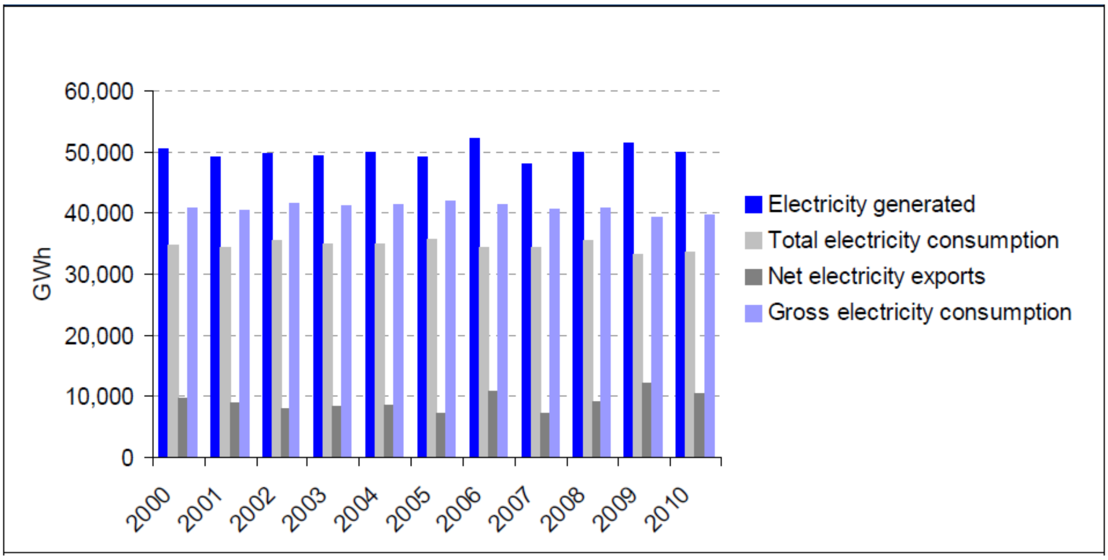


Figure 1.4- Electricity Generated, Consumed, and Transferred in Scotland

1.2.4 Feed-in Tariffs

Since 2010, the UK Government has been paying small-scale energy producers for the energy they generate and for surplus energy exported to the grid to encourage renewable energy production. Feed-in Tariffs (FITs) are currently available for multiple types of renewable energy generation for up to twenty years:

- solar electricity (PV) (roof mounted or standalone)
- wind turbines (building mounted or free standing)
- hydroelectricity

- anaerobic digesters
- micro- combined heat and power (CHP).

This is to promote small scale renewable generation and encourage future carbon emissions savings. The following generation tariffs currently apply in the UK, with the export tariff set at a further 4.64 p/kWh. Tables 1.1 and 1.2 are extrapolated directly from the Energy Saving Trust website (Energy Saving Trust, 2013).

Table 1.1- FITs for Photovoltaics

Total installed capacity (kW)	**Generation tariff with eligibility date or after 1 May 2013 and before 1 July 2013**	**Generation tariff with eligibility date on or after 1 July 2013 and before 1 October 2013**	**Lower tariff (if EPC requirement not met) with eligibility date 1 May 2013 – 1 October 2013**
<4kW (new build and retrofit)	15.44p/kWh	14.90p/kWh	6.85p/kWh
>4-10kW	13.99p/kWh	13.50p/kWh	6.85p/kWh
>10-50kW	13.03p/kWh	12.57p/kWh	6.85p/kWh
stand-alone	6.85p/kWh	6.85p/kWh	6.85p/kWh

Table 1.2- FITs for Hydro, Wind, and MicroCHP

Technology	**Tariff band (kW capacity)**	**Tariffs from 1 December 2012 to 31 March 2014**
Hydro	<15	21.65p/kWh
	>15 to <100	20.21p/kWh
Wind	<1.5	21.65p/kWh
	>1.5 to <15	21.65p/kWh
	>15 to <100	21.65p/kWh
Micro-CHP	<2kW	12.89p/kWh

It can be seen above that the greater the installation size, the greater the benefit. A similar scheme is available for thermal energy generation- the Renewable Heat Incentive (RHI).

1.2.5 Renewable Heat Incentive

Heating accounts for approximately 55% of total energy demand in Scotland, so fossil fuel use for heating should be minimised where possible (Scottish Government, 2012). Like the FITs for electricity generation, the RHI scheme exists to promote the uptake of renewable energy technology for small-scale thermal power generation. RHIs are available for up to twenty years for non-domestic biomethane producers and recently for domestic customers using air source heat pumps (ASHPs), biomass systems, ground source heat pumps (GSHPs) and solar thermal technologies. The tariffs for the domestic sector are listed in Table 1.3 below (Energy Saving Trust, 2013).

Table 1.3- Domestic FITs for HPs, Biomass, and Solar Thermal

	ASHP	**Biomass**	**GSHP**	**Solar thermal**
Tariff (p/kWh renewable heat)	7.3	12.2	18.8	19.2

Policies such as the RHI and FITs will play a key role in defining the small-scale generation market in Scotland in the near future. The Energy Saving Trust calculates that approximately 65% of household emissions could be reduced in a DER system with a FIT and RHI in place (Energy Saving Trust, 2008).

1.2.6 Renewables Obligation

The Renewables Obligation (RO) requires electricity distribution companies to source electricity from renewable technologies. RO Certificates (ROCs) are presented to the Office of and Electricity Markets (OFGEM) to cover renewables use requirement (Department of Energy and Climate Change and Department of Transport, 2013). If companies do not meet their minimum targets, they must buy additional ROCs to balance the system at £42.02 per MWh per ROC at 0.206 ROC/MWh for 2013-2014 and so on (Scottish Government, 2013). That is over 5 times the price of electricity for domestic use (if it is assumed to be 15 p/kWh).

The Renewables Obligation (Scotland) has been effective as of 2002 and costs the average household £30 a year (Scottish Government, 2013).

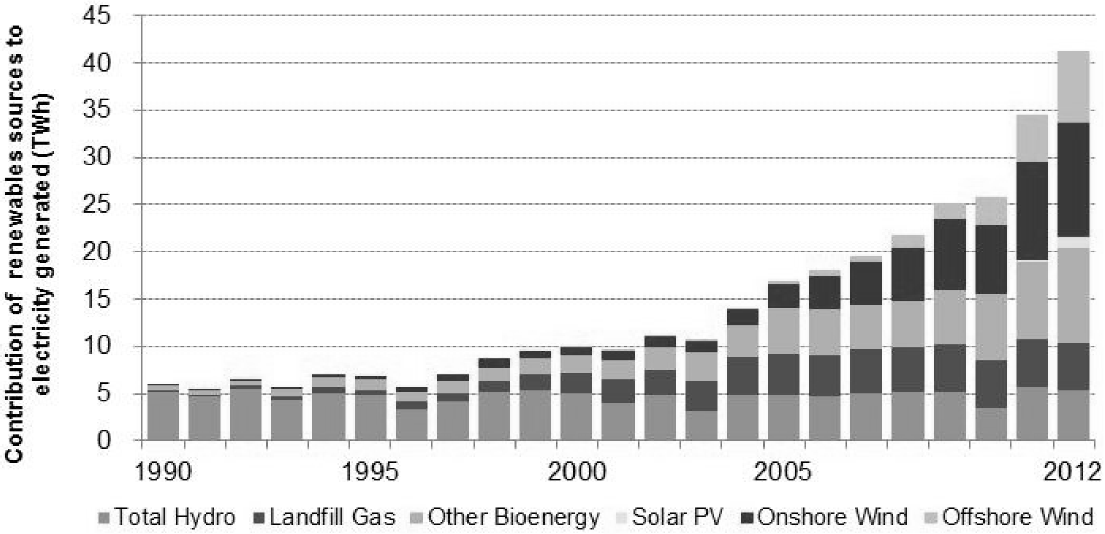
1.2.7 International Energy Agency's BLUE Map Scenario

In 2010, the International Energy Agency (IEA) created a target-oriented scenario looking into 2050 to reduce global carbon emissions by 50%, or some 2 gigatonnes (compared to 2005), by increasing energy efficiency and using low- or zero-carbon (LZC) technologies for heating and cooling. The Agency warns that for this scenario to come to pass, the market must increase twelve fold; research and development must receive significant funding in order to improve technology, particularly for renewable energy storage, to meet demand cost-effectively (International Energy Agency, 2011).

1.3 Renewable Technology for DER Systems in Scotland

Scotland is a particular windy country, which makes the area ideal for wind power in addition to tidal and wave power off shore in the North Sea. Additionally, solar photovoltaics, solar thermal, and heat pumps all have great potential for smaller scale or building integrated application.

Electricity generation from renewable sources has been increasing at an exponential rate since 1990; Figure 1.5 below illustrates the renewable electricity generation by source in the UK (Department of Energy and Climate Change, 2013). Onshore wind and solar PV currently dominate the majority of the renewable market, with offshore wind, hydropower, and bioenergy contributing as well. Some of these technologies are beginning to gain popularity for small scale application in the UK and are explained below.



Note: Hydro bar includes shoreline wave/tidal (0.004TWh in 2012)

Figure 1.5- Electricity Generation in the UK by Main Renewable Sources since 1990

Renewable electricity generation in Scotland was 14,825 GWh in 2012, or 36% of total UK renewable generation (Scottish Government, 2013). A breakdown of renewable energy use in the UK in 2012 can be seen below in Figure 1.6.

Additionally, renewable heat generation in Scotland accounted for approximately 15% of UK renewable generation (Department of Energy and Climate Change, 2013).

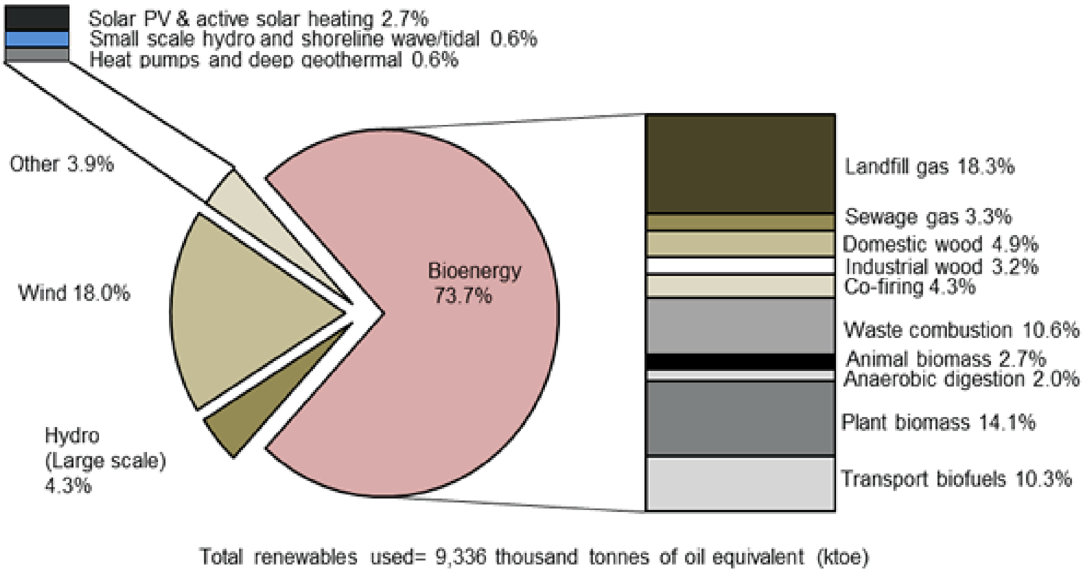


Figure 1.6- Renewable Energy Utilisation in 2012

Although there are many benefits to increasing renewable energy generation in Scotland, as the country's energy landscape evolves, environmental challenges such as air quality, population density, population health, soil quality, water quality, biodiversity, and cultural heritage must be considered (Scottish Government, 2012). These environmental impacts, if visible, could be warning signs that the technologies are not working. Strategic planning and environmental impact assessments must be carried out in order to avoid these potential outcomes.

Furthermore, transmission charges due to infrastructure and losses account for approximately 20% of domestic energy bills (Scottish Government, 2012). Therefore, localised generation could save a significant portion of those charges, as transmission losses and infrastructure costs could be minimised. The following renewables for localised generation are introduced, and the use of multiple systems in tandem is encouraged to obtain the best match scenario.

1.3.1 Local Small-Scale Wind

Small-scale wind power can be considered as a system of turbines with up to 50 kW (Carbon Trust, 2008). Small-scale wind can provide a portion of total energy demand. Centralised wind turbine generation for local communities can benefit consumers and energy producers alike, as they are linked through the electricity district to the turbines nearby, which minimises transmission losses.

Onshore wind capacity in Scotland in 2012 was up 27% from 2011 to approximately 5.8 GW (Department of Energy and Climate Change, 2013). Figure 1.7 below, extrapolated from the DUKES 2013 report, illustrates the installed wind capacity in Scotland in 2012. The smallest dot represents the wind farm size considered in typical DER systems (Department of Energy and Climate Change, 2013).

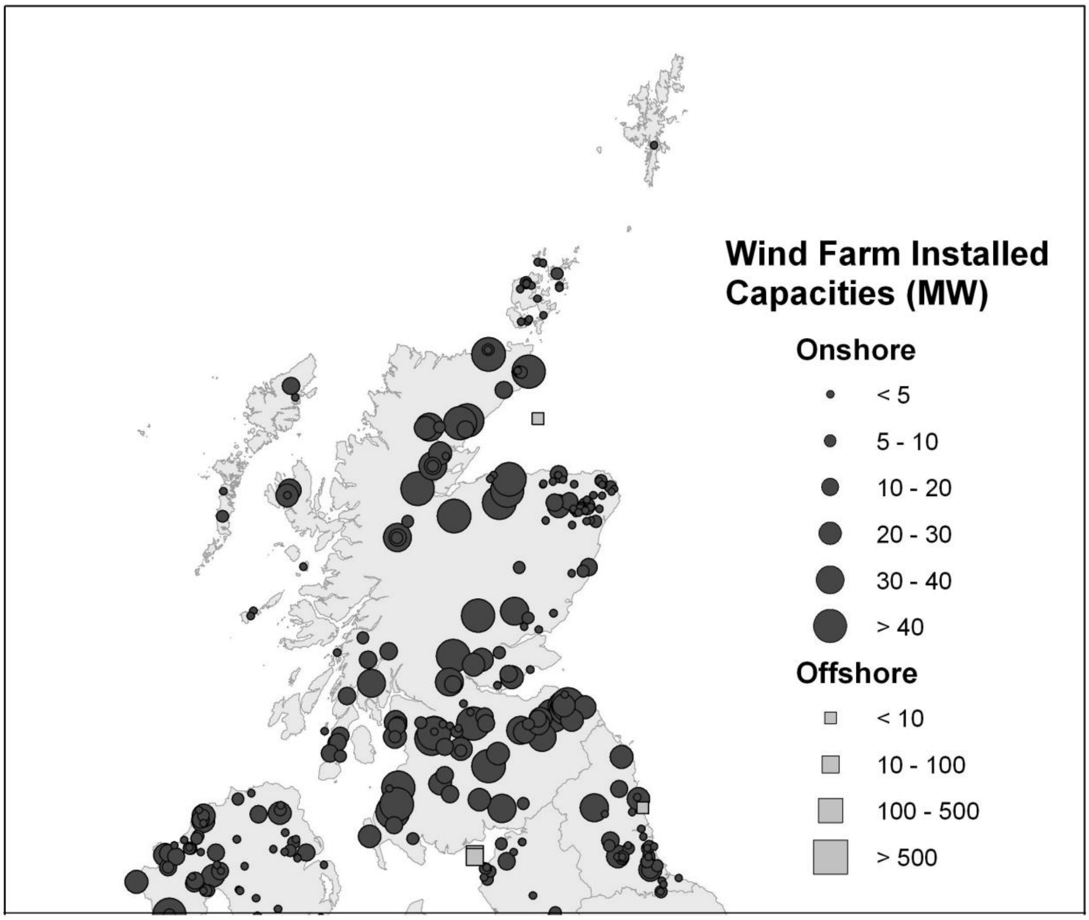


Figure 1.7- Wind Farm Locations in Scotland by Installed Capacity

1.3.2 Photovoltaics

Solar photovoltaics (PV) are gaining popularity even in Scotland where sunshine is not considered ‘reliable’, as is shown above in Figure 1.5. Modules are continuing to increase in efficiency and FITs are helping to support PV installations, including small scale systems. Small scale PV generation is considered as less than 5 MW of installed capacity.

The energy generated by PV in the northern UK is significant enough to provide a portion of daily electricity demand. Significant enough so that in 2012, installed PV capacity in Scotland was 1,705.5 MW- up a staggering amount from just 10.9 MW in 2005 (Department of Energy and Climate Change, 2013).

Research and development is still needed for this technology due to the low efficiencies of existing modules, and investigation into technologies such as thin films or building integrated photovoltaics is highly recommended, as the amount of solar energy available on earth is 4.2 W/m^2/day, which is more than four times the amount current technologies can generate under good conditions (The GW Solar Institute, 2013).

1.3.3 Micro-hydropower

For communities located along rivers, micro-hydro generation from a weir along the river, for example, could provide renewable electricity to meet a significant portion of demand, based on the change in height of the river. It could be enough for a cluster of homes or an entire city, if it were located on a micro grid. According to the DECC, a ‘small-scale hydropower’ system has a capacity less than 5 MW.

215 MW of installed capacity exists in Scotland as of 2012, up 11 MW from 2011. 60% of the capacity is owned by small-scale energy producers and the majority of the schemes are supported by FITs or ROCs (Department of Energy and Climate Change, 2013).

1.3.4 Tidal Power

Tidal power can be used to create electricity to be used in a local grid. Several designs exist, but the technology must be improved and tested, so research into this technology is encouraged at this time. Transmission losses can also be kept to a minimum by supplying the local grid (Scottish Government, 2012).

Another method of harnessing tidal power is to create a ‘tidal lagoon’ off the side of a river that fills as the tide increases and is dammed up until low tide when it is released to generate energy (Department of Energy and Climate Change, 2013).

1.3.5 Heat Pumps

Heat pumps are gaining popularity as renewable sources of heating and cooling. Some models can work in both directions, making them ideal for seasonal climates. There are three types of heat pumps: air-source (ASHP), ground-source (GSHP), and water-source (WSHP). They utilise a relatively small amount of electricity (typically 1/3 to 1/4 of the output), a heating/refrigerant chemical, and the available heat sinks (i.e. the atmosphere, ground, and large water source) to produce thermal energy.

Heat pumps accounted for just 4% of renewable heat generation in the UK in 2012, mainly in the domestic sector (Department of Energy and Climate Change, 2013). That number has potential for expansion in the future as technology becomes more affordable.

1.3.5.1 Air Source Heat Pumps

Air source heat pumps perform optimally in consistently warm or cool temperatures, for it takes time for the heat pump to change operation to allow for temperature fluctuation throughout the day, thus reducing the overall output.

1.3.5.2 Ground Source Heat Pumps

Ground source heat pumps perform well when installed correctly, but correct installation is difficult in many climates. Therefore, ground source heat pumps are only recommended if uncertainty can be minimised in the design process.

1.3.5.3 Water Source Heat Pumps

Water source heat pumps are ideal for heating when they are connected to a consistently cool source such as the mouth of a river. Since commercial WSHPs can produce a significant amount of power, a district heating scheme and thermal storage are investigated to accommodate the output.

1.3.6 Combined Heat and Power

Combined heat and power (CHP) is gaining popularity in Scotland due to high efficiency and rate of return on investment. Combined heat and power systems utilise waste heat from power generation processes for district heating, for example, which provide an additional energy source to replace fossil fuels. CHP had an installed capacity of 6.1 MW at the end of 2012, a figure which has nearly doubled since 1997

(Department of Energy and Climate Change, 2013). Due to the wide applicability to CHP systems, growth is anticipated in CHP generation and similar technologies.

1.3.7 Solar Thermal

Solar thermal technology is not popular in Scotland due to the cold climate in the winter months, but it can be very effective in the summer due to long days with significantly more daylight hours. In 2012, an estimated 252 GWh of domestic hot water from gas and electricity heating in the UK was replaced by solar thermal collector technologies (Department of Energy and Climate Change, 2013). There is, therefore, still potential in the UK for this technology, especially on a small or domestic scale.

1.3.8 Storage Technologies

To increase the overall efficiency of a renewable energy system such as one of the aforementioned, energy storage is a key player. Most renewable energy today cannot be stored, i.e. electricity from wind turbines. Several methods therefore used to transform the excess energy generated into another form for storage. Batteries and fuel cells for electricity storage and sensible and latent heat stores and phase change materials for thermal storage exist today; much of the technology is in its infancy. A few existing storage options are described in the following sections.

Table 1.4 below, which is extrapolated from ECES and Roth, K. Zogg, R. and Brodrick, J. (2006) (International Energy Agency, 2011), lists thermal storage options that exist today. The cost in p/kWh for each storage method is approximated given an exchange rate of 0.64 GBP/USD on 26th August 2013 (X-Rates, 2013). Thermal storage in water tanks proves to be the least expensive option at the time until reliable, affordable competition enters the market.

Table 1.4- Energy capacities, power, efficiency and storage time of thermal energy storage technologies

TES Technology	**Capacity kWh/t**		**Power kW**		**Efficiency (%)**		**Storage time**	**Cost (USD/kWh)**		**Cost (p/kWh)**	
Hot water tank	20	80	1	10000	50	90	day-year	0.1	0.13	6.4	8.32
Chilled water tank	10	20	1	2000	70	90	hour-week	0.1	0.13	6.4	8.32
ATES low temp.	5	10	500	10000	50	90	day-year	Varies		Varies	
BTES low temp.	5	30	100	5000	50	90	day-year	Varies		Varies	
PCM-general	50	150	1	1000	75	90	hour-week	13	65	832	4160
Ice storage tank	100		100	1000	80	90	hour-week	6	20	384	1280

Thermal-chemical	120	150	10	1000	75	100	hour-day	10	52	640	3328

Losses and high cost of materials currently limit renewable energy storage, and if cheaper, more efficient methods can be developed, renewable energy will thrive over fossil fuel technology.

1.3.8.1 Batteries

Battery technology is currently in its infancy, with lead acid batteries continuing to dominate the market for electrical storage and lithium ion and nickel cadmium batteries beginning to appear in electric vehicles. Other types of batteries are being tested, but cost outweighs energy production for most, so research must be done to develop cost-effective battery solutions for the future unless other storage methods progress significantly (Koch, 2013). Electric vehicles are gaining popularity, so research is being done in this area. Battery storage may work alongside electricity demand at home as a common distributed energy resource in the future if the batteries can be developed to a more powerful level or demand can be reduced.

1.3.8.2 Thermal Buffer Tanks

Storage for surplus thermal energy generated is imperative, especially as maximum demand is significantly higher than the average demand in current systems. A DER system with energy efficient buildings could smooth peak demands, allowing excess thermal energy generated by the heat pumps and other renewable sources to be stored in the tanks to be drawn from as needed.

1.3.8.3 Fuel Cells

The majority of fuel cells are currently in laboratory testing phases, but the technology is promising if the funding can be continually generated to reduce the cost of the materials for the hydrogen cells, for example. State of the art fuel cell technology costs are still in the £50/kWh range (The Carbon Trust, 2012).

1.3.8.4 Phase Change Materials

New phase change materials are beginning to appear in buildings that store thermal energy. This technology is still in development as well, for the materials are expensive. Once normalised on the market, phase change materials will greatly improve a building’s thermal envelope, changing the face of sustainable design.

Until costs for storage technology can be reduced to competitive values, DER systems will be limited primarily to wind, photovoltaics, district heating from biomass, heat pumps, cheap thermal storage, and fossil fuels or nuclear for electricity and heating provision.

1.4 Distributed Energy Resources

A distributed energy resource (DER) system is ‘a collection of energy sources, energy storage and distribution networks linked to local demand’ (Institution of Mechanical Engineers, 2009). The renewable energy and storage technologies are called DERs, and when they are distributed on a community level, it can be considered as a DER system. Emphasis is put on using energy from sustainable sources, such as the DERs listed above, at a community level and matching demand and supply appropriately. This outlook minimises transmission losses, as many small-scale supply plants are located close to the demand and increases overall efficiency (as opposed to using the resources separately), as excess supply from one area can be met with excess demand in another. When the supply exceeds the overall demand, storage methods such as thermal buffer tanks or batteries can be added to the system to be drawn from in times of peak thermal demand.

The idea of DER systems is beginning to gain popularity, especially with the need for significant carbon emissions reduction coupled with the decreasing output from coal-fired and nuclear power plants in the UK. The future of nuclear power in the UK is uncertain at this time, and half of the coal-fired plants in the UK are at the end of their life cycle and are being phased out by 2015. Greenhouse gas emissions are predicted to increase by 55% by 2030 if no action is taken, for global energy demand may increase by 50% by 2030, according to the Institution of Mechanical Engineers (2009). The Energy Saving Trust proves that system wide emissions reduction in communities with more than 50 buildings increases when approached systematically and as system size increases (Energy Saving Trust, 2008), and distributed generation from DER systems in the UK, without any additional policy, can potentially meet 4.3% of total energy demand. Additional policy should be implemented, though. Current microgeneration deployment is estimated at 60 MW, but expansion of all renewable energy sectors is required if the country is to meet the targets set by the Government (2012). That number is expected to jump to around 500 MW of electricity by 2020 from locally owned schemes to meet those targets.

1.4.1 Financial Considerations

The Institution of Mechanical Engineers warns that the same planning and finance systems used for large scale power plants may not apply, for the capital costs are likely to be higher and the running costs lower, thus new systems must be placed in effect (2009). A more flexible payback method should be developed based on total energy produced and consumed by the system.

1.5 Case Study: Dundee Waterfront

Dundee is centrally located in Scotland, with 90 per cent of the population living within just a 90 minutes' drive of the city; however, the city's current layout does not make it such a popular choice for tourists and business. The A991 motorway currently runs straight through the city, cutting the centre off from the waterfront along the River Tay. So in 1998, in order to boost business and tourism and to bring culture back to the largely academic population in the city, the Dundee Partnership began looking into redeveloping the city centre area so that it connects to the waterfront. The £1 billion, 30-year master plan that was developed aims to do just that (Dundee City Council, 2013).

One particularly important addition to the Waterfront will be the new Victoria and Albert Museum (V&A). It is a £45 million art and design museum that is being constructed as a supplement to the existing V&A Museum in London and is estimated to attract several hundred thousand visitors a year. Construction is due to start in 2014, and the museum to open in 2015 (Bain, 2013).

Currently at its half-way point, this project is the third most active regeneration project in the UK, creating over 9,000 jobs in total, and is estimated to generate an additional £1 billion from leisure and business tourism by 2025 (Galloway, 2013).

The Waterfront is laid out five 'zones' that total approximately 240 hectares of land along 8km of the River Tay: Riverside, Seabraes, The Central Waterfront, City Quay, and Dundee Port. There will be new shops, restaurants, and bars downtown, along with new office space and flats. As an exemplar for sustainable economic development, the Partnership aims to make Dundee 'the first Building Research Establishment Environmental Assessment Method (BREEAM) sustainable community in Scotland' (Dundee City Council, 2013) and Scotland's first solar city (Dundee Renewables, 2013). In order to meet these goals, emphasis is being put during the design stage on minimising the Central Waterfront's carbon footprint by combining low-energy building design with renewable energy technology.

1.6 Project Description

This project aims to assess the feasibility of approaching the Central Waterfront as a Distributed Energy Resource (DER) System to maximise carbon emissions savings through the use of integrated renewable energy technologies and efficient building design. Plots 5 and 6 in addition to the V&A Museum are circled in blue on the map below in Figure 1.8 and are chosen to represent how a DER system would be modelled for the entire Waterfront.

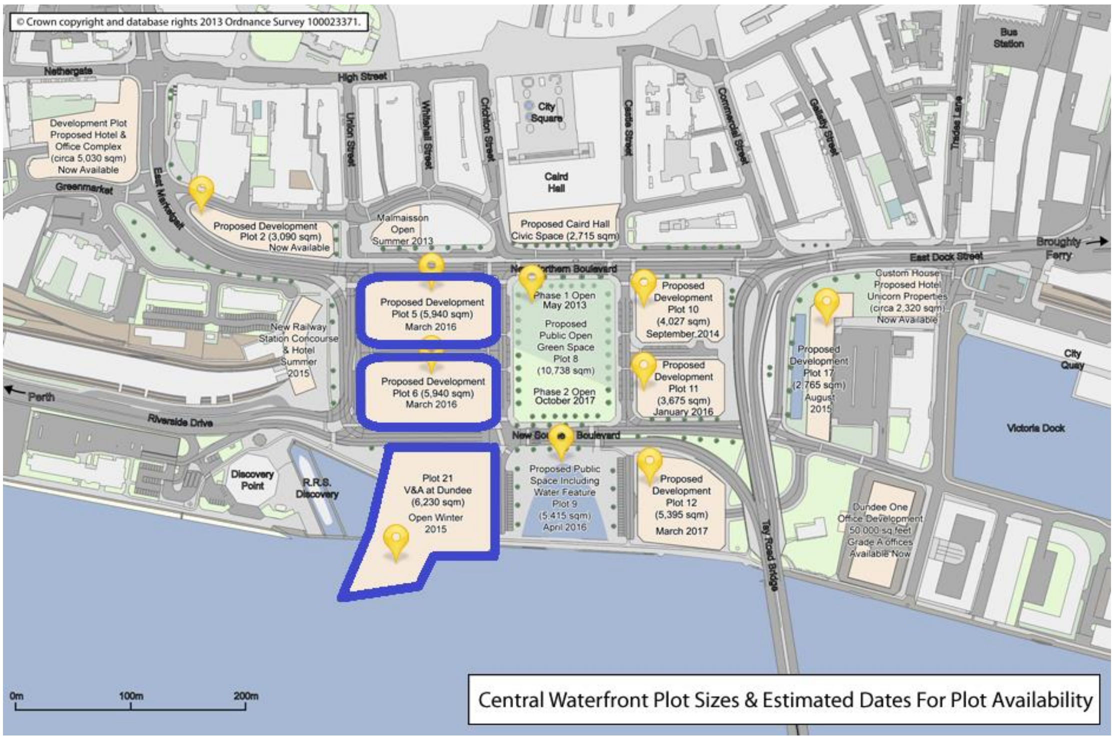


Figure 1.8- Dundee Central Waterfront Map

Plots 5 and 6 are very similar; they will both have retail shops, bars and leisure, flats, and offices. The V&A Museum will also play a significant role in this DER system. Combinations of DERs and storage options are considered to determine the optimal supply/demand match so the most cost effective and balanced option can therefore be delivered.

2 Methodology

To assess the feasibility of treating the Central Waterfront as a DER system in order to minimise carbon footprint and increase system reliability during peak hours, the electrical and thermal demands for this DER system including Plot 5, Plot 6, and the V&A Museum are matched with various combinations of supply and storage from renewable and local sources through district heating and electricity schemes. The models are simulated in a demand/supply matching programme called Merit to determine the optimal combination of DERs that will maximise renewable energy use and minimise waste and fossil fuel use.

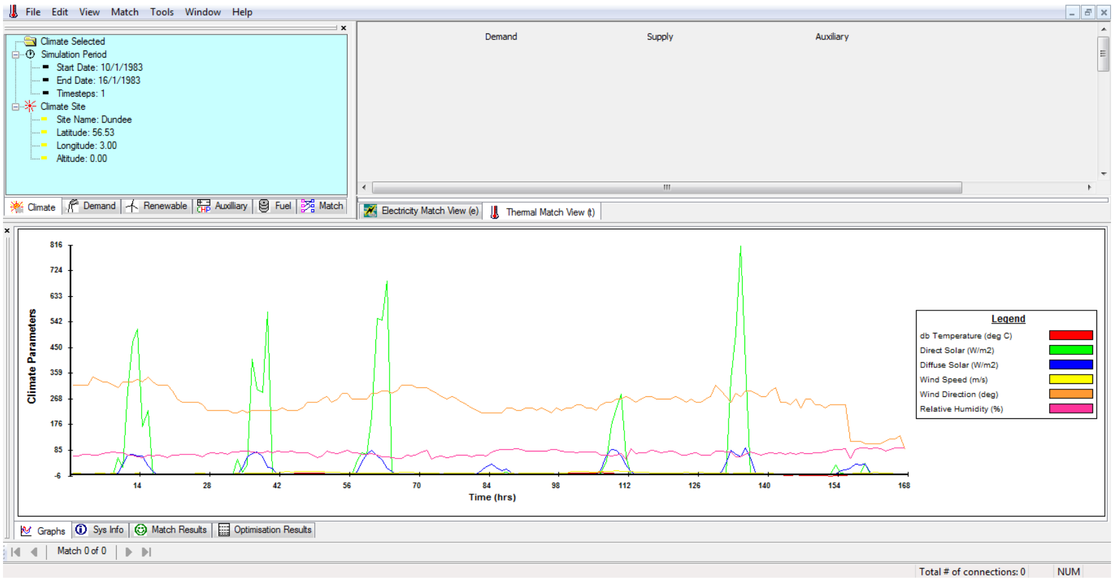
2.1 Project Objectives

A database is created and uploaded to Merit, a supply/demand matching programme. Electrical and thermal load profiles are also created through private contact with Catherine Cooper at Scottish and Southern Energy (SSE) and the existing data published by Elexon Ltd for the UK Energy Research Centre in 1997; the process is described in Section 2.4. A series of combinations of DERs are then assessed using Merit for their estimated demand/supply match in order to appropriately outfit the proposed buildings with renewable energy technologies. Results are then discussed and recommendations are made accordingly.

2.2 Modelling Software

The modelling software used for this analysis is Merit, a programme created by the Energy Systems Research Unit (ESRU) at the University of Strathclyde. It is used primarily as a teaching tool for its flexibility with many types of renewable systems, and it can be used to calculate the estimated percentage of renewable supply that meets demand on a household or community wide basis (Energy Systems Research Unit, 2013). Certain properties are built into the software for each type of DER to deliver the most accurate results possible based on given weather and location data.

First, a database is created with the location's weather data and each of the DERs to be considered in the model. The location is chosen and the dates are modified. The date range can be changed within the year, but just a week's weather data from Dundee (10th to 16th January 1983) is simulated here, due to software limitations, and shown below in Figure 2.1.



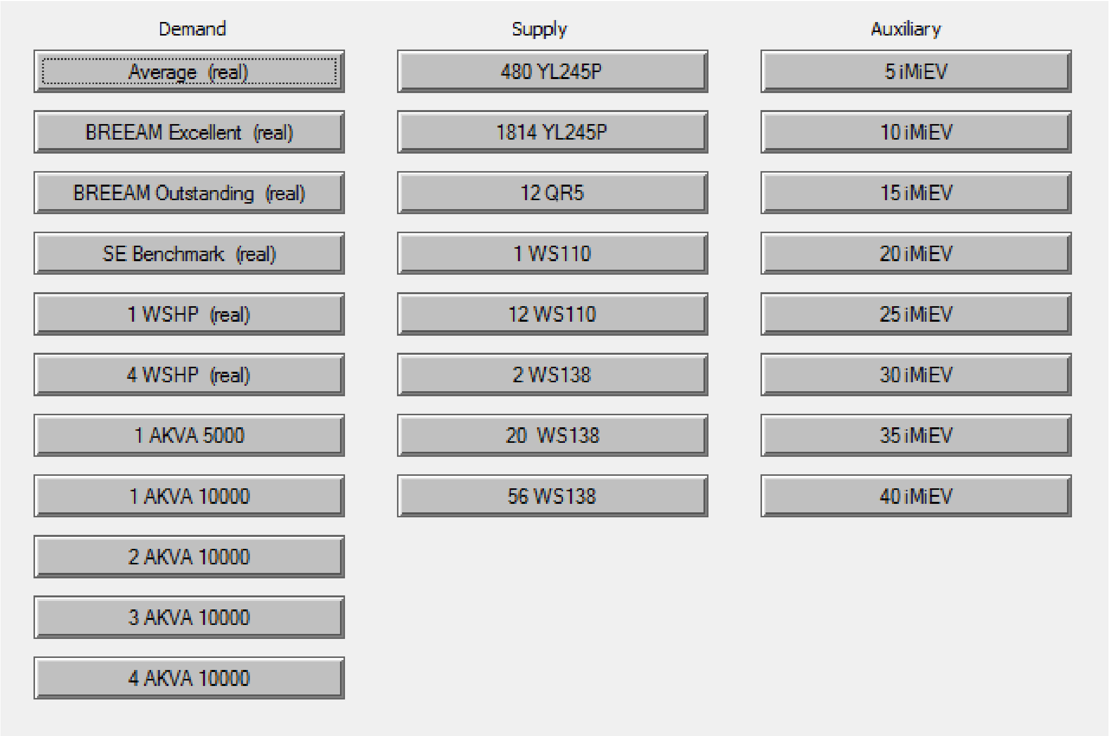
Climate Selected
Simulation Period
  Start Date: 10/1/1983
  End Date: 16/1/1983
  Timesteps: 1
Climate Site
  Site Name: Dundee
  Latitude: 56.53
  Longitude: 3.00
  Altitude: 0.00

Match 0 of 0

Total # of connections: 0

Figure 2.1- Merit Software: Weather Data

The electrical and thermal load profiles are then uploaded and the desired DERs for assessment are chosen. The images from screenshots below, Figure 2.2 and Figure 2.3, list the electrical and thermal match options.



Demand	Supply	Auxiliary
Average (real)	480 YL245P	5 iMiEV
BREEAM Excellent (real)	1814 YL245P	10 iMiEV
BREEAM Outstanding (real)	12 QR5	15 iMiEV
SE Benchmark (real)	1 WS110	20 iMiEV
1 WSHP (real)	12 WS110	25 iMiEV
4 WSHP (real)	2 WS138	30 iMiEV
1 AKVA 5000	20 WS138	35 iMiEV
1 AKVA 10000	56 WS138	40 iMiEV
2 AKVA 10000		
3 AKVA 10000		
4 AKVA 10000		

Figure 2.2- Electrical Match Options

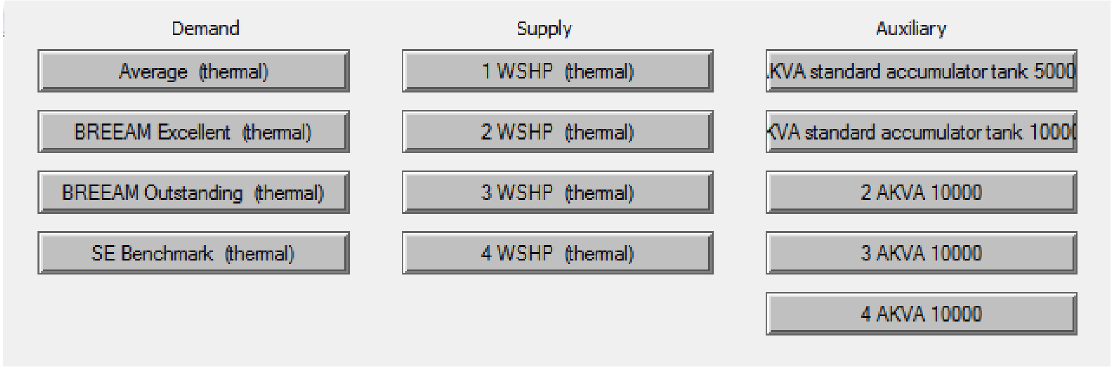


Figure 2.3- Thermal Match Options

Combinations of DERs are selected from the lists above, and the percentage match of supply and demand is calculated by the programme. The results show a ‘match percentage’ for each combination, which is defined by Merit as precisely enough supply to meet demand. It should be noted that Merit does not recognise surplus renewable supply as a system ‘match’; the match percentage is determined, rather, as an exact demand/supply match.

Results from the programme include total consumption, renewable supply, surplus, deficit, and overall match percentage. Results can be exported for external use as well. By assessing the surplus and deficit supply and the match percentage, the best choice for a combination of DERs in the system can be made.

2.2.1 Software Limitations

At this time, the programme is unable to calculate an annual match percentage for the best combination of DERs and electrical and thermal demand. Therefore, simulations are run for the one week period in January that falls in the middle of the ‘winter’ season and a one week period in August that falls in the middle of the ‘high summer’ season (as described below). These weeks are chosen because the demand in the winter months is higher and in the summer months is lower due to required lighting, space heating, etc. This simulates a ‘worst case’ and a ‘best case’ demand scenario. Only one week’s time is simulated so the match profiles can be seen clearly. Match percentages are then calculated for January to November (for the programme cannot simulate the match for December) using the following formulas as defined in Equation 1 and Equation 2 by the ESRU Department at the University of Strathclyde (2013) and Williamson (1994):

$$Percentage\ match\ (\%) = (1 - IC) * 100\% \tag{1}$$

with

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

and D_t = Demand at time t
S_t = Supply at time t
n = number of intervals in time period

The resulting match percentage is then evaluated as falling under one of the ten categories listed below (University of Strathclyde ESRU, 2013), and recommendations are therefore made based on how high the overall match is:

Percentage match ≥ 99: Perfect Match
Percentage match > 90 : Excellent Match
Percentage match > 80 : Very Good Match
Percentage match > 70 : Good Match
Percentage match > 60 : Reasonable Match
Percentage match > 50 : Poor Match
Percentage match > 40 : Very Poor Match
Percentage match > 30 : Bad Match
Percentage match > 20 : Very Bad Match
Percentage match > 10 : Almost No Match
Percentage match > 0 : No Match

Another limit Merit at this time is that it is currently unable to simulate more than 40 EV batteries for all demand and supply profile combinations. For that reason, only up to 40 EV batteries are modelled. Additionally, the batteries cannot be simulated for an annual period. The addition of 40 batteries to the week simulations is enough to draw conclusions about the effect of adding additional batteries to this model, however.

2.3 Database Creation

When creating the database, certain features are coded into Merit such as the location and weather data and the renewables to be assessed for their feasibility on site. The following sections describe how the figures used in this model are derived.

2.3.1 Weather Profile

Merit has a list of weather databases that exist within the programme, one of which is the weather in Dundee. The weather data used for simulation is from 1983, however, so to test the accuracy of the data in comparison to today's figures, the weather at the Met Office's metering station in the neighbouring town of Leuchars for the years 2010-2012 was mapped against the weather in 1983 (Met Office, 2013). The following graph, Figure 2.4, depicts the result. There appears to be no obvious effect of climate change since 1983, so that year is the best choice for weather data in comparison to recent years' data, for 1983 experienced both a cold winter and a warm summer.

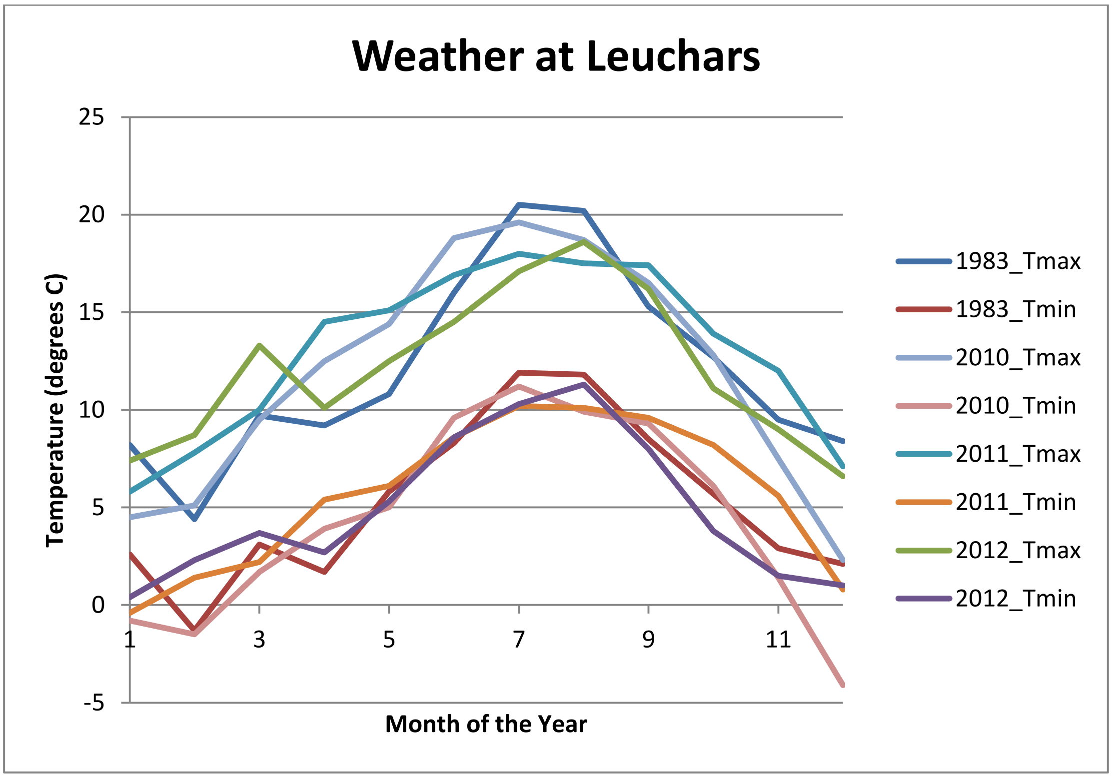


Figure 2.4- Weather Comparison at Leuchars

The coldest average temperatures in 1983 occurred in February between -1.3 and 4.4 degrees Celsius, and the warmest average temperatures occurred in July between 11.9 and 20.5 degrees Celsius.

2.3.2 Renewable Energy Systems

Although there are many renewable energy technologies available in Scotland, Scottish Enterprise (SE) has already assessed the feasibility of using combined heat and power (CHP) systems to supply district heating, ground and air source heat pumps, large scale wind power, building integrated solar thermal, building integrated photovoltaics (PV), water source heat pumps (WSHPs), and district heating from biomass as potential DERs. For the V&A building in this study, they determined that solar PV and WSHPs would be feasible options (Scottish Enterprise, 2013). Small scale wind turbines are also being considered in addition to electric vehicle (EV) batteries and thermal storage from excess heat output from the WSHPs. Table 2.1 below lists the DERs considered in this feasibility study as determined and the estimated power output of each (Cooper, 2013; Akvaterm, 2013; Climaveneta, 2013; Green Car Congress, 2008; Yingli Green Energy Holding Co. Ltd., 2013; Quiet Revolution, n.d.; TG, 2013). They are described further in the following sections.

Table 2.1- DERs in This Model

DER Name	DER Type	Output Type	Power Output (kW)	Nominal Input (kW)
Yingli YL245P-29b	PV	Electrical	0.245	
Quiet Revolution QR5	Wind	Electrical	6.5	
Swift Windsurfer WS110	Wind	Electrical	4.6	
Swift Windsurfer WS138	Wind	Electrical	18.3	
Mitsubishi iMiEV	EV Battery	Electrical	16.3 (kWh)	
Climaveneta NECS-WN/B 0704	WSHP	Thermal	230	56.5
AKVA 5000	Storage Tank	Thermal		
AKVA 10000	Storage Tank	Thermal		

Other options are encouraged to be assessed if the model is to represent the entire Central Waterfront, such as different models or sizes and other DERs; however, for the time allotted and depth of scope of this project, the combinations are limited to those in the table above. The reasoning for choosing each DER is described in the following section.

2.3.2.1 Photovoltaics

SE has determined that 480 solar modules will be placed on the roof of the V&A museum (Cooper, 2013). This feasibility study assesses whether additional modules on plots 5 and 6 will increase the overall match percentage and the return period on the capital investment. The modules chosen for installation at the V&A by SSE are Yingli Solar's YL245P-29b, which have a maximum power output of 245 W each (Yingli Green Energy Holding Co. Ltd., 2013). For simplicity of the model, the same panels are used for the entire model, not just the V&A. If the module choice changes in a future design stage, the database must therefore be updated accordingly.

Other options for the number of PV modules that would maximise output are considered in the model. SE estimates that 40% of the roof space will be available for solar PV installations (Scottish Enterprise, 2013). Since the buildings at plots 5 and 6 have roof areas of 3253 m^2 and 4160 m^2, respectively, a maximum of 796 modules on Plot 5 and 1018 modules on Plot 6 at 1650 x 990 mm each can be installed (Cooper, 2013) (Yingli Green Energy Holding Co. Ltd., 2013). 1814 modules at 245 W each is a significant addition to the electricity supply to this DER system.

If considering the whole Central Waterfront DER system, the maximum number of modules that can be installed on roofs is calculated as in Equation 3 using the area of each panel and the percentage of roof area that can have PV modules installed:

$$Max\ \#\ of\ Modules = 0.4 * \frac{total\ roof\ area\ (m^2)}{1.6335\ (m^2/module)} \tag{3}$$

2.3.2.2 Wind Turbines

Three different wind turbine designs are being considered for this area. Quiet Revolution's QR5 and Swift TG's Windsurfer series WS110 and WS138 are being assessed for their feasibility so that an optimal match can be reached. Twelve QR5 turbines are being considered for installation along the boardwalk at the waterfront. One WS110 turbine (for the interim period), being replaced by two WS138 turbines is the other option currently posed (Cooper, 2013). This report also considers the feasibility of using twelve WS110 turbines in place of the twelve QR5 turbines, for their physical sizes are similar. Other combinations including adding more WS138 turbines at a site nearby are considered. It would take 22 WS138 turbines to provide enough electricity to match average annual consumption, but surplus and deficit periods will continue to exist. To fully eliminate electrical deficit from wind power alone in this DER system, hundreds of turbines would be required because there are periods of time where very little wind power is produced. Therefore, a limit must be set (usually by cost and space provisions) as to how many turbines can be installed for the system's use.

Since wind turbines are rarely located in city centres, systems for transmission and distribution of wind turbines must be considered, so it is better to group them geographically close to the demand (or DER system) and with localised cables rather than multiple small sets of cables. Therefore, a DER system is suggested for output from wind turbines and should be further investigated to optimise renewable energy use along the Dundee Central Waterfront.

2.3.2.3 Electric Vehicle Batteries

Investigation into models of EV cars and bikes available for potential future use in Dundee is carried out in this feasibility study as well. Because the City Council in Dundee is trying to boost tourism and energy supplier SSE encourages electric vehicle use, the feasibility of adding charging portals for EVs to offset peak loads is being assessed. A simple model is built for this DER system, but can be adapted to add complexity.

The formula used to calculate the power output to the system can be seen below. The EV battery model chosen for this feasibility study is Mitsubisihi's iMiEV, which has an output of 16.3 kWh (Green Car Congress, 2008). It would only take 5 EV charging stations in this model to supply enough electricity to power the pavement and parking lighting at night, a load of 14.25 kW (Cooper, 2013). That is just 3% of parking spaces available at plots 5 and 6. It is likely that a higher percentage of environmentally conscious residents and visitors will come to Scotland's first BREEAM sustainable and solar city; therefore, additional scenarios are considered. The UK is also investing £37 million in EV charging points by 2015 (Clean Energy Ministerial, 2013). Unfortunately, the modelling programme, Merit, is incapable at this time of simulating more than 40 EV batteries. Therefore, up to 40 of the 165 spaces in plots 5 and 6 are considered for EV charging stations. The output to the system is then calculated using the following Equation 4:

$$Output\ to\ system\ (kWh) = e * B - e * C\ (kWh) \tag{4}$$

with e (number of EV batteries) = % of total parking spaces
B (battery power per car) = 16.3 kWh
C (charging consumption) = x kWh

Another option to maximise future DER use would be to add electric bike charging stations along the Waterfront for tourists' use. Bike stations could be located outside the V&A Museum and at each end of the Waterfront, for example. This would increase the electrical input to the system if needed to offset peak loads. For the simplicity of this model, however, EV bike batteries are not considered. Additional simulations should be undertaken if further investigation into the modelling results is desired.

2.3.2.4 Water Source Heat Pumps

It had been previously determined that four WSHPs would be installed beneath the V&A Museum that stretches slightly over the Tay: two 234 kW Climaveneta NECS-WN/B 0704 for heating and two 243 kW Climaveneta NECS-W 0804 for cooling, which require 56.6 and 43.1 kW of electricity input, respectively (Cooper, 2013). This model looks instead at installing four reversible heat pumps so that they can be outfitted with buffer tanks to mitigate or eliminate peaks in the system's thermal load. Four of the reversible NECS-WN/B 0704 are considered with 230 kW output and COP = 4.08 (input = 56.5 kW) or 203 kW output and EER = 4.4 (input = 46.1 kW) (Climaveneta, 2013). In this simple model, they are not used for cooling, but only for heating.

Scenarios with optimal matches of combinations of up to four WSHPs and thermal storage of up to 45,000 litres are considered in this case study, for the demand for this DER system is just a fraction of the Central Waterfront demand.

To model the entire Central Waterfront using WSHPs, one must be careful not to allow the pumps to raise the temperature of the river water too high, for it reduces the overall efficiency of the heat pumps and can negatively impact local marine life. Dundee is, however, located close to the ocean, so the tide would flush the warm water out. If more than the four WSHPs are to be installed along the Waterfront in the future, it may be advisable to therefore operate the pumps in a cycle rather than simultaneously or settle for a smaller, less hazardous size.

2.3.2.5 Thermal Storage

Energy storage is a key player in DER systems, and the use of buffer tanks to store excess thermal energy from the WSHPs can also aid demand-side management of a DER system (but is not used for that purpose in this model). Two tanks are simulated in the database- the 5,000 litre AKVA 5000 and the 10,000 litre AKVA 10000 (Akvaterm, 2013). German law requires a minimum capacity of 25 litres per kW when sizing tanks, which would be up to 23,000 litres for the four WSHPs in this model; other sources recommend up to 50 L/kW, which would be up to 46,000 litres (Solar Energy Ireland, 2003) (Thermal Store UK, 2013) (Reflex, 2013).

Storage in increments of 5,000 litres is assessed in the model for feasibility in this DER system and for the Central Waterfront as a whole.

The tanks to support these systems are quite large, and would require a significant amount of space allocation. The WSHPs are to be connected to the district, however; so fewer tanks may be needed. This model assesses several situations and can be expanded for the entire DER system.

2.4 Load Profile Compilation

Although smart meters are being installed in ‘all homes and small businesses in the UK by 2020’ (Department of Energy & Climate Change, 2013), the amount of half-hourly data that currently exists is astonishingly low. Peak load data for office, residential, retail, leisure and bars, V&A, and parking/general loads was given in terms of kW in two maximum loads assessments (MLAs). Unfortunately, load profiles for electrical data are not available, but load profiles for thermal data, were provided by SSE (Cooper, 2013). Electrical load profiles are estimated using the figures that Elexon Ltd. calculated for the UK Energy Research Centre (UKERC) in 1997.

The baseline assumptions made in this feasibility study are:

- All non-residential buildings have air conditioning

- All heating is non-electric
- All heating and electricity is provided through a district scheme, as seen in Figure 2.5 below

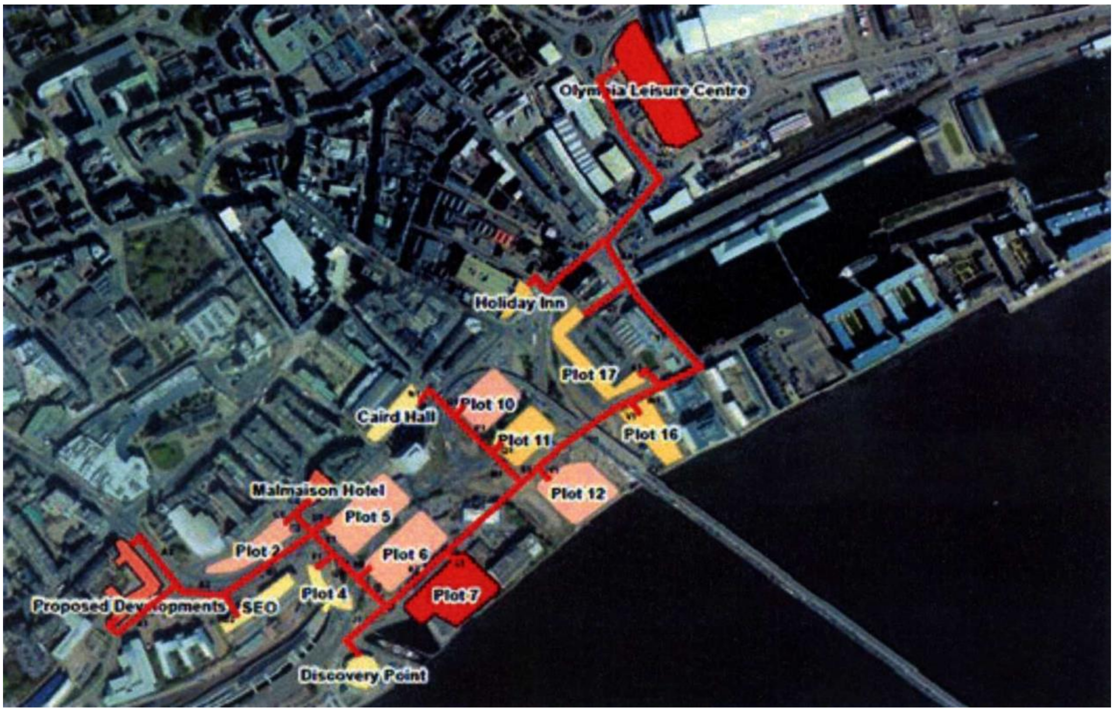


Figure 2.5- Central Waterfront District Heating Scheme Layout

It is also assumed that carbon emissions conversions factors of 0.445 $kgCO_2e/kWh$ electricity and 0.184 $kgCO_2e/kWh$ gas are used to reduce loads accordingly (Department for Environment Food & Rural Affairs, 2013). It should be noted that the carbon emissions factors for electricity and gas in this report are different from those in the Scottish Enterprise report, 0.517 $kgCO_2e/kWh$ and 0.198 $kgCO_2e/kWh$, respectively (2013). Although the electricity conversion factor that Scottish Enterprise estimates appears high, another source uses that same figure.

The figures in the following profiles are both of maximum and average demand. Load factors are therefore used to relate the two types of demand. A load factor (LF) is defined in Equation 5 as the average load divided by the maximum load in a given time period (UK Energy Research Centre, 1997).

$$LF = \frac{Average\ load}{Maximum\ load\ in\ time\ period} \tag{5}$$

A LF of 77% was used in the MLA for electricity, and no LF was provided for the gas assessment. The residential demand in the MLA is more than eight times the average demand data for the Dundee city centre from the DECC if the given LF=77% is used and nearly four times the Dundee city centre data if LF=35% is used. This could be due to any number of factors including end-use LFs and different ‘common practice’ demands in Dundee. However, since this source appears unreliable and no LFs for thermal demand profiles are given, LFs are estimated in this model as follows.

The load factors used in this feasibility study are as follows in Table 2.2. The electrical load factors are estimated given the information from CED Engineering (Guyer, 2010), and the thermal load factors are based on the profiles given by SSE (Cooper, 2013).

Table 2.2- Load Factors in this Model

Demand Type	Name	Load Factor (%)
Electrical	Retail	25
	Leisure/Bars	25
	Offices	35
	Flats	35
	V&A	35
	Parking/General	100
Thermal	Front of House	34
	Office	28
	V&A	56

As the breakdown of maximum demands from the MLAs is all confidential, specific numbers cannot be listed in this report. General observations are therefore made when comparing the loads to the various sources in the following sections.

2.4.1 Comparison to BSRIA Guidelines

In order to validate the given demand values from the electricity MLA, they are compared to the Building Research and Information Association’s (BSRIA) Rules of Thumb for common practice; the recommended loads are listed below in Table 2.3 (Hawkins, 2011). Not all loads have listed recommendations; those corresponding boxes contain a ‘-’.

Table 2.3- BSRIA Standards for Electricity and Heating Demand

Load Type	BSRIA Electricity Est. (W/m^2)	BSRIA Heating Est. (W/m^2)
Flat	80	60

Office	87	70
Lighting	*12*	*N/A*
Small Power	*25*	*N/A*
A/C	*87*	*N/A*
Retail	160	100
Lighting	-	*N/A*
Small Power	-	*N/A*
A/C	*70*	*N/A*
Higher Ed. (similar to V&A)	55	87
Car Parking	4	N/A

The offices' electrical load in the MLA appears to be higher than the recommended load by BSRIA despite the lower lighting, small power, and air conditioning demands. The retail sector load is similar to the leisure and bars sector in the MLA, and it is nearly a third less than the BSRIA guidelines. Demand in the flats is slightly lower than BSRIA recommends. The parking load is nearly identical.

Finally, the V&A load, which was not originally included in the MLA, is over five times less than the BSRIA standard due primarily to best practice design, although it is difficult to compare to BSRIA guidelines as the building use is also different (secondary/higher education was the closest match).

The thermal load estimates in the MLA are nearly identical to those listed in the BSRIA table above, which validate them accordingly.

These guidelines validate the majority of the loads in the MLA, but leave significant room for improvement in this feasibility study, for these are 'common practice' values, and it is desired to construct the buildings to meet BREEAM standards (Cooper, 2013).

2.4.2 Comparison to Dundee City Centre Consumption Data

The average annual electricity and heating consumption per household in the Dundee city centre have been estimated by the Department for Energy & Climate Change (DECC) at 4.838 MWh of electricity and 14.032 MWh of gas (Rogers, 2012). Overall loads are calculated using this data and scaled appropriately.

- The average home size in the UK is 85 m^2 (Roberts-Hughes, 2011); therefore:

    - The average electricity consumption per home in the Dundee city centre is 56.92 kWh/m^2/yr.
    - The average gas consumption per home in the Dundee city centre is 165.08 kWh/m^2/yr.
- There are 176 proposed flats estimated in this DER system model, and each flat is estimated at 65 m^2 (Cooper, 2013); therefore:
    - The total annual electricity consumption for the flats in this model is 651,165 kWh.
    - The total annual gas consumption for the flats in this model is 1,888,515 kWh.

Converting these figures to total consumption for this DER system using the relationships between loads in the MLAs:

- Total electricity consumption = 1.187 * Residential electricity consumption (kWh/m^2/yr) (Cooper, 2013))
- Total gas consumption = 1.674 * Residential gas consumption (kWh/m^2/yr) (Cooper, 2013))

yields the resulting figures in Table 2.4 below.

Table 2.4- Loads from Dundee Average Consumption

Load Type	**Average Electricity Est. (kWh/m^2/yr)**	**Average Heating Est. (kWh/m^2/yr)**
Residential	56.92	165.08
Total	67.57	276.36

It would be unwise to over-design (especially if carbon emissions are to be reduced); therefore, load profiles in this feasibility study use the Dundee city centre average consumption data for 2012 rather than the MLA data provided by SSE, as the above numbers accurately represent the location's annual consumption.

2.4.3 Comparison to Scottish Enterprise Benchmarks

SE has recently completed a feasibility study on the Central Waterfront and has used the figures in Table 2.5 for energy consumption, which are derived from CIBSE benchmarks (Scottish Enterprise, 2013). The electricity figures are closer to Dundee's average consumption figures in the previous section, but are still lower, for they are listed for existing buildings having had emissions reductions and efficiency improvements to building fabric and appliances (similar to that of a BREEAM rated building).

Table 2.5- Scottish Enterprise Energy Consumption Benchmarks

Load Type	SE Electricity Est. (kWh/m^2/yr)	SE Heating Est. (kWh/m^2/yr)
Office	74.2	43.3
Retail	154	30.8
Residential	38.7	44.6
Leisure	160.7	160.7
Cultural	40.6	89.3

The SE estimates for heating requirements are still approximately half the values for the average consumption data in Dundee, even considering the consumption reduction from 'good practice'. This could be due to the current infrastructure in Dundee. Older buildings require significantly more heat than new, energy-efficient buildings. For this reason, load profiles using the SE benchmark consumption data are created for this feasibility study in addition to those for the average consumption in Dundee. Load profiles to achieve BREEAM Excellent and Outstanding status (based on the average consumption data in Dundee), as explained below, will also be compared.

2.4.4 Building Research Establishment Environmental Assessment Method

Multiple load profiles are created for the electrical and thermal loads in this feasibility study, for each building is being designed to meet BREEAM qualification standards, according to SSE (Cooper, 2013). An average load profile (derived from the Dundee city centre consumption data), that to achieve BREEAM Excellent status, and that to achieve BREEAM Outstanding status are considered in this report in addition to a load profile derived using the SE benchmarks. A guide to achieving BREEAM status is outlined by Barlow and summarised below (2011).

At least six credits must be obtained in the ene01 section on reduction of emissions to achieve Excellent status, and ten credits to achieve Outstanding status. Additionally, in order to achieve BREEAM Excellent status, a minimum of 25% reduction of carbon emissions (from original estimates) must be met. To achieve BREEAM Outstanding Status, a minimum of 40% reduction of carbon emissions (from original estimates) must be met (Building Research Establishment, 2012). For this model, the ‘original estimate’ values are based on the average annual consumption in the Dundee city centre in 2012.

The following Table 2.6 is extrapolated directly from the BREEAM specifications book for new construction of non-domestic buildings. The paragraph following explains how the credits are achieved.

Table 2.6- ene01 BREEAM Credits by EPR_{NC}

BREEAM Credits	EPR_{NC}	Minimum Requirements
1	0.06	Requires a performance improvement progressively better than the notional building level (as defined in the 2010 version of the Building Regulations, Part L2a).
2	0.12	
3	0.18	
4	0.224	
5	0.3	
6	0.36	BREEAM Excellent requires a minimum EPR_{NC} of 0.36 (6 credits) and a 25% reduction in CO_2emissions arising from regulated building energy consumption.
7	0.42	
8	0.48	
9	0.54	
10	0.6	BREEAM Outstanding requires a minimum EPR_{NC} of 0.60 (10 credits) and a 40% reduction in CO_2emissions arising from regulated building energy consumption.
11	0.66	
12	0.72	
13	0.78	
14	0.84	
15	0.9	15 credits require a minimum EPR_{NC} of 0.90 and a 100% reduction in CO_2emissions arising from regulated building energy consumption i.e. zero net CO_2emissions.

> *The method for calculation of energy performance ratio (EPR_{NC}) takes account of the following parameters:*
>
> - *the building’s operational energy demand*
> - *the building's primary energy consumption*
> - *the total resulting CO_2 emissions*
>
> *The calculation is determined using the following performance data from energy modelling of the building’s specified/designed regulated fixed building services and fabric,*

> *as undertaken by an accredited energy assessor using approved building energy calculation software:*
>
> - *Building floor area (m^2)*
> - *Notional building energy demand (mJ/m^2)*
> - *Actual building energy demand (mJ/m^2)*
> - *Notional building energy consumption (kWh/m^2)*
> - *Actual building energy consumption (kWh/m^2)*
> - *Target Emission Rate ($kgCO_2/m^2$)*
> - *Building Emission Rate ($kgCO_2/m^2$)*
>
> *-Building Research Establishment, 2012*

Another noteworthy requirement for buildings to be constructed to meet BREEAM Excellent or Outstanding specifications is that one ‘credit’ must be awarded in the ene04 section on low and zero carbon (LZC) technologies (Building Research Establishment, 2012) for having an energy specialist conduct a renewable energy feasibility study and either:

- installing an appropriate renewable energy system as a result **or** signing a contract with an energy supplier to receive energy from an off-site renewable source for a minimum of 3 years.
- meeting the hea03 credit requirement for thermal comfort by designing to CIBSE standards for thermal comfort level and acceptable range of thermal discomfort **and** using a free cooling strategy as those listed below in Table 2.1. For simplification of this model, free cooling systems are not included, but should be if the entire Central Waterfront is being assessed.

This requires the use of renewable technology for energy generation in BREEAM Excellent and Outstanding buildings, which further emphasises the importance of this feasibility study.

2.4.5 Loads for Profiles in this Model

To meet the Scottish Building Regulation 6 objective of reduction of emissions for both domestic and non-domestic buildings (Scottish Government, 2013; Scottish

Government, 2013), four load profiles are considered in this feasibility study, which represent four likely outcomes:

- Average, estimated using Dundee city centre annual consumption (Rogers, 2012)
- BREEAM Excellent, based on average (Building Research Establishment, 2012)
- BREEAM Outstanding, based on average (Building Research Establishment, 2012)
- SE Benchmarks, estimated using CIBSE design for best practice (Scottish Enterprise, 2013)

The four profiles are compared in the following sections to assess the feasibility of four different design scenarios that could be followed for the Dundee Central Waterfront. Their comparison is used to verify the accuracy of each scenario and to justify modelling, constructing, and servicing the Central Waterfront as a DER system in order to minimise carbon footprint and maximise monetary savings over the system life cycle.

The two tables below, Table 2.7 and Table 2.8, show the overall consumption and equivalent carbon dioxide emissions of the four profiles being considered. Equivalent emissions are calculated using the carbon emissions factors as defined in the previous section. It should be noted that the SE benchmark scenario is the most ambitious by far for gas emissions and therefore produces much less carbon dioxide than the others; the electricity figures are the least ambitious, though, so the carbon emissions may be reduced further. Considering only carbon dioxide emissions reduction, the SE Benchmark is the best option with fewer than 1750 metric tonnes of equivalent emissions. The second choice is evidently the BREEAM Outstanding profile, with fewer than 3180 metric tonnes of equivalent emissions. System cost must also be considered, for it may be difficult to reduce the heating load by such a large amount, for example. Therefore, a cost analysis should be done in addition to this study to determine the best match for the Central Waterfront system in its entirety.

Table 2.7- Total Annual Electricity Consumption and Carbon Dioxide Emissions

	Average	**BREEAM Excellent**	**BREEAM Outstanding**	**SE Benchmark**

Ann. Consump. (kWh)	2,649,277	1,986,558	1,589,246	2,899,373
Ann. Consump. (kWh/m^2)	67.57	50.68	40.54	73.95
kgCO$_2$e	1,178,928	884,196	707,357	1,290,221

Table 2.8- Total Annual Gas Consumption and Carbon Dioxide Emissions

	Average	**BREEAM Excellent**	**BREEAM Outstanding**	**SE Benchmark**
Ann. Consump. (kWh)	8,844,902	6,633,677	5,306,941	2,496,256
Ann. Consump. (kWh/m^2)	225.64	169.23	135.38	63.68
kgCO$_2$e	3,935,982	2,951,986	2,361,589	456,815

Although the average heating demand in the UK is 55% of total energy demand, that figure is currently higher for Dundee city centre's average at 77% (Scottish Government, 2012; Rogers, 2012). This is likely due to infrastructure, which is old and in need of redevelopment. Building to BREEAM standards decreases the total demand, and building to SE Benchmark standards decreases the heating demand significantly to a mere 46% of total demand. For this reason, all four thermal profiles are considered in this model, as the data does not correlate exactly with this figure.

2.4.6 Electrical Load Profiles

As no electrical load profiles for this DER system exist, they are estimated given the profiles published by the UKERC in 1997. There are eight UKERC load profile classes- two for residential and six for commercial customers. A list of them can be seen below in Table 2.9.

Table 2.9- Load Profile Class Definitions

Load Profile Class Number	**Load Profile Class Description**
1	Domestic Unrestricted
2	Domestic Economy-7
3	Non-Domestic Unrestricted
4	Non-Domestic Economy-7
5	Non-Domestic Maximum Demand (LF=0-20%)
6	Non-Domestic Maximum Demand (LF=20-30%)
7	Non-Domestic Maximum Demand (LF=30-40%)

8	Non-Domestic Maximum Demand (LF>40%)

Electrical loads are categorised into flats (‘Profile 1’), retail (‘Profile 6’), office (‘Profile 7’), leisure/bars (‘Profile 6’), V&A Museum, and parking/general (the profile assumes consumption during night time hours). The profiles are given as averages for a week period during the specified season. The seasons are defined as the following, with the 1983 dates following in parentheses (UK Energy Research Centre, 1997):

- *Spring: the period from the day of clock change from GMT to BST in March, up to and including the Friday preceding the start of the summer period*
  (27th March-13th May)
- *Summer: the ten-week period, preceding High Summer, starting on the sixteenth Saturday before the August Bank Holiday*
  (14th May-23rd July)
- *High Summer: the period of six weeks and two days from the sixth Saturday before August Bank Holiday up to and including the Sunday following August Bank Holiday*
  (24th July-4th September)
- *Autumn: the period from the Monday following the August Bank Holiday, up to and including the day preceding the clock change from BST to GMT in October*
  (5th September-29th October)
- *Winter: the period from the day of clock change from British Summer Time (BST) to Greenwich Mean Time (GMT) in October, up to and including the day preceding the clock change from GMT to BST in March*
  (1st January-26th March; 30th October-31 Dec)

The profiles are then compared to those existing in Merit, although the sources of the Merit profiles are unknown and should thus not be used in the model.

The total annual electrical load profile based on Dundee city centre ‘average’ data as it appears in Merit is shown below in Figure 2.6. It is a summation of the average demand profiles for all the building use types listed in the next sections, with the respective load factors (LFs) already applied from the MLA and outside research. It can be seen that the profile experiences seasonal changes, which can be associated with factors including amount of daylight available and air conditioning required.

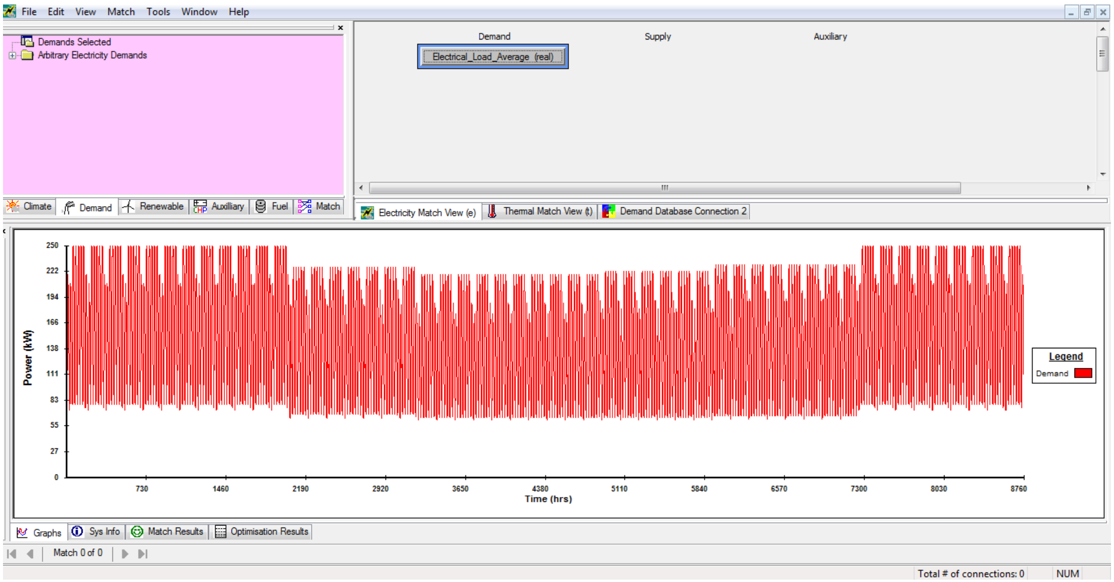


Figure 2.6- Average Annual Electricity Demand

The load profiles are then scaled based on the ‘average’ profile to meet the annual consumptions listed in the above section; a weekly comparison of electrical loads for this system (10th to 16th January) can be seen in Figure 2.7 below. Simulations look at this week time period, for it is the middle week of the highest-demand winter season (and the modelling programme prohibits annual simulation periods at this time, so a week is chosen for clarity). Demand peaks in the morning when electricity customers wake up and turn on their lights, kettle, and stove and as lights and electronics in offices and shops are turned on. Demand also peaks again as people return home from work or school. Weekend demand peaks are slightly smoothed out, for people may stay at home longer in the mornings on weekends, for example. The weekend demands are also slightly lower due to offices being closed on weekends.

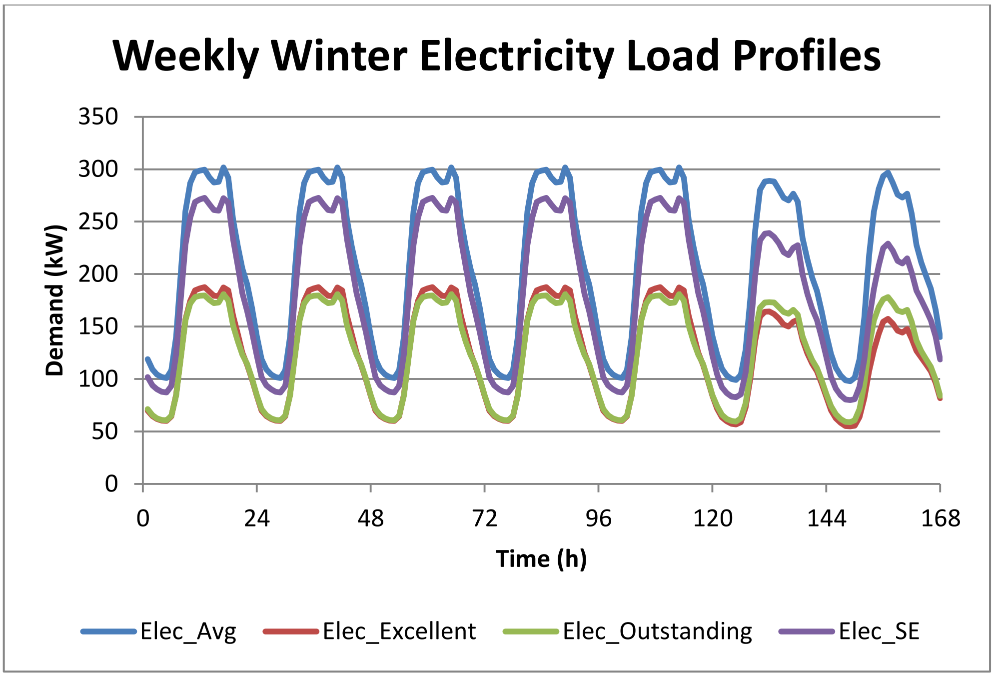


Figure 2.7- Electricity Profiles in this Model

To confirm the accuracy of the weekday load profile shape derived in the following sections, it is compared to the profile that SE uses in their feasibility study for the Central Waterfront, which can be seen below in Figure 2.8. Similar peaks exist in the morning and evening hours, when consumers first turn lights and appliances on in the morning and leave school and work to return home at night. The scale is also in line with the entire project’s demand, as the predicted maximum demand for this feasibility study by SE is approximately 275 kW.

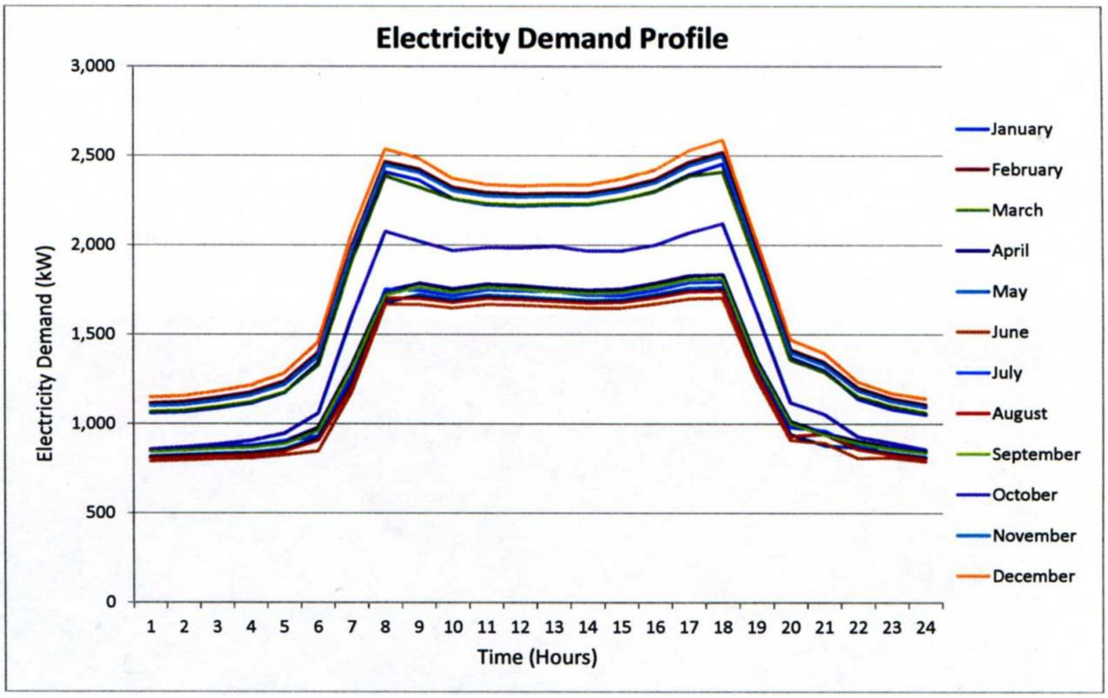


Figure 2.8- Scottish Enterprise Central Waterfront Electricity Demand

Seasonal fluctuations in electricity demand are highly likely due to the climate, which provides sunlight for many hours in the summer months and few in the winter months. Lighting demand is a significant portion of overall electricity demand, so it has a noticeable effect.

It is unsure what the breakdown of SE's entire Central Waterfront demand is per building use type, so an accurate comparison is not possible at this time. Further investigation should be done in the future if a more accurate model is desired. Therefore, the profiles used for comparison in the following sections are from the UKERC data and existing profiles in Merit alone.

2.4.6.1 Office

Four load profiles are considered for use in the model- one UKERC profile for LF=77% (Cooper, 2013), which is load profile class 8, one UKERC profile for LF=35%, which is load profile class 7, and two existing profiles within Merit, A and B. Figure 2.9 and Figure 2.10 are shown below, comparing the UKERC load class 8 profile with the Merit A and B profiles. A one week period in winter and high summer are shown for comparison, with the first day of the week being Monday (represented below as 0-24 hours). 'Winter' demand is highest, whereas 'high summer' demand is the lowest, so the two seasons are the best choice for comparison.

The UKERC data does not match the other office profiles well, especially Merit profile B on the weekends and during the summer.

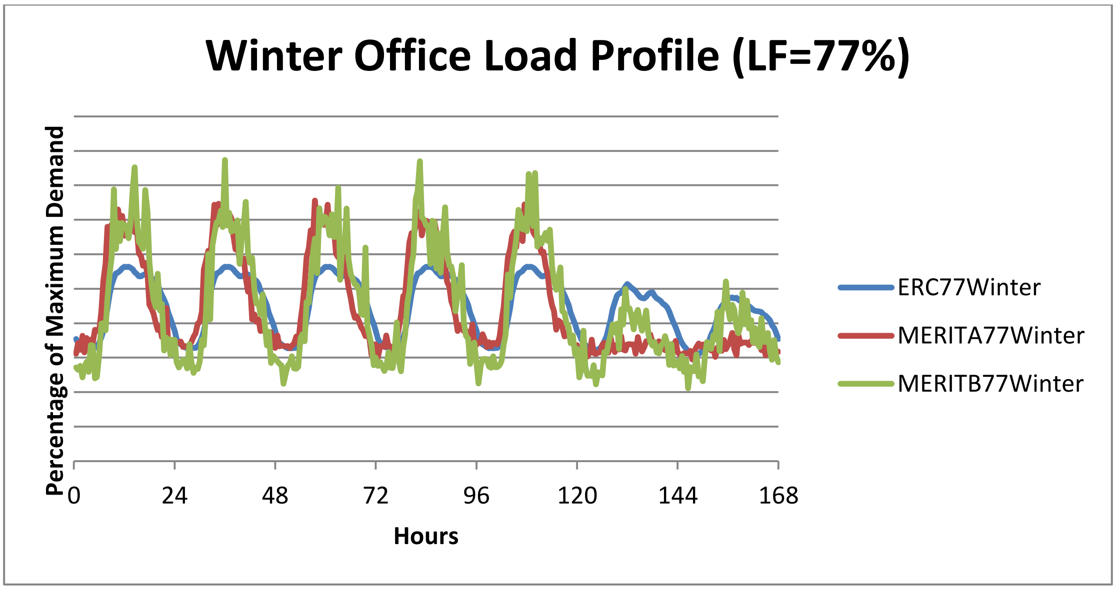


Figure 2.9- Winter Office Profiles for LF=77%

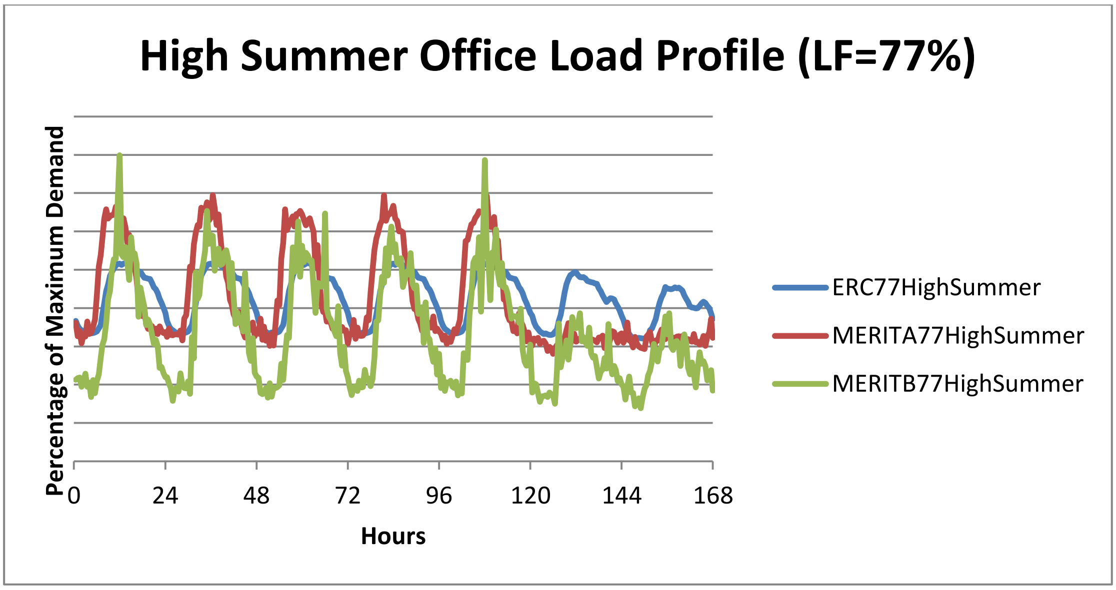


Figure 2.10- Summer Office Profiles for LF=77%

Since the UKERC load profile for class 8 does not match the others well, the profile for LF=30-40% (class 7) is assessed alongside the Merit profiles. Figure 2.11 and Figure 2.12 below represent the load profile with an optimal match to the Merit profiles. Once again, the Merit B profile does not appear to match well, especially in the warmer months. The spikes in the Merit A demand are again avoided, for the demands are average for the whole system.

Finally, the UKERC profile for load class 8 is chosen to represent the average electrical demand in an office building in this model, for the profile is similar to an average of multiple single-office Merit A profiles, and the origin of the Merit profiles is unsure at this time. The UKERC load class 8 profile is seen below in blue.

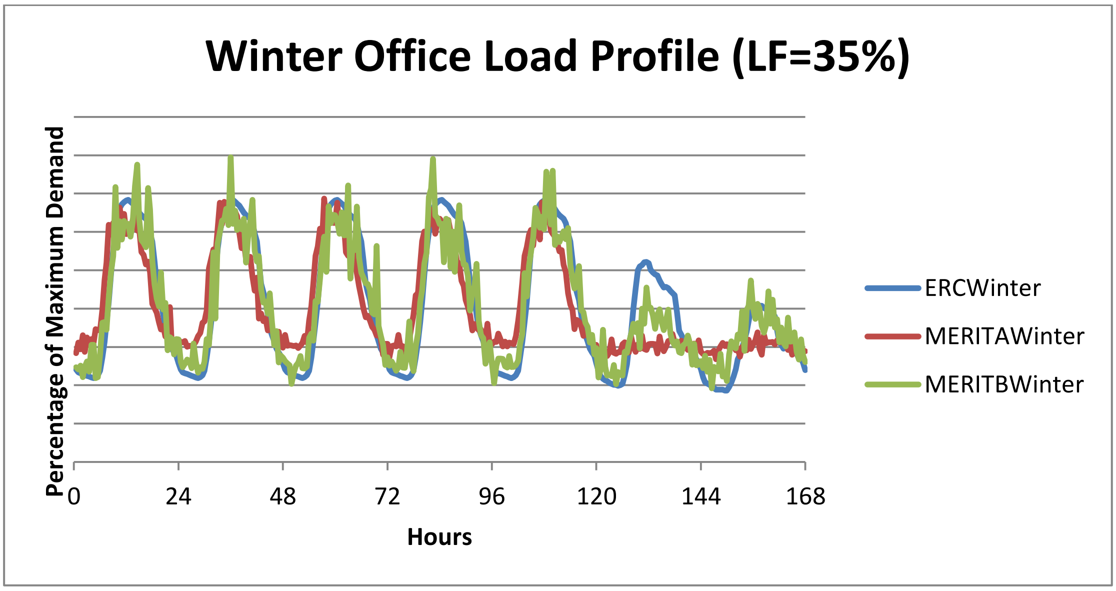


Figure 2.11- Winter Office Profiles for LF=35%

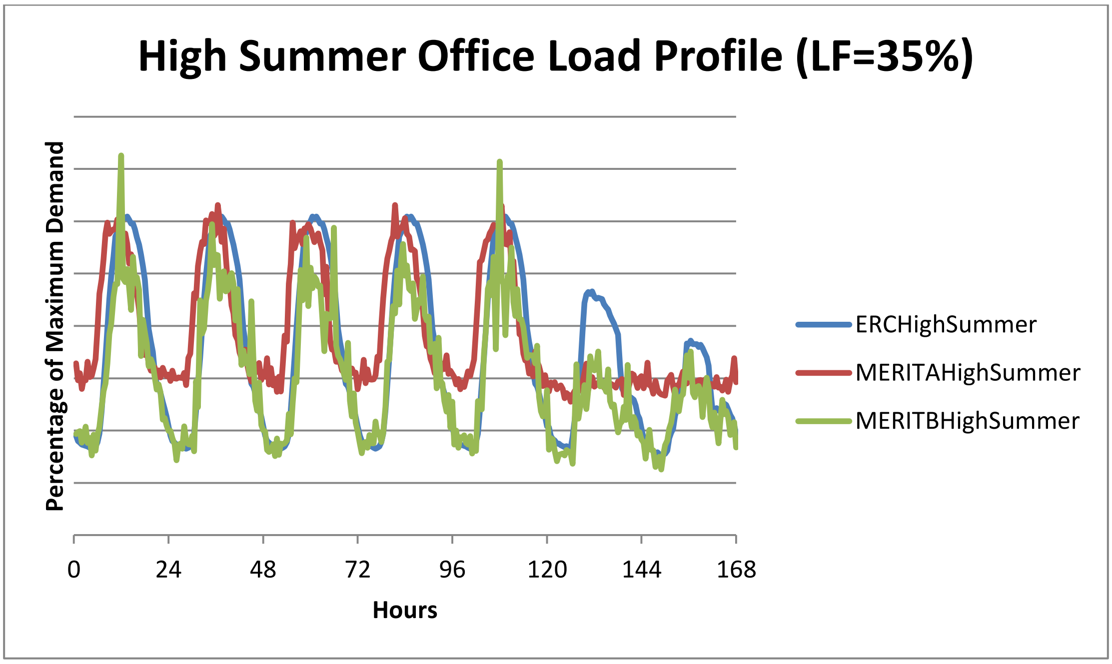


Figure 2.12- High Summer Office Profiles for LF=35%

2.4.6.2 Residential

Two residential load profiles are considered for this feasibility study. The first is that of load class 1 from the UKERC, domestic unrestricted customers. Since this DER system will operate on a district heating scheme with demand-side management, customers do not have the economy-7 tariff choice, so load profile class 2 is ignored in this model. The profile in comparison is from Merit for a 1-2 bedroom home in the UK. Once again, the origin of the Merit profile is unknown, but it gives a rough idea of accuracy for the UKERC profile. The following Figure 2.13 and Figure 2.14 compare the two. The peaks and troughs occurring in the Merit profile occur on a house-by-house basis, and when an average profile is being considered, they should be smoothed out to look like the UKERC profile below. The UKERC data for the 'High Summer' period is also a better representation of the demand, as lighting loads and air conditioning requirements could be much less than the Merit data, the UK source for which is unknown, but likely south of, Dundee.

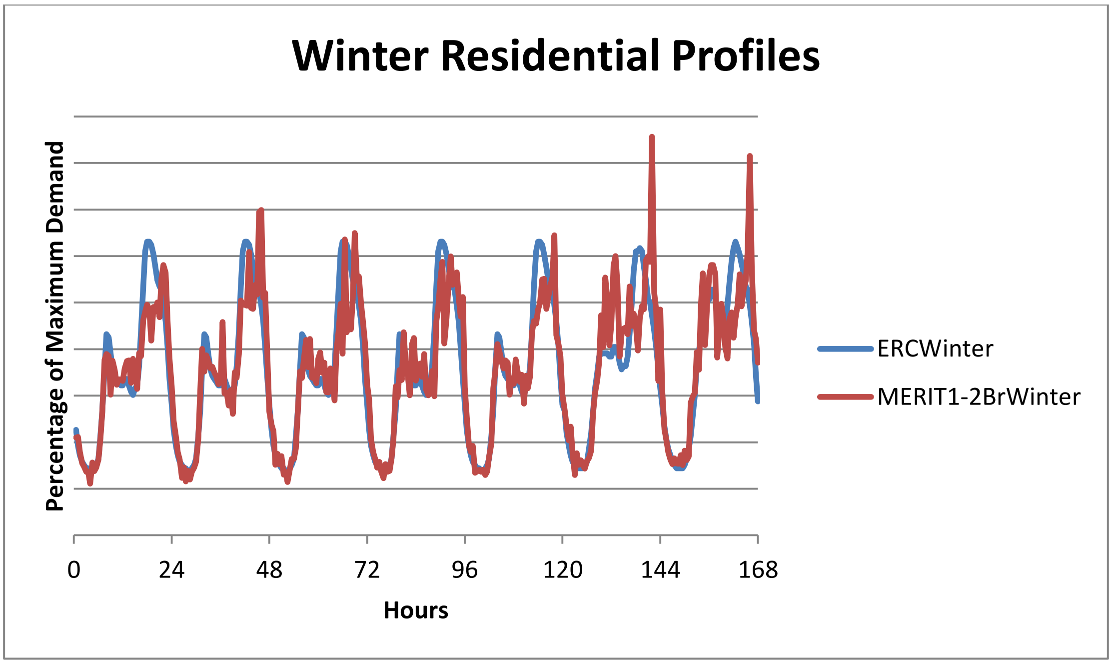


Figure 2.13- Winter Residential Profiles

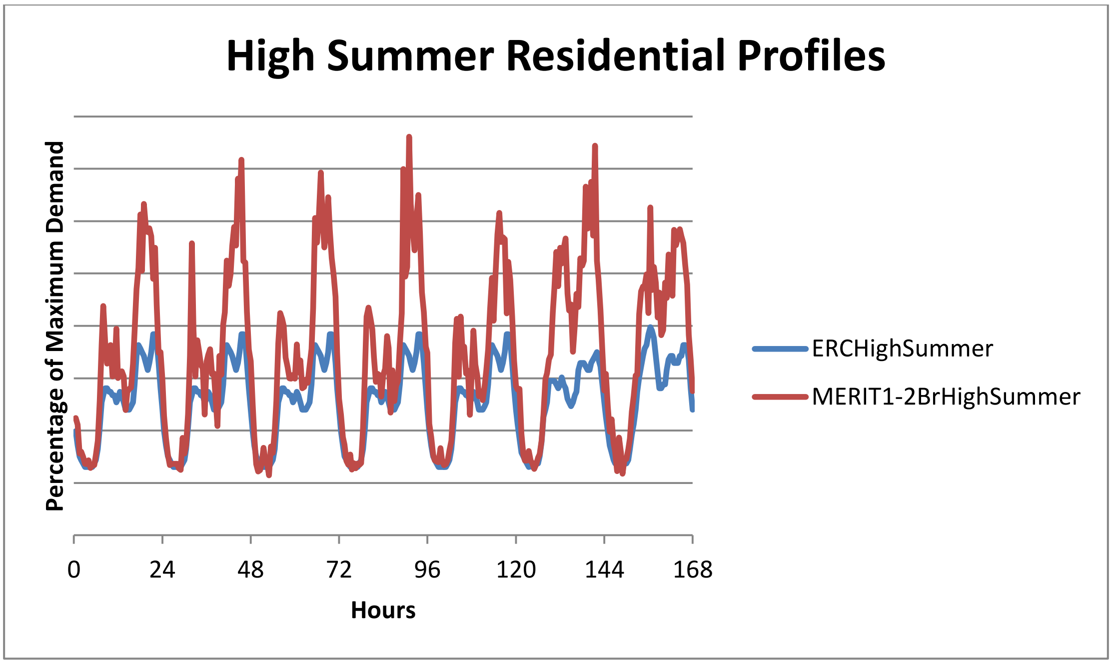


Figure 2.14- High Summer Residential Profiles

2.4.6.3 Retail

The UKERC load profile class chosen for retail is based on a load factor between 25-32% (Guyer, 2010), so the profile for class 6 represents the retail load profile to be compared to the Merit load profile for a craft and grocery store. It is assumed that consumption on weekend days will be the same as during the weekdays, for shops will be open 7 days per week. Therefore, the UKERC profile is updated to allow for that demand. The resulting comparison is shown in the following Figure 2.15 and Figure 2.16. The UKERC retail peaks and troughs are pronounced as should be, and the Merit C&G Store data is different on Thursday and Friday (in addition to the source being unknown). Thus, the modified UKERC profile is chosen for this model.

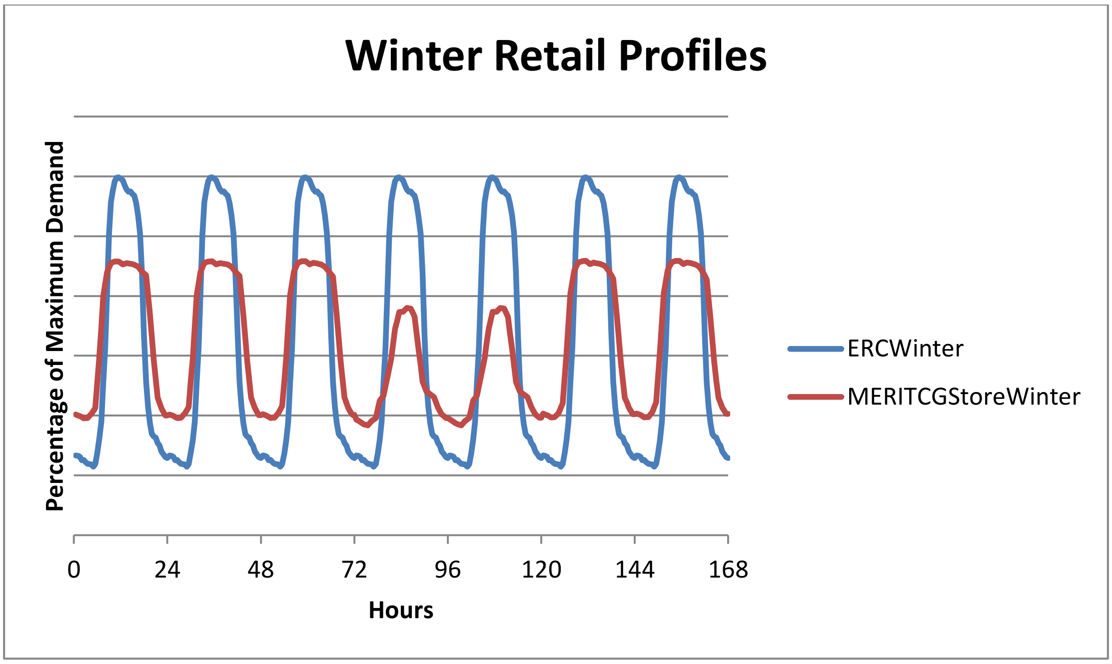


Figure 2.15- Winter Retail Profiles

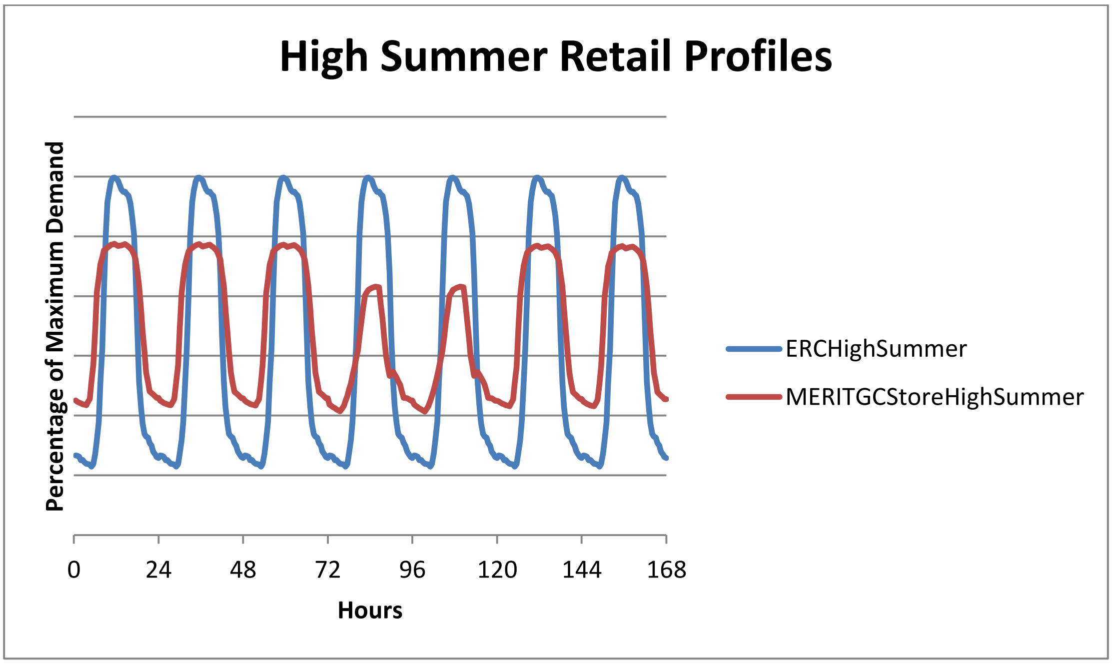


Figure 2.16- High Summer Retail Profiles

2.4.6.4 Leisure and Bars

The profile chosen to represent leisure and bars is the same as the above profile for retail, as typical load factors for restaurants are 15-25% and hobby shops are 25-30% (Guyer, 2010), so load profile class 6 is chosen. It is also updated to have the same demand on weekend days, for the shops are expected to run as others in Scotland do- 7 days a week from approximately 9:00-18:00.

2.4.6.5 V&A Museum

A profile does not exist in Merit for comparison, but the V&A Museum can be considered to have a load factor similar to an office or retail shop (Cooper, 2013). Load profile 7 is therefore chosen, with a LF=35%. The weekend days are scaled to be the same as the weekdays, for the opening hours on the weekend days will guarantee the same demand. Therefore, the profile to be used for the V&A Museum is the same as that of an office, but with the same demands on weekend days, as seen below in Figure 2.17 and Figure 2.18.

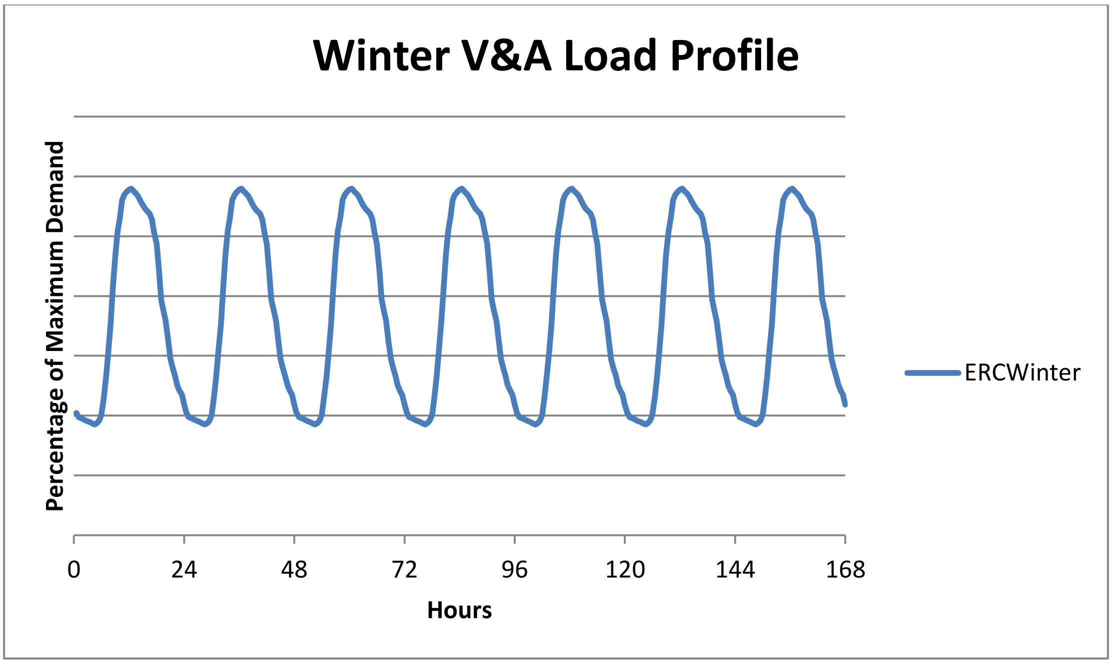


Figure 2.17- Winter V&A Load Profile

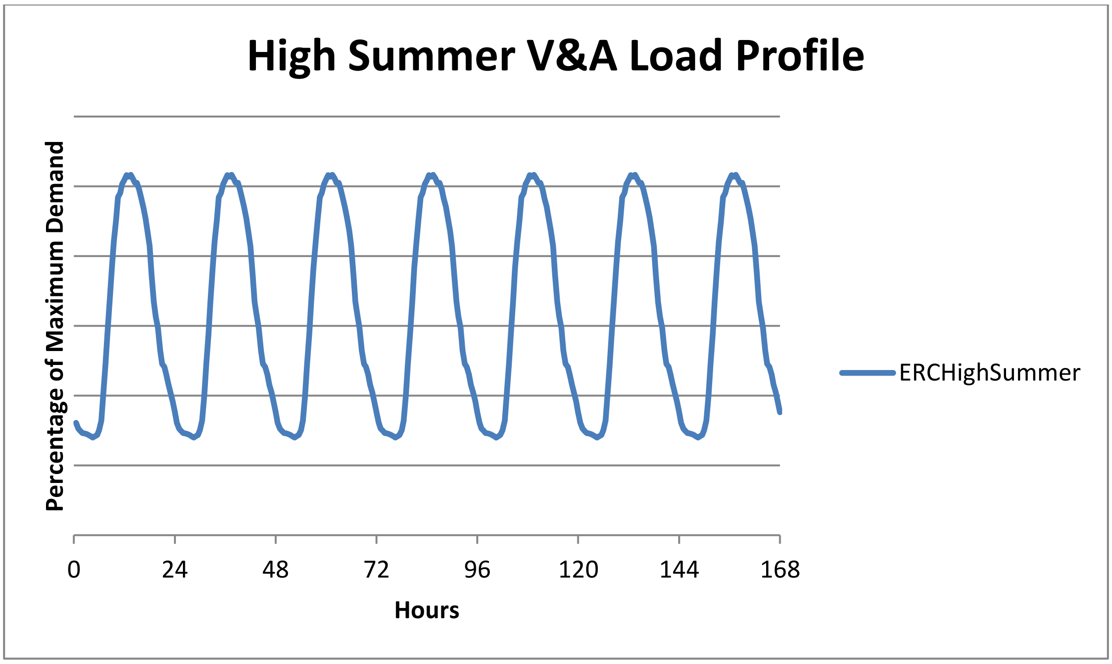


Figure 2.18- High Summer V&A Load Profile

2.4.6.6 Parking and General

Parking/general load profiles are determined from the number of estimated night time hours, a table for which is shown below in Table 2.10. The dates chosen are the exact middle of each 'season', and the number of required hours of lighting is used to derive the load profile for the parking/general loads (Time and Date, 2013). According to the Road Vehicles Lighting Regulations, 'lighting up' time in the UK is 30 min after sunset to 30 min before sunrise, therefore lighting for parking will be needed for these times (Her Majesty's Government, 1989).

Table 2.10- Hours of Lighting Demand per Season

Month	Day	Sunrise	Sunset	Hours of Darkness	Hours of Lighting Demand
January	13	8:40	16:12	15	14
April	21	5:58	20:35	7.5	6.5
June	16	4:31	22:05	4.5	3.5
Aug	18	5:53	20:47	7.5	6.5
Oct	6	7:29	18:40	11	10

The estimated daily profiles during the winter and high summer are shown below in Figure 2.19 and Figure 2.20 for clarity. The lighting load occurs approximately from 15:00 to 8:30 in the winter and 21:30 to 6:00 in the high summer period.

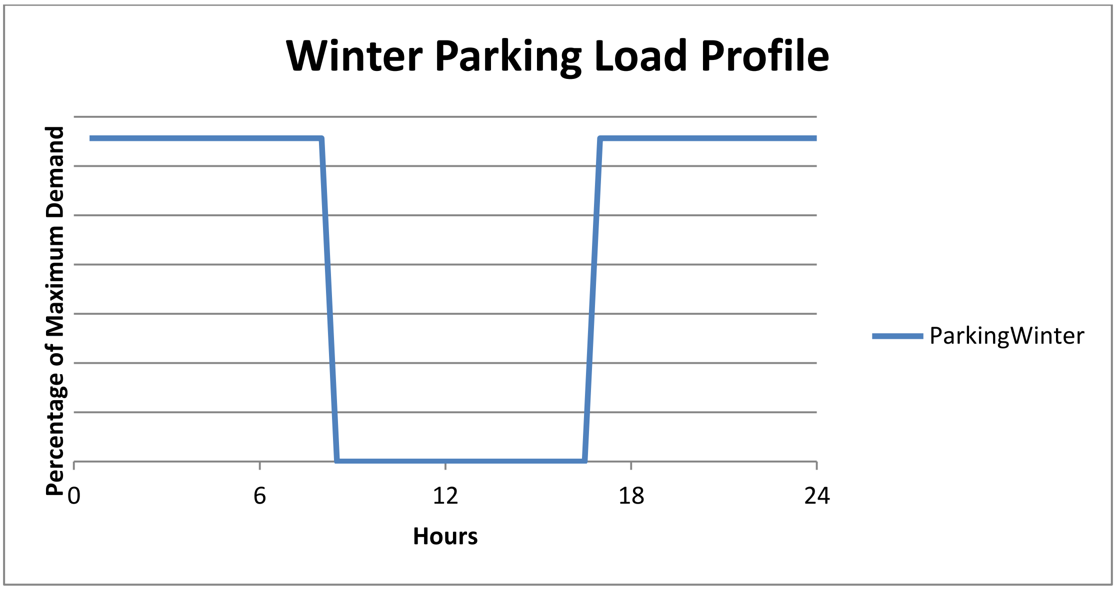


Figure 2.19- Winter Parking Load Profile

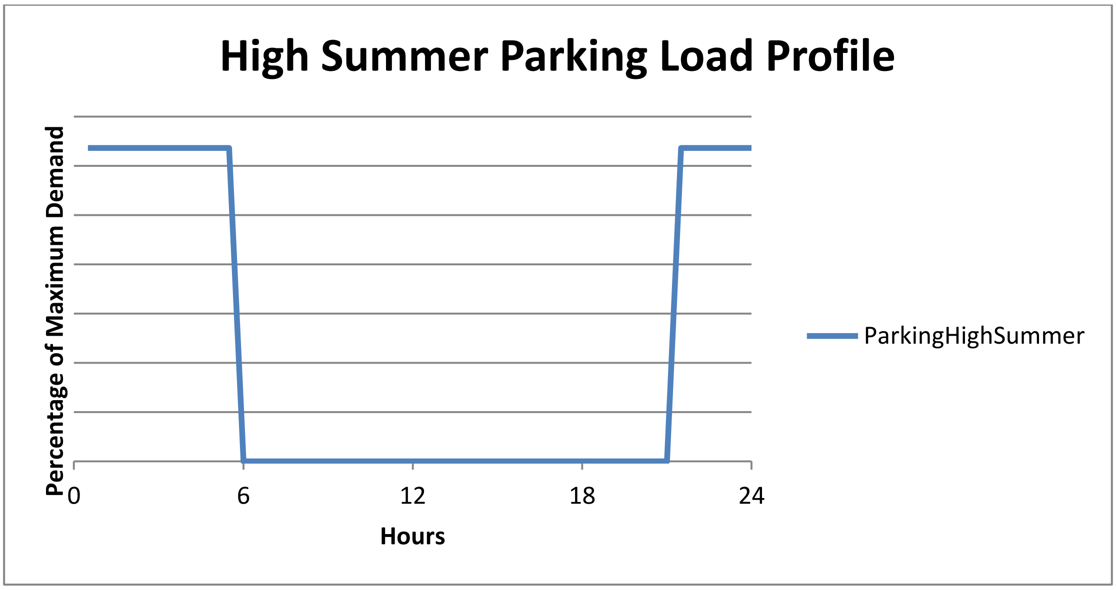


Figure 2.20- High Summer Parking Load Profile

2.4.7 Thermal Load Profiles

Thermal load profiles are provided by Douglas Duncan at SSE through Catherine Cooper (Cooper, 2013). They are expert judgement-aided profiles that are similar to that for existing buildings. Three profiles are assumed here and used to calculate the overall thermal load profile for the DER system in this model. Heating demand load profiles all spike in the morning hours, but as this feasibility study is being conducted for a DER system, it would be wise to design buildings to higher building standards in order to maintain indoor temperatures within the envelope of comfort for each customer for as long as possible, reducing carbon footprint overall. The heating profiles for some buildings can then be shifted by a projected number of hours, based on building U-values, to offset peaks; the overall heating load could therefore be smoothed out over the entire Central Waterfront DER system using a demand-side management scheme (this is not considered in this model, however).

The annual thermal load based on demand profiles provided by SSE is shown as it appears in the modelling programme Merit in Figure 2.21 below. For seasonal variations in percentage of maximum demand, the same percentages are used as for and office building's electrical load profile comparison.

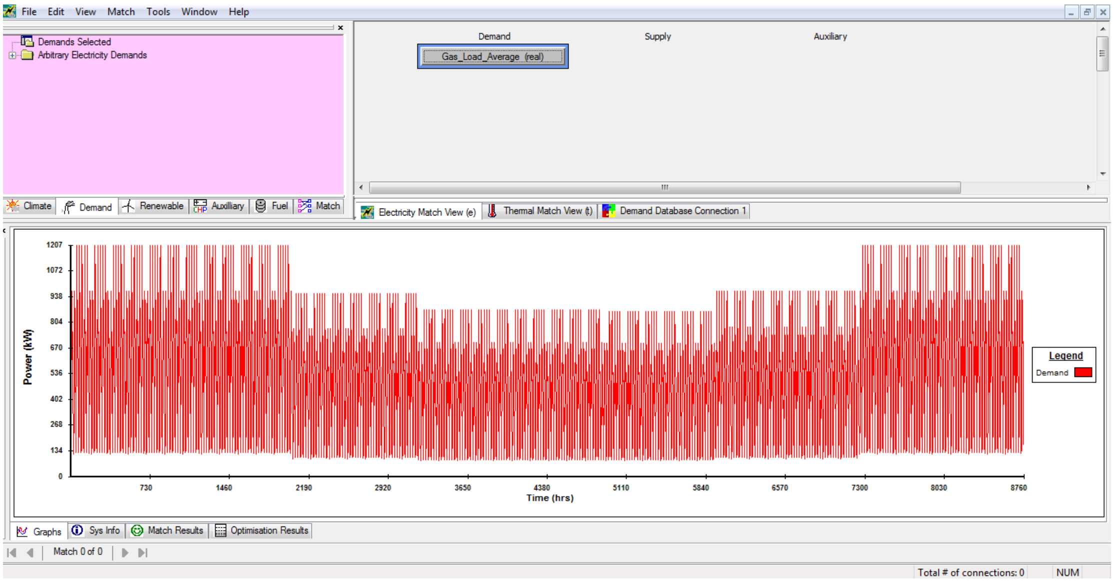


Figure 2.21- Average Annual Heating Demand

For comparison, the thermal demand for a typical weekday day in the winter is shown below in Figure 2.22. The demand peaks between 7 and 8am typically, and at other times for those buildings that begin heating later in the day. It can be seen that the SE Benchmark and BREEAM Outstanding standards require much less heat demand, for those buildings can retain heat longer. Additional flexibility for the future is also available here if buildings are designed to higher standards, and peak heating per building could be later in the day, for example, which would spread out the peak gas demand and could allow for better integration of renewable sources.

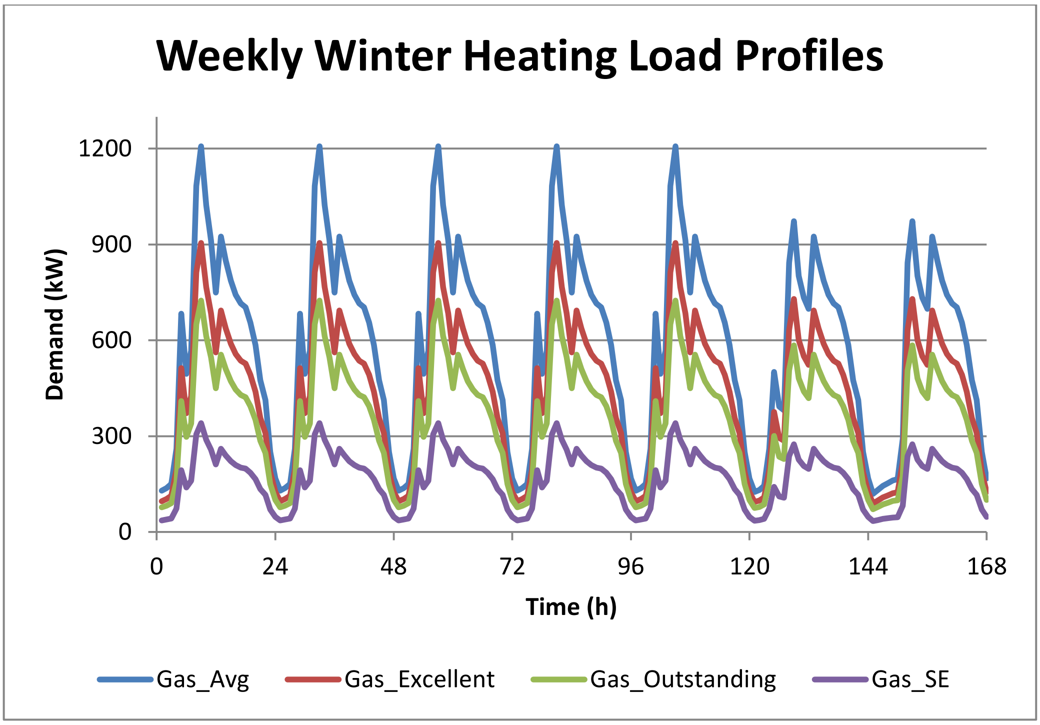


Figure 2.22- Heating Profiles in This Model

For validation purposes, the profile shape for the weekday demand above is compared to the shape and scale of the weekday demand profile that SE uses in their feasibility study, which can be seen in Figure 2.23. Multiple peaks occur in each profile, although at slightly different times. This is likely due to modelling assumptions including thermal building envelope properties. Both sets of profiles have a maximum demand between 6:00 and 8:00 when electricity demand peaks, likely for the same reasons.

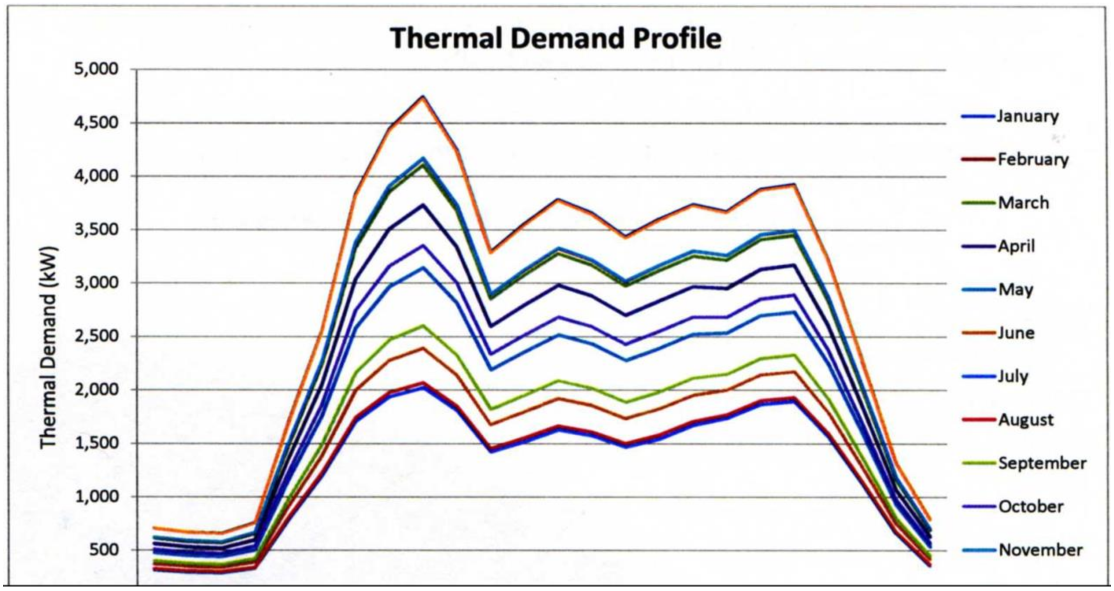


Figure 2.23- Scottish Enterprise Central Waterfront Thermal Demand

The scale of the profiles compared to SE's feasibility study profiles is similar, which confirms this modelling method. Seasonal thermal demand is also similarly affected both scenarios. The reduction during the summer is significant due to the local climate in Dundee.

2.4.7.1 Office

The office thermal load profile is as shown below in Figure 2.24. Demand peaks in the morning to heat the building, and tapers off as desired room temperature is achieved. It can be seen that the demand is expected to decrease during weekend days to avoid heating an empty office.

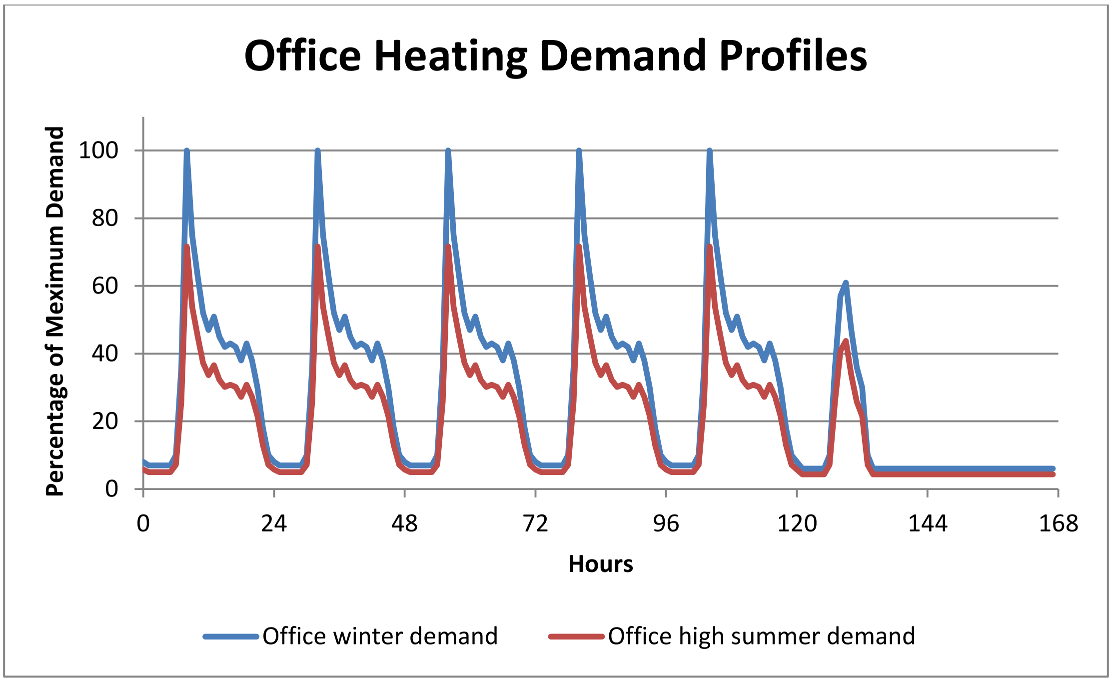


Figure 2.24- Office Heating Load Profiles

2.4.7.2 Front of House

The front of house (FOH) load profile in the winter and summer can be seen below in Figure 2.25. Weekend loads are the same as weekday loads, for the retail and leisure/bars are open seven days a week and residential demand is anticipated to be constant throughout the week in this DER system. The profiles are a bit smoother than the office profiles, as they are anticipated for multiple uses and are more of a ‘average’.

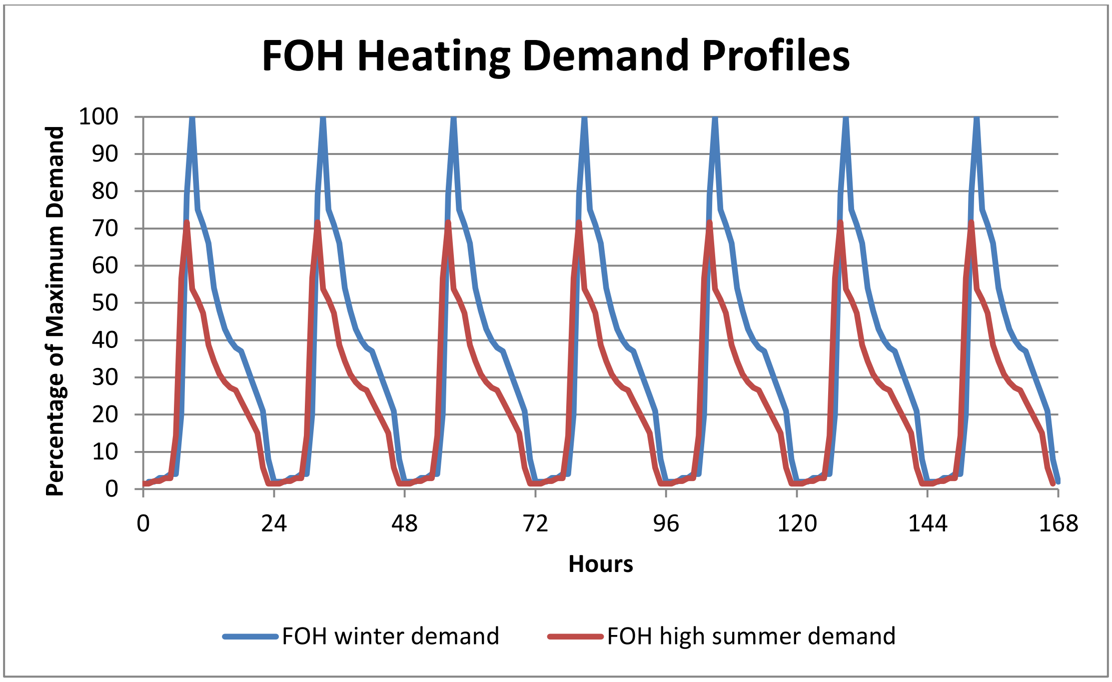


Figure 2.25- FOH Heating Demand Profiles

2.4.7.3 V&A Museum

The V&A Museum will require its own unique heating load, the profile for which can be seen in the following Figure 2.26. Heating is constantly required at over 10% of maximum demand, which is noticeably higher than the other profiles. The LF of the V&A is therefore higher than the other two profiles, likely due to its relatively predictable energy demand, for museumgoers do not have a significant impact on the thermal demand of a large museum.

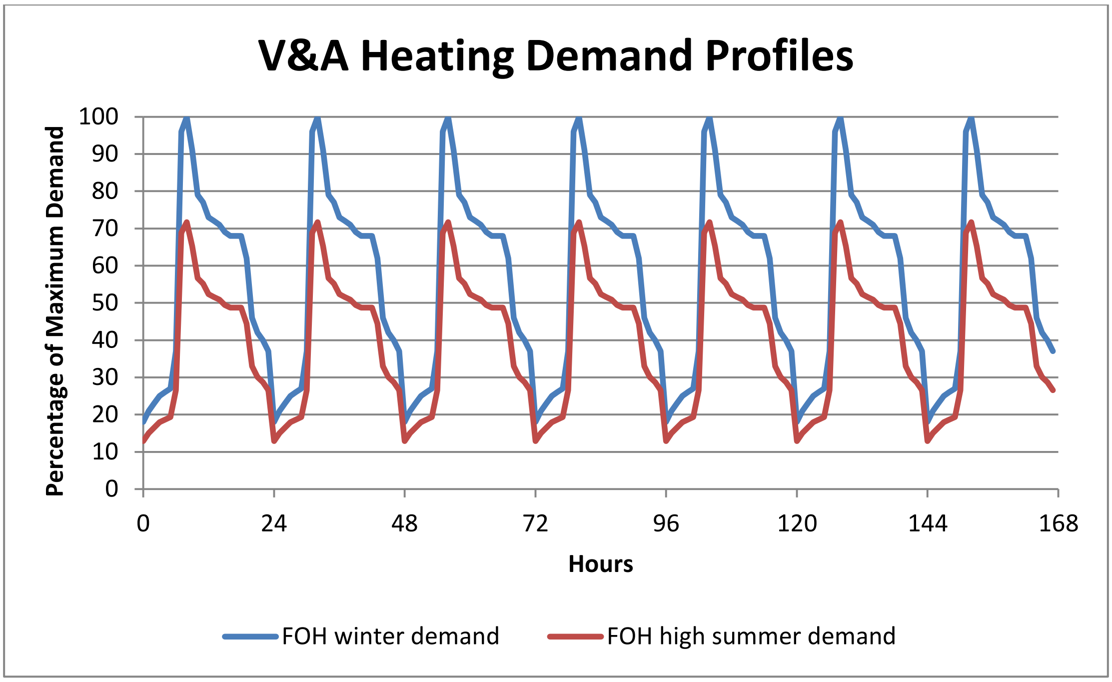


Figure 2.26- V&A Heading Demand Profiles

2.5 Demand/Supply Combinations for Modelling

The combinations of DER options as discussed previously are matched against the estimated demand profiles to determine the optimal match for the system for each load profile. The best match is simulated first in Merit for the week in the middle of the winter period (in 1983 it is 10th to 16th January), the reasoning for which can be found in the section discussing Merit and its limitations; once the best match is determined for that week, the best match is then determined for the week in the middle of the 'high summer' period (15th to 21st August 1983) and calculated manually for the entire year. The systems are assessed for their match percentage, surplus and deficit renewable supply, total demand, and total DER supply, which are decision-making factors in determining the optimal DER system for the 3 buildings along the Dundee Waterfront in this feasibility study.

In order to determine the optimal DER combination for this feasibility study, thermal simulations are run first, for the electrical load required by the WSHPs must be added onto the electrical demand for the DER system. The electrical simulations are then run second.

Four water source heat pumps and up to 45,000 litres (in 5,000 litre increments) of thermal energy storage are modelled in this feasibility study. Combinations of 1 WSHP, 2 WSHPs, 3 WSHPs, and 4 WSHPs with 0 L, 5,000 L, 10,000 L, 15,000 L, 20,000 L, 25,000 L, 30,000 L, 35,000 L, 40,000 L, and 45,000 L are simulated to determine the optimal combination for this DER system and determine the feasibility of the Central Waterfront as a DER. The resulting optimal number of WSHPs is then added to the electrical demand profiles for electrical simulations.

As explained in the previous section introducing the DERs in this case study, two PV scenarios are modelled, and four wind turbine combinations are modelled for each load profile scenario and the corresponding optimal number of WSHPs. This done is to compare the installation of solar modules on the V&A only to the installation of modules on all three buildings. It is also done to compare installing 12 QR5 turbines with installing 12 WS110 turbines and to optimise the capacity of WS138 turbines required for a system best electrical match. After the best match combination for the above DERs is determined, groups of 5 EV batteries are added at a time to the system to simulate the effect of using electric vehicles to help offset peak loads. Combinations of electrical DERs simulated, in simulation order, are listed below:

- 480 YL245P
- 1814 YL245P
- 12 QR5
- 1814 YL245P + 12 QR5
- 1 WS110
- 12 WS110
- 2 WS138
- 1814 YL245P + 12 WS110 + 2 WS138
- 20 WS138
- 1814 YL245P + 12 WS110 + 22 WS138
- 56 WS138
- 1814 YL245P + 12 WS110 + 58 WS138
- 1814 YL245P + 12 WS110 + 22 WS138 + 5 iMiEV
- 1814 YL245P + 12 WS110 + 22 WS138 + 10 iMiEV
- 1814 YL245P + 12 WS110 + 22 WS138 + 15 iMiEV

- 1814 YL245P + 12 WS110 + 22 WS138 + 20 iMiEV
- 1814 YL245P + 12 WS110 + 22 WS138 + 25 iMiEV
- 1814 YL245P + 12 WS110 + 22 WS138 + 30 iMiEV
- 1814 YL245P + 12 WS110 + 22 WS138 + 35 iMiEV
- 1814 YL245P + 12 WS110 + 22 WS138 + 40 iMiEV

These combinations are partly chosen because the simulations were run sequentially to reduce the required number of simulations for this model.

3 Results and Discussion

Several simulations were run to model multiple renewable energy scenarios to determine the optimal system match that provides the greatest percentage of energy demand from DERs.

For visual aid purposes, match results are given for the winter period of Monday to Friday 10th to 16th January (1983). Since demand percentage changes in summer months are equal for all four models, only winter simulations are used to determine the best annual match in this feasibility study. Once the best match for this week period is determined, the annual match is calculated by hand for the best match scenarios. This simulation technique is used because the modelling software, Merit, cannot support an annual model at this time. Further investigation can be undertaken if desired, but is outside the scope of this project.

It is suggested that the remaining heating and electricity demand that the DERs cannot match comes from renewable sources such as biomass or low greenhouse gas emissions sources such as nuclear until it is phased out. The consequence of storing hazardous used reactor elements must be considered when assessing nuclear power for its emissions, however.

Both electrical and thermal matches must be analysed for a DER system to function properly. The 'highest match percentage' is not always the best choice, either. Therefore, simulations are run sequentially and best match decisions are made at intervals throughout the simulation process.

3.1 Thermal Match

Thermal match simulations were run first to determine the optimal heat pump and storage tank sizes. The number of heat pumps in the system is needed for the electrical match, as the heat pumps use electrical energy to create thermal energy.

The resulting best match demand/supply profiles in the 'winter' week, one for each design scenario as mentioned in the report, are shown in Figure 3.1 below. A summary table of the best match results is presented below the graphs, and tables including all match combinations simulated and results extrapolated from Merit can also be seen in Appendix A. The demand profiles are shown in red and the supply from DERs is shown in green. It can be seen that as the thermal demand decreases, less auxiliary supply from the buffer tanks is required, so the supply surplus increases.

The profiles ‘match’ when they overlap, so it is clear that the best match of the four scenarios is that for the ‘average’ consumption in the Dundee city centre, which is one WSHP with 25,000 litres of thermal storage. The best match scenarios are not necessarily the best choices for this DER system, however. The best matches occur with the maximum amount of storage (45,000 litres), but close matches (less than 0.1% less than the best) that use significantly less storage are more ideal. Since 20,000-40,000 litres of extra storage is unnecessary for a small system and costly, the close matches are therefore the ‘best’.

The ‘average’ profile is best matched to 1 WSHP and 25,000 litres of storage, with a match percentage of 97.38%. The ‘BREEAM Excellent’ profile is best matched to 1 WSHP and 20,000 litres of storage, with a match percentage of 94.74%. The ‘BREEAM Outstanding’ profile is best matched to 1 WSHP and 15,000 litres of storage, with a match percentage of 92.01%. The ‘SE Benchmark’ profile is best matched to 1 WSHP and 5,000 litres of storage, with a match percentage of 76.01%.

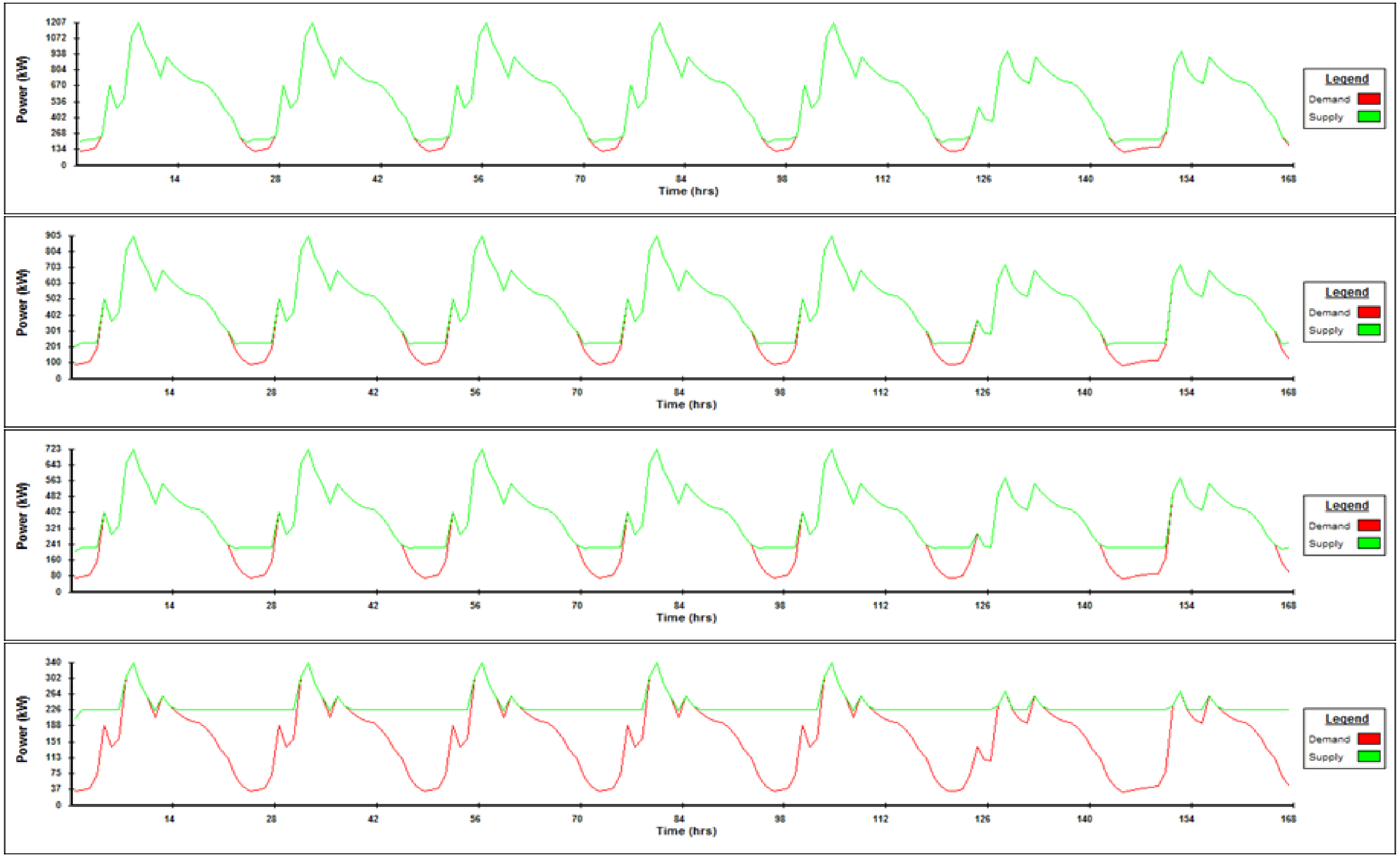


Figure 3.1- Optimal Thermal Combination

Table 3.1 below summarises the data for the best match profiles in the four preceding graphs. The highest percentage matches and the 'optimal' matches are listed for each load profile. The optimal match choices are highlighted in purple for the 'winter' simulations and blue for the 'high summer' simulations, with their match percentage bolded. As mentioned above, the highest-match combinations are not always the most practical, for the extra storage is not necessary in this DER system. Also, if considering the Central Waterfront as a DER system, four WSHPs are recommended for use and further investigation into thermal storage sizing should be undertaken. Electrical best match simulations are therefore run with both one and four WSHPs for this reason.

Additionally, although the winter matches for the 'average' profile are the closest, BREEAM Outstanding standards are deemed best for carbon emissions reduction (and renewable surplus is subsequently increased), so 'high summer' matches are run for one week for the BREEAM Outstanding profile rather than the 'average' profile to better simulate this DER system as a part of the Central Waterfront.

The resulting match percentage in Merit decreases as the demand decreases. This is due to the size of the WSHPs and the way Merit classifies a 'match' (best matches have no surplus or deficit supply from DERs). There is no deficit in any of the best matches because the supply from the heat pumps and buffer tanks exceeds the demand. The DERs are quite excessive for this system on their own- surplus exceeds 125 MWh in one week with four heat pumps and 45,000 litres of storage against the SE Benchmark (lowest) load profile. This is ideal, however, if approaching the entire Central Waterfront as a DER system with district heating, for 125 MWh/wk could cover over 40% of the remaining 15.5 GWh of SE's predicted system heating requirements. Four WHSPs in combination with 45,000 litres of storage could be combined with other sources throughout the system such as biomass boilers or CHP systems to meet the total demand. A grid connection to a fossil fuel source could also provide backup supply during peak times or if renewable supply is not available.

The optimal 'BREEAM Outstanding' match profiles for the 'winter' and 'high summer' week period are shown following Table 3.1 in Figure 3.2 and Figure 3.3 . The demand decreases due to the warmer external temperatures. The energy surplus in the summer increases slightly as well. In the summer, one WSHP and one AKVA

10000 litre tank are the optimal match against the ‘BREEAM Outstanding’ profile. It is still beneficial, as well, to connect four WSHPs to a larger demand than this DER system- even more so as surplus increases.

Table 3.1- Thermal Match Results from Merit

Best Matching Electrical Profile	**RE Supply Name**	**Aux Supply Size**	**Demand**	**RE Supply**	**Aux Supply**	**Match Rate (%)**	**Energy Delivered**	**Energy Surplus**	**Energy Deficit**
Average	1 WSHP	25000 L	99.05 MWh	38.64 MWh	62.80 MWh	**97.38**	98.91 MWh	2.33 MWh	0.00 kWh
Average	1 WSHP	45000 L	99.05 MWh	38.64 MWh	62.77 MWh	97.4	98.91 MWh	2.29 MWh	0.00 kWh
BREEAM Excellent	1 WSHP	20000 L	74.29 MWh	38.64 MWh	39.84 MWh	**94.74**	74.18 MWh	4.08 MWh	0.01 kWh
BREEAM Excellent	1 WSHP	45000 L	74.29 MWh	38.64 MWh	39.66 MWh	94.8	74.18 MWh	3.90 MWh	0.01 kWh
BREEAM Outstanding	1 WSHP	15000 L	59.43 MWh	38.64 MWh	26.21 MWh	**92.01**	59.34 MWh	5.29 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	45000 L	59.43 MWh	38.64 MWh	26.12 MWh	92.08	59.34 MWh	5.20 MWh	0.00 kWh
BREEAM Outstanding	4 WSHP	5000 L	59.43 MWh	154.56 MWh	-14044.99 Wh	**54.88**	59.34 MWh	94.29 MWh	0.00 kWh
BREEAM Outstanding	4 WSHP	45000 L	59.43 MWh	154.56 MWh	-69288.63 Wh	54.9	59.34 MWh	94.26 MWh	0.00 kWh
SE Benchmark	1 WSHP	5000 L	27.96 MWh	38.64 MWh	1.73 MWh	**76.01**	27.91 MWh	12.23 MWh	0.00 kWh
SE Benchmark	1 WSHP	45000 L	27.96 MWh	38.64 MWh	1.71 MWh	76.05	27.91 MWh	12.22 MWh	0.00 kWh
HighSummer BREEAM Outstanding	1 WSHP	10000 L	42.60 MWh	38.64 MWh	11.57 MWh	**86.4**	42.54 MWh	7.24 MWh	0.00 kWh
HighSummer BREEAM Outstanding	1 WSHP	45000 L	42.60 MWh	38.64 MWh	11.52 MWh	86.43	42.54 MWh	7.41 MWh	0.00 Wh
HighSummer BREEAM Outstanding	4 WSHP	15000 L	42.60 MWh	154.56 MWh	-42953.72 Wh	**43.67**	42.54 MWh	111.08 MWh	0.00 Wh
HighSummer BREEAM Outstanding	4 WSHP	45000 L	42.60 MWh	154.56 MWh	-42953.72 Wh	43.67	42.54 MWh	111.08 MWh	0.00 Wh

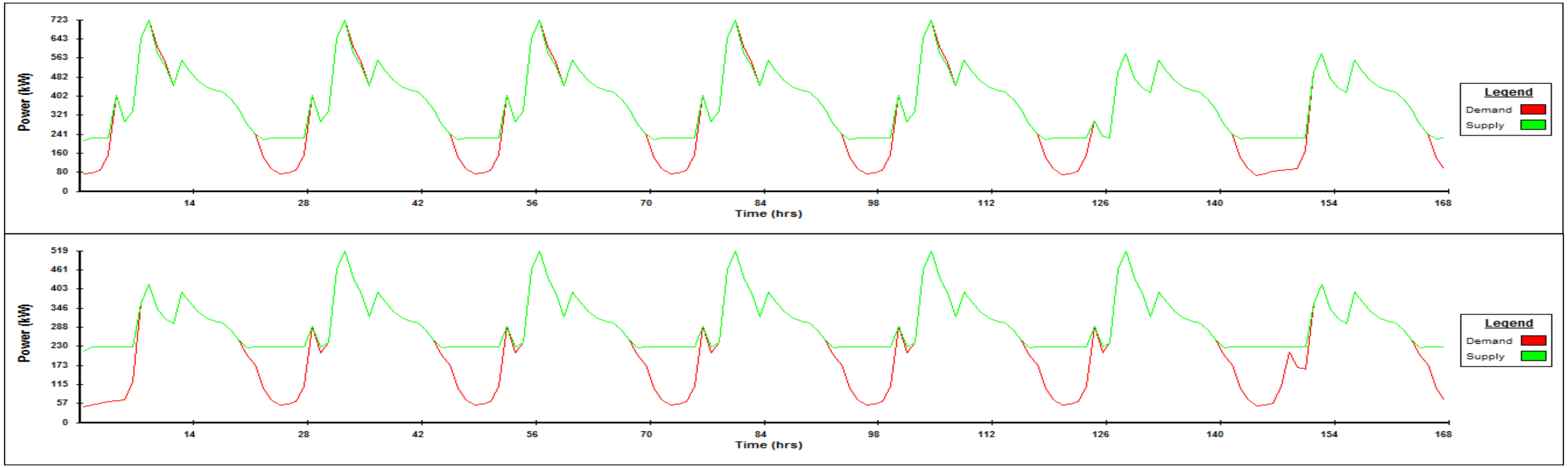


Figure 3.2- Best 'Winter' and 'High Summer' BREEAM Outstanding Thermal Matches with 1 WSHP

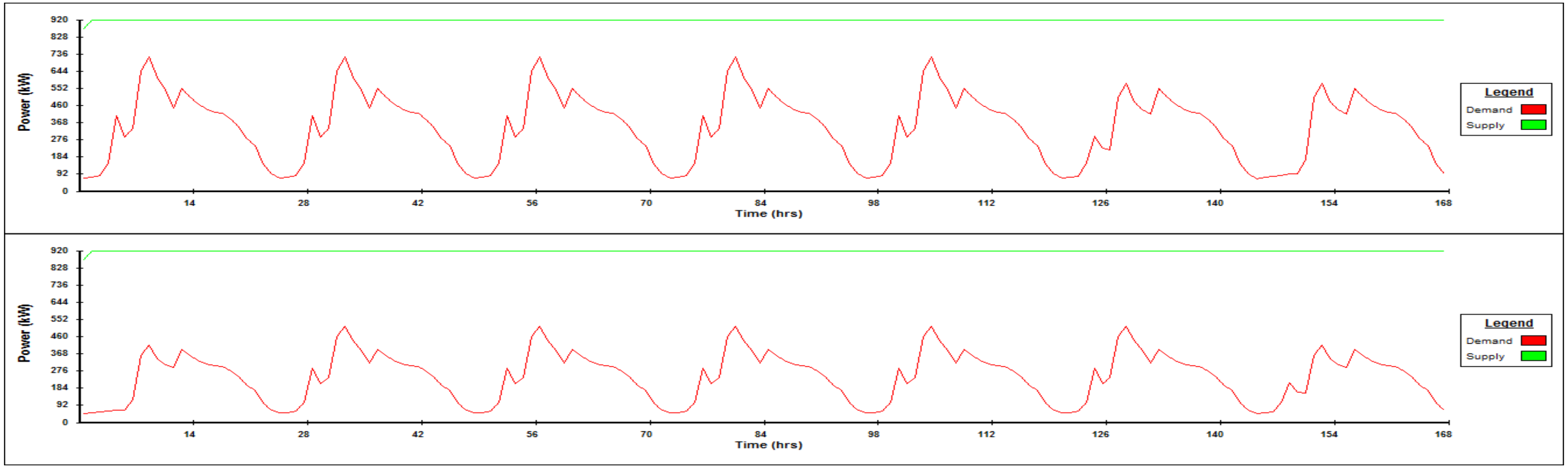


Figure 3.3- Best 'Winter' and 'High Summer' BREEAM Outstanding Thermal Matches with 4 WSHPs

3.2 Electrical Match

As mentioned in the previous section, thermal simulations were run first to determine the electrical load required for the heat pumps to operate. The resulting best matches for each thermal load profile occurred when just one WSHP was simulated, so the electrical load of one heat pump is added to the electrical load profiles. However, the Central Waterfront is being considered for a DER system in this case study, so the electrical loads for four WSHPs are also added to the existing load profiles for simulation.

As previously mentioned, the results of the simulations in Merit report a ‘match’ as having no surplus or deficit renewable supply. The best matched profile in the winter with one WSHP is the ‘average’ profile, with a match of 63.37%, and with four WSHPs is the ‘BREEAM Outstanding’ profile, with a match of 63.53%. However, because the goal is emissions reduction, energy efficiency measures and thus electricity demand are expected to be lower than average values, so both matches are shown for BREEAM Outstanding demand profiles for one week during the ‘winter’ and ‘high summer’ periods instead.

The four profiles are shown below in Figure 3.4 and Figure 3.5. During the ‘winter’ week, the match with one WSHP is 59.3% and with four WSHPs is 63.5%; during the ‘high summer’ week, the match with one WSHP becomes 64.6% and with four WSHPs increases to 66.2%. It can be seen that the supply exceeds the demand nearly half the time in the summer and less in the winter, so increasing the supply is recommended. Also, if the supply is increased to meet the demand, additional electrical storage should be considered.

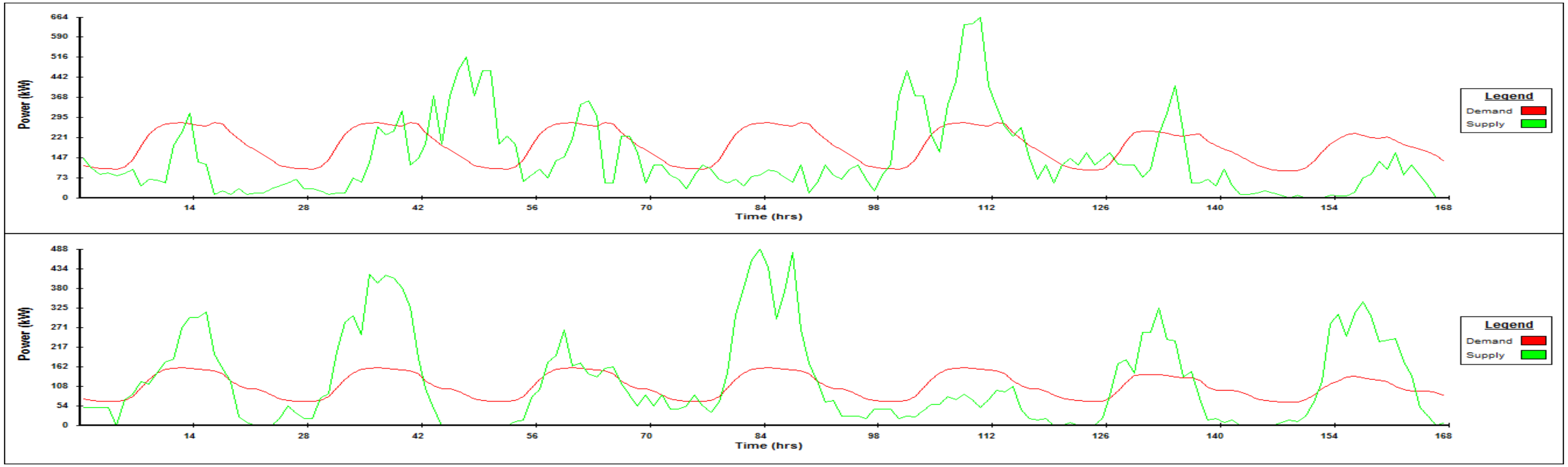


Figure 3.4- Best 'Winter' and 'High Summer' BREEAM Outstanding Electrical Matches with 1 WSHP

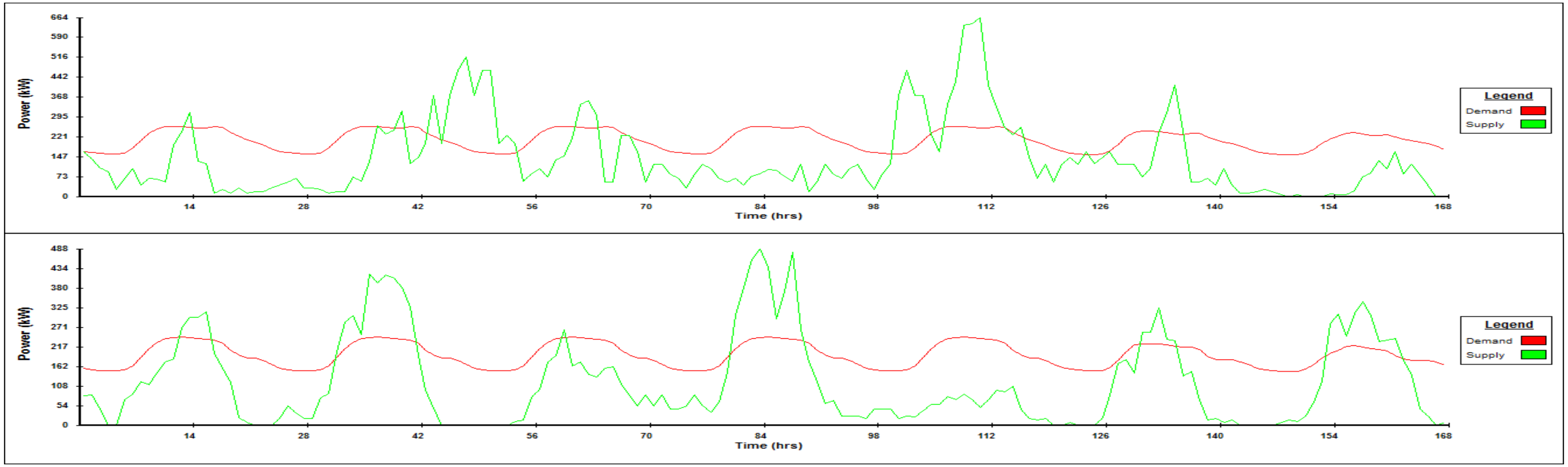


Figure 3.5- Best 'Winter' and 'High Summer' BREEAM Outstanding Electrical Matches with 4 WSHPs

Table 3.2 below shows the best match combinations for electrical loads with one WSHP (the matches are highlighted in orange) and with four WSHPs (the matches are highlighted in green). The overall best matches for a ‘winter’ and ‘high summer’ week are highlighted in purple and blue, respectively. For further reference, the tables in Appendix A summarise the results from all electrical simulations run in this feasibility study. The best fit matches combine 1814 Yingli YL245P modules with 12 Swift WS110 turbines, 22 Swift WS138 turbines, and 40 Mitsubishi iMiEV batteries (and are highlighted in purple for the ‘winter’ and blue for the ‘high summer’). As expected, 1814 solar modules match the load profiles closer than 480 modules do. Twelve WS110 turbines match the demands better than twelve QR5 turbines, and the optimal number of off-site WS138 turbines is 22, which produce 15.07 MWh of electricity. Adding EV batteries also increases the match percentage, but only by a fraction of a percent.

Match percentages are higher for all combinations with one WSHP than with four WSHPs until the maximum system match (excluding auxiliary power from the EV batteries) is achieved and the match percentages are nearly equal. After the point of optimisation, higher matches are then achieved with four WSHPs. Adding EV batteries as auxiliary supply increases the match percentage as well.

Although the best electrical match is considered as ‘reasonable’ (as defined above), less than half the demand is met by renewable supply, so additional supply options such as building integrated photovoltaic shingles or much larger off-site wind turbines with ample electrical storage should be considered for installation if space allocation and budget allow. Another option for additional investigation would be creating a tidal lagoon in the Tay beside the V&A Museum. This is further discussed in the ‘recommendations’ section.

Table 3.2- Electrical Match Results from Merit

Best Matching Electrical Profile	RE Supply Name	Aux Supply Size	Consumption	RE Supply	Aux Supply	Match Rate (%)	Energy Delivered	Energy Surplus	Energy Deficit
BREEAM Outstanding + 1 WSHP	480 YL245P	NULL	21.48 MWh	1.14 MWh	0.00 Wh	16.93	1.14 MWh	0.00 Wh	20.26 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	1.14 MWh	0.00 Wh	10.85	1.14 MWh	0.00 Wh	34.41 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P	NULL	21.48 MWh	4.30 MWh	0.00 Wh	41.73	3.60 MWh	597.61 kWh	17.56 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	4.30 MWh	0.00 Wh	31.14	4.20 MWh	73.30 kWh	31.32 MWh
BREEAM Outstanding + 1 WSHP	12 QR5	NULL	21.48 MWh	2.77 MWh	0.00 Wh	24.66	2.76 MWh	0.00 Wh	18.64 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	2.77 MWh	0.00 Wh	16.68	2.76 MWh	0.00 Wh	32.79 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 QR5	NULL	21.48 MWh	7.07 MWh	0.00 Wh	50.3	6.17 MWh	720.40 kWh	14.96 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	7.07 MWh	0.00 Wh	38.42	6.93 MWh	95.22 kWh	28.56 MWh
BREEAM Outstanding + 1 WSHP	1 WS110	NULL	21.48 MWh	351.49 kWh	0.00 Wh	3.68	350.17 kWh	0.00 Wh	21.04 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	351.49 kWh	0.00 Wh	2.32	350.17 kWh	0.00 Wh	35.20 MWh
BREEAM Outstanding + 1 WSHP	12 WS110	NULL	21.48 MWh	4.22 MWh	0.00 Wh	33.68	4.12 MWh	60.46 kWh	17.25 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	4.22 MWh	0.00 Wh	23.47	4.20 MWh	0.00 Wh	31.34 MWh
BREEAM Excellent + 1 WSHP	2 WS138	NULL	21.48 MWh	1.41 MWh	0.00 Wh	13.62	1.40 MWh	0.00 Wh	19.99 MWh

BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	1.41 MWh	0.00 Wh	8.84	1.40 MWh	0.00 Wh	34.15 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	21.48 MWh	9.92 MWh	0.00 Wh	57.5	8.32 MWh	1.37 MWh	12.85 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	9.92 MWh	0.00 Wh	45.81	9.65 MWh	193.61 kWh	25.75 MWh
BREEAM Outstanding + 1 WSHP	20 WS138	NULL	21.48 MWh	14.06 MWh	0.00 Wh	58.98	10.34 MWh	3.56 MWh	10.94 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	14.06 MWh	0.00 Wh	52.54	12.34 MWh	1.53 MWh	23.08 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	32.64 MWh	23.98 MWh	0.00 Wh	63.22	18.10 MWh	5.51 MWh	14.09 MWh
BREEAM Outstanding + 4 WSHP		NULL	35.72 MWh	23.98 MWh	0.00 Wh	63.32	18.80 MWh	4.73 MWh	16.39 MWh
SE Benchmark + 1 WSHP	56 WS138	NULL	35.17 MWh	39.37 MWh	0.00 Wh	54.62	22.33 MWh	16.39 MWh	12.28 MWh
SE Benchmark + 4 WSHP		NULL	49.41 MWh	39.37 MWh	0.00 Wh	59.51	26.84 MWh	12.07 MWh	21.95 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	35.17 MWh	49.29 MWh	0.00 Wh	52.57	26.06 MWh	22.23 MWh	8.42 MWh
SE Benchmark + 4 WSHP		NULL	49.41 MWh	49.29 MWh	0.00 Wh	59.7	32.00 MWh	16.68 MWh	16.48 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	21.48 MWh	23.98 MWh	207.60 kWh	63.37	18.32 MWh	5.50 MWh	13.88 MWh
BREEAM Outstanding + 4 WSHP		40 iMiEV	35.72 MWh	23.98 MWh	203.03 kWh	63.53	19.00 MWh	4.72 MWh	16.19 MWh
HighSummer BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	18.71 MWh	20.30 MWh	209.54 kWh	64.64	13.07 MWh	7.32 MWh	5.44 MWh
HighSummer BREEAM Outstanding + 4 WSHP		40 iMiEV	32.95 MWh	20.30 MWh	219.60 kWh	66.16	16.99 MWh	3.34 MWh	15.63 MWh

3.3 ‘Annual’ Best Matches for this DER System

Although both the electrical and thermal match combinations with the highest percentages were achieved when considering the ‘average’ Dundee demand profile in this DER system (plots 5 and 6 and the V&A Museum), it is recommended instead to design to BREEAM Outstanding standards. The ‘BREEAM Outstanding’ scenario is the best matched profile in eight out of twelve electrical simulations with one WSHP, and the best ‘BREEAM Outstanding’ thermal match is just 4% lower than the ‘average’ match. Designing to BREEAM Outstanding standards decreases overall system demand, so deficit decreases and surplus supply from DERs increases. This is ideal when this system is considered as part of the whole Central Waterfront, as is the purpose of this case study, for the surplus supply can be used elsewhere in the system.

Match percentages for the best scenarios are hand-calculated from January to November, for an error in the Merit software prohibited annual simulations. A graph of the match for the ideal combination of DERs considered in the system including Plot 5, Plot 6, and the V&A Museum is shown below in Figure 3.6. The ‘BREEAM Outstanding’ demand profile is matched with 1814 Yingli YL245P modules, 12 Swift WS110 turbines, 22 Swift WS138 turbines, 40 Mitsubishi iMiEV batteries, 1 Climaveneta water source heat pump, 1 AKVA 10,000 litre thermal storage tank, and 1 AKVA 5,000 litre thermal storage tank. A graph of the match for the same combination of electrical DERs and 4 water source heat pumps with 4 AKVA 10,000 litre thermal storage tanks and 1 AKVA 5,000 litre thermal storage tank is shown second in Figure 3.7. This better represents the system as it would contribute to the entire Central Waterfront DER system, for the surplus supply from the WSHPs and storage would be met with demand from other areas of the system.

The resulting IC values are 0.398 and 0.077 with match percentages of 60.2% and 92.3% for January through November to the ‘BREEAM Outstanding’ demand for electricity and heating, respectively. This deems the ideal combination of renewables for this system as ‘reasonable’ for electricity and ‘excellent’ for heating by Merit’s match standards. It would therefore be suggested to add additional substantial electricity storage to capture as much renewable electricity as possible.

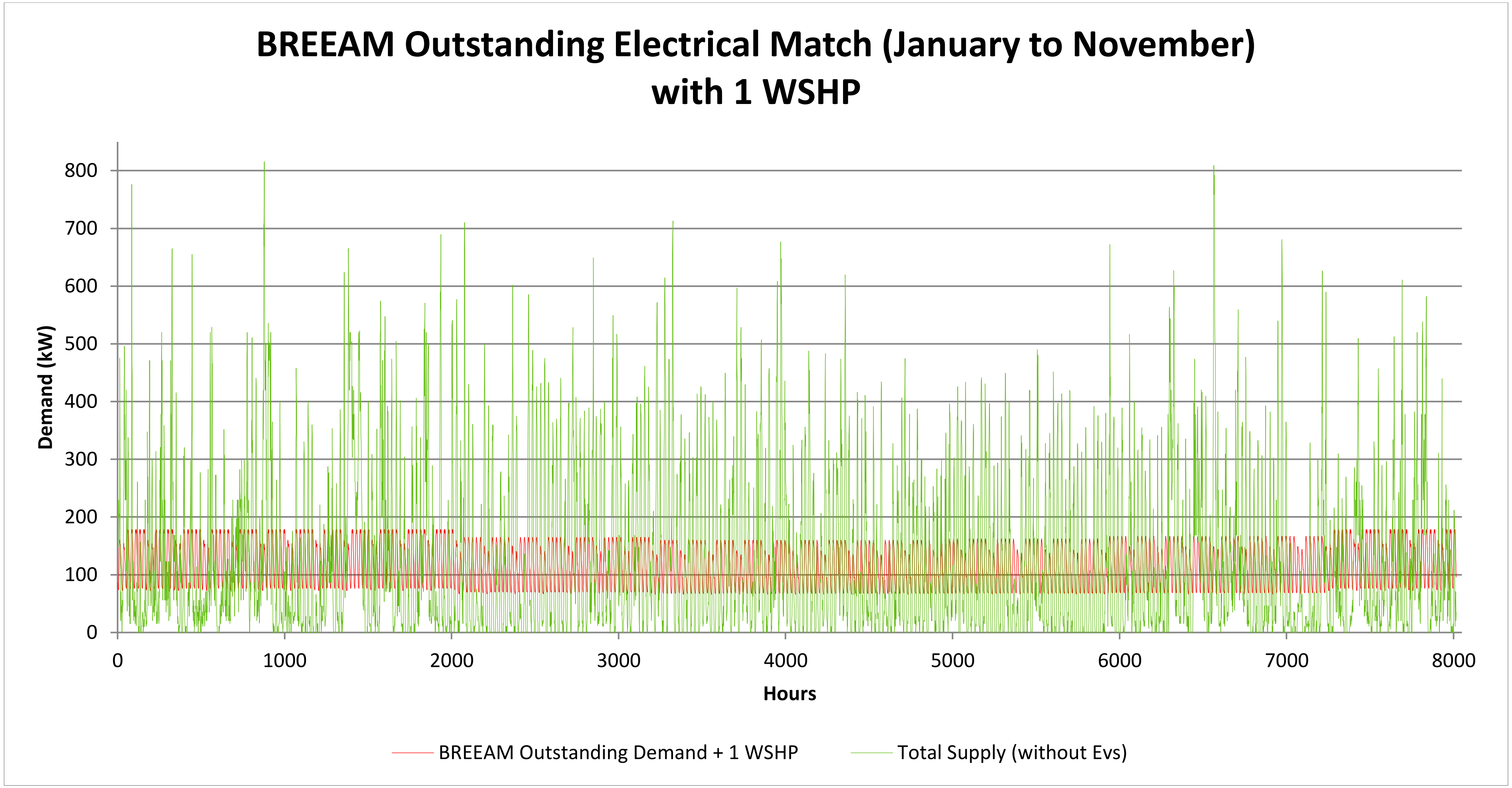


Figure 3.6- Electrical Match with 1 WSHP for January to November

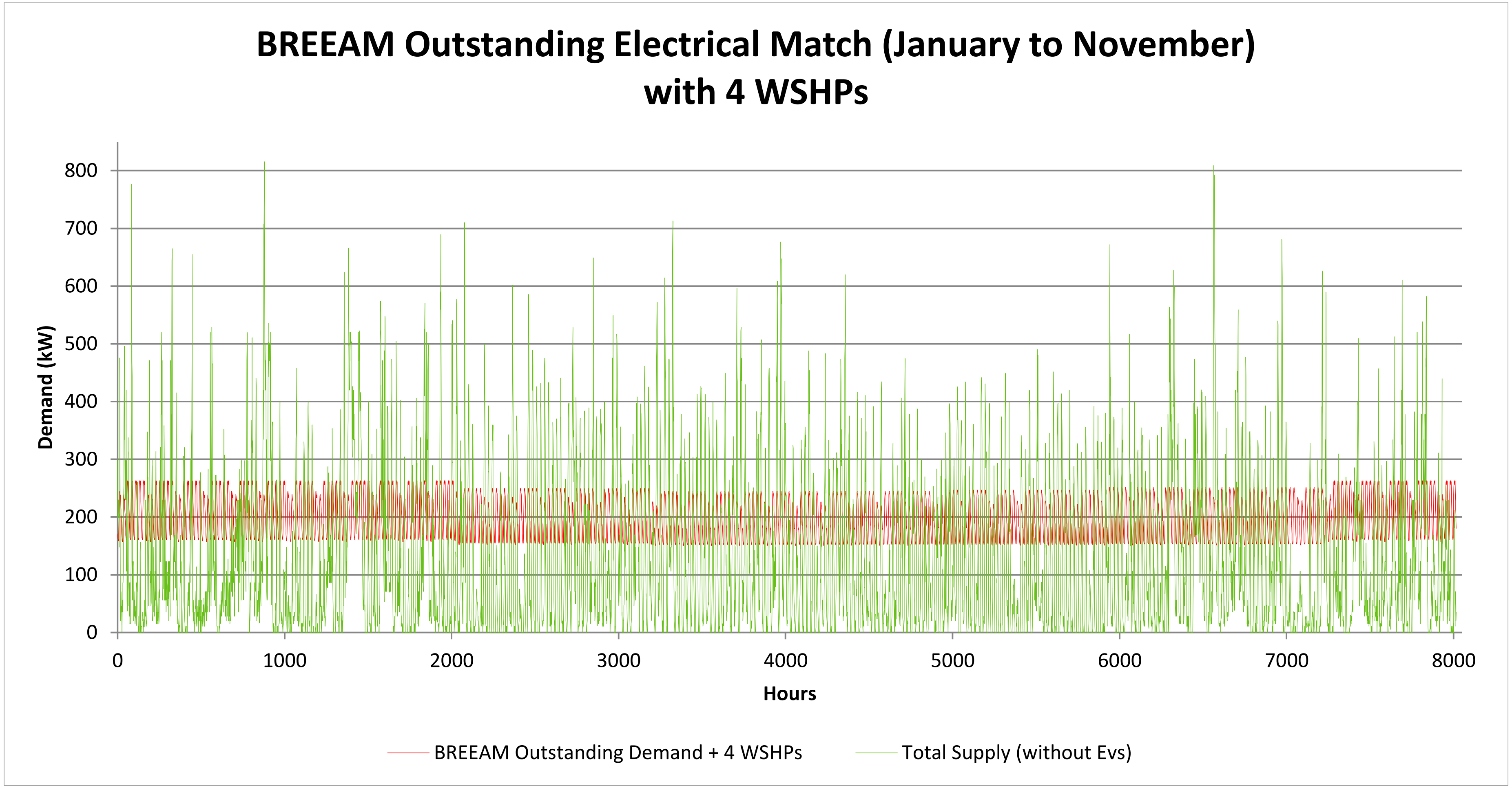


Figure 3.7- Electrical Match with 4 WSHPs from January to November

4 Conclusions and Recommendations

The results of the modelling simulations are analysed above and conclusions that are drawn are mentioned in this section. Design recommendations are then made for the Dundee Central Waterfront redevelopment project.

4.1 Conclusions

Conclusions are drawn from the results in the previous section concerning the feasibility of approaching three buildings along the Dundee Waterfront as a DER system and applicability of this design choice on a wider scale, such as the entire Central Waterfront. The conclusions are then used to support recommendations for future investigation of the Central Waterfront energy systems.

4.1.1 Design Values for Consumption

Of the four profiles chosen to represent four design choices in this feasibility study, designing to BREEAM Outstanding standards for electricity consumption is the most ambitious choice at 40.54 kWh/m^2, and designing to SE Benchmark standards is the least ambitious choice at 73.95 kWh/m^2. For district heating consumption, designing to SE Benchmark standards is the most ambitious choice at 63.68 kWh/m^2, whereas designing to Dundee city centre's current 'average' standards is the least ambitious of the four choices at 225.64 kWh/m^2.

Through investigation via simulations in Merit, it has been determined that designing to 'BREEAM Outstanding' standards for this feasibility study and along the Central Waterfront will save a significant amount of carbon (over 2000 metric tonnes compared to Dundee's 'average' demand) and provide a strong platform for renewable energy generation on a city scale. Additionally, it would bring Dundee one step closer to becoming Scotland's first BREEAM sustainable city.

4.1.2 Optimal Distributed Energy Resource Combination

The optimal DER scenario for the simulations run in this feasibility study is a combination of 1814 Yingli solar panels, 12 Swift WS110 wind turbines, 22 Swift WS138 turbines, 40 Mitsubishi iMiEV batteries, 1 Climaveneta WSHP, and 1 AKVA 10,000 litre thermal storage tank. The 10,000 litre tank is sized so that it will meet both high and low demands through the seasons. Only one WSHP is necessary to meet the heating demand for the 3 buildings, but four WSHPs are recommended for the Central Waterfront.

4.1.2.1 For This Feasibility Study

One WSHP is required in this scenario. During the ‘winter’ week, the electrical match is 59.3%, with 14.76 MWh of energy delivered, 9.04 MWh surplus, and 6.31 MWh deficit. During the ‘high summer’ week, it is 64.6%, with 13.07 MWh of energy delivered, 7.32 MWh surplus, and 5.44 MWh deficit.

During the ‘winter’ week, the thermal match is 92%, with 59.34 MWh of energy delivered, 5.29 MWh surplus, and no deficit. During the ‘high summer’ week, it is 86.4%, with 42.54 MWh of energy delivered, 7.24 MWh surplus, and no deficit.

4.1.2.2 For this study as a part of the Central Waterfront

Four WSHPs are required in this scenario. During the ‘winter’ week, the electrical match is 63.5%, with 19 MWh of energy delivered, 4.72 MWh surplus, and 16.19 MWh deficit. During the ‘high summer’ week, it is 66.3%, with 16.99 MWh of energy delivered, 3.34 MWh surplus, and 15.63 MWh deficit.

During the ‘winter’ week, the thermal match is 54.9%, with 59.34 MWh of energy delivered, 94.29 MWh surplus, and no deficit. During the ‘high summer’ week, it is 43.7%, with 42.53 MWh of energy delivered, 111.08 MWh surplus, and no deficit.

The thermal match is ‘excellent’ for this DER system, whereas the electrical match is ‘reasonable’, but not ideal. Suggestions such as addition of electrical storage are therefore made in the following section considering system improvement.

4.2 Recommendations

Based on the modelling results and comparisons to other design values, the optimal design choice for this feasibility study if it is to be considered as a DER system is to design at a minimum to BREEAM Outstanding standards (compared to Dundee city centre’s current average annual consumption) to reduce overall deficit through efficient building design and subsequently energy conservation. BREEAM Outstanding design for these buildings would meet Dundee’s goal of becoming Scotland’s first BREEAM certified city and would encourage emissions reduction through energy efficiency and renewable energy use.

Other DERs and models of these DERs should be considered further, as this feasibility study only assesses a few options, and they are not ideal if the goal is a 100% 'match' of supply to demand. Additionally, the design values derived in this report should be verified before a final choice is made.

The cost of each DER required for the best match scenario for this system must also be considered. If a significantly less expensive system delivers nearly the same demand match, that system should be selected instead. In order for the Central Waterfront to be considered as a DER system, costs must be considered for installations on all buildings. Methods of payment for the renewable systems could include payment through a payback scheme via. electricity and heating bills to ensure swift repayment for the energy companies installing the systems.

Approaching the Dundee Central Waterfront as a DER system will benefit the project on the whole if the system's carbon savings can outweigh the monetary cost, for the peaks and troughs in demand can be distributed from one area of the system to another. Energy storage is also key in approaching the Central Waterfront as a DER system. The peaks and troughs that occur in Investigation into less expensive electrical and thermal storage options is highly recommended.

Other sources of renewable energy should be considered in this DER system and for the Central Waterfront such as building integrated PV tiles or sun shades, or biomass district heating or solar thermal modules to serve the remaining demand after the WSHP supply. It is recommended to extend photovoltaic modules onto every building if cost effective and to source electricity from a wind farm near the city centre.

Another potential source of renewable electricity could come from a tidal 'lagoon' system. Figure 4.1 below shows an inlet on the Tay which could be used to generate electricity during low tide. Tidal energy is extremely reliable, so it could provide a 'base load' for generation during periods of low tide. This system could be incorporated with the rest of the Central Waterfront to provide electricity. Additional storage such as batteries or fuel cells could be added to store the surplus supply over the 12 hour period until the next low tide. It is likely based on the results from this report, however, that there may be no surplus supply, as supply from renewables in this study did not meet 100% of demand.

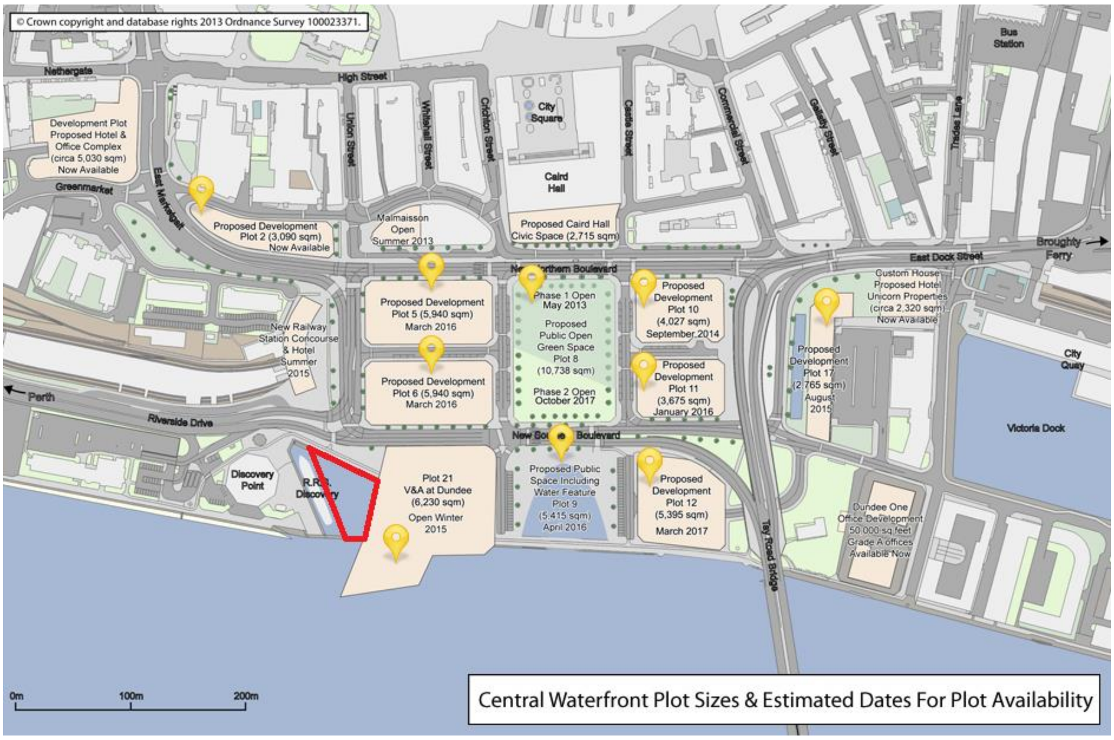


Figure 4.1- Potential Tidal Lagoon at the Central Waterfront

Therefore, it is highly recommended to consider this option in addition to those studied in this report and those already recommended. Other options not covered in this report such as waste combustion should be considered as well.

Treating electricity and heating generation, transmission, and distribution on a community level with distributed energy resources in an ideal combination (as determined in this study using results from the modelling programme Merit) can lead to a reduction of carbon emissions to the atmosphere through energy efficiency and localised generation, which minimises transmission losses and maximises use of low or zero carbon technologies. Peaks and troughs in energy demand can be met on a community level, and storage can greatly increase the output of renewable systems such as a heat pump, wind turbines, or photovoltaics. Investigation should therefore be undertaken into improving percentage of energy demand met by renewable supply through increase of electrical storage, for example. It is also recommended to design the Central Waterfront to high standards, such as BREEAM Outstanding standards, to minimise greenhouse gas emissions and maximise renewable energy generation and consumption. This will be of benefit to the city, energy suppliers, energy customers (who can enjoy zero net carbon energy and a cleaner environment), and can generate additional interest in Dundee as a hub for sustainable business and tourism.

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Appendix A

The results of the thermal simulations undertaken for the ‘winter’ week period (10th to 16th January 1983) are shown below in Table 4.1. The optimal choices for the system considered in this feasibility study are highlighted in purple.

Table 4.1- Thermal Modelling Results with Match Percentages

Thermal Profile	RE Supply Name	Aux Supply Size	Consumption	RE Supply	Aux Supply	Match Rate (%)	Energy Delivered	Energy Surplus	Energy Deficit
Average	1 WSHP	NULL	99.05 MWh	38.64 MWh	0.00 Wh	47.37	35.89 MWh	2.27 MWh	62.92 MWh
Average	2 WSHP	NULL	99.05 MWh	77.28 MWh	0.00 Wh	70.7	64.09 MWh	12.27 MWh	34.30 MWh
Average	3 WSHP	NULL	99.05 MWh	115.92 MWh	0.00 Wh	76.45	86.02 MWh	28.82 MWh	12.30 MWh
Average	4 WSHP	NULL	99.05 MWh	154.56 MWh	0.00 Wh	71.7	96.00 MWh	56.64 MWh	2.50 MWh
Average	1 WSHP	5000 L	99.05 MWh	38.64 MWh	20.08 MWh	65.85	56.16 MWh	2.27 MWh	42.75 MWh
Average	1 WSHP	10000 L	99.05 MWh	38.64 MWh	38.51 MWh	79.86	74.41 MWh	2.39 MWh	24.22 MWh
Average	1 WSHP	15000 L	99.05 MWh	38.64 MWh	51.89 MWh	88.84	87.99 MWh	2.33 MWh	10.87 MWh
Average	1 WSHP	20000 L	99.05 MWh	38.64 MWh	61.91 MWh	96.84	97.88 MWh	2.34 MWh	907.63 kWh
Average	1 WSHP	25000 L	99.05 MWh	38.64 MWh	62.80 MWh	97.38	98.91 MWh	2.33 MWh	0.00 kWh
Average	1 WSHP	30000 L	99.05 MWh	38.64 MWh	62.97 MWh	97.28	98.91 MWh	2.37 MWh	0.01 kWh
Average	1 WSHP	35000 L	99.05 MWh	38.64 MWh	62.77 MWh	97.39	98.91 MWh	2.30 MWh	0.00 kWh
Average	1 WSHP	40000 L	99.05 MWh	38.64 MWh	62.92 MWh	97.32	98.91 MWh	2.33 MWh	0.01 kWh
Average	1 WSHP	45000 L	99.05 MWh	38.64 MWh	62.77 MWh	97.4	98.91 MWh	2.29 MWh	0.00 kWh
Average	2 WSHP	5000 L	99.05 MWh	77.28 MWh	16.77 MWh	80.96	80.96 MWh	12.57 MWh	17.94 MWh
Average	2 WSHP	10000 L	99.05 MWh	77.28 MWh	29.11 MWh	86.8	93.23 MWh	12.71 MWh	4.79 MWh
Average	2 WSHP	15000 L	99.05 MWh	77.28 MWh	34.36 MWh	89.14	98.60 MWh	12.60 MWh	309.45 kWh
Average	2 WSHP	20000 L	99.05 MWh	77.28 MWh	34.78 MWh	89.18	98.91 MWh	12.70 MWh	0.00 kWh
Average	2 WSHP	25000 L	99.05 MWh	77.28 MWh	34.67 MWh	89.2	98.91 MWh	12.60 MWh	0.00 kWh

Average	2 WSHP	30000 L	99.05 MWh	77.28 MWh	34.71 MWh	89.19	98.91 MWh	12.64 MWh	0.00 kWh
Average	2 WSHP	35000 L	99.05 MWh	77.28 MWh	34.67 MWh	89.2	98.91 MWh	12.61 MWh	0.00 kWh
Average	2 WSHP	40000 L	99.05 MWh	77.28 MWh	34.75 MWh	89.19	98.91 MWh	12.68 MWh	0.00 kWh
Average	2 WSHP	45000 L	99.05 MWh	77.28 MWh	34.67 MWh	89.2	98.91 MWh	12.60 MWh	0.00 kWh
Average	3 WSHP	5000 L	99.05 MWh	115.92 MWh	9.63 MWh	79.54	95.68 MWh	29.03 MWh	3.10 MWh
Average	3 WSHP	10000 L	99.05 MWh	115.92 MWh	12.84 MWh	80.53	98.91 MWh	29.17 MWh	0.00 kWh
Average	3 WSHP	15000 L	99.05 MWh	115.92 MWh	12.81 MWh	80.53	98.91 MWh	29.14 MWh	0.00 Wh
Average	3 WSHP	20000 L	99.05 MWh	115.92 MWh	12.83 MWh	80.54	98.91 MWh	29.17 MWh	0.00 kWh
Average	3 WSHP	25000 L	99.05 MWh	115.92 MWh	12.77 MWh	80.55	98.91 MWh	29.12 MWh	0.00 Wh
Average	3 WSHP	30000 L	99.05 MWh	115.92 MWh	12.82 MWh	80.54	98.91 MWh	29.16 MWh	0.00 kWh
Average	3 WSHP	35000 L	99.05 MWh	115.92 MWh	12.81 MWh	80.55	98.91 MWh	29.16 MWh	0.00 Wh
Average	3 WSHP	40000 L	99.05 MWh	115.92 MWh	12.80 MWh	80.55	98.91 MWh	29.15 MWh	0.00 kWh
Average	3 WSHP	45000 L	99.05 MWh	115.92 MWh	12.77 MWh	80.55	98.91 MWh	29.12 MWh	0.00 Wh
Average	4 WSHP	5000 L	99.05 MWh	154.56 MWh	2.84 MWh	72.29	98.91 MWh	57.58 MWh	0.92 Wh
Average	4 WSHP	10000 L	99.05 MWh	154.56 MWh	2.87 MWh	72.3	98.91 MWh	57.61 MWh	0.92 Wh
Average	4 WSHP	15000 L	99.05 MWh	154.56 MWh	2.82 MWh	72.31	98.91 MWh	57.57 MWh	0.00 Wh
Average	4 WSHP	20000 L	99.05 MWh	154.56 MWh	2.86 MWh	72.31	98.91 MWh	57.61 MWh	0.92 Wh
Average	4 WSHP	25000 L	99.05 MWh	154.56 MWh	2.80 MWh	72.32	98.91 MWh	57.56 MWh	0.00 Wh
Average	4 WSHP	30000 L	99.05 MWh	154.56 MWh	2.85 MWh	72.32	98.91 MWh	57.61 MWh	0.92 Wh
Average	4 WSHP	35000 L	99.05 MWh	154.56 MWh	2.79 MWh	72.32	98.91 MWh	57.56 MWh	0.00 Wh
Average	4 WSHP	40000 L	99.05 MWh	154.56 MWh	2.84 MWh	72.32	98.91 MWh	57.60 MWh	0.92 Wh
Average	4 WSHP	45000 L	99.05 MWh	154.56 MWh	2.79 MWh	72.32	98.91 MWh	57.56 MWh	0.00 Wh
BREEAM Excellent	1 WSHP	NULL	74.29 MWh	38.64 MWh	0.00 Wh	57.28	34.28 MWh	4.00 MWh	39.27 MWh
BREEAM Excellent	2 WSHP	NULL	74.29 MWh	77.28 MWh	0.00 Wh	76.23	59.60 MWh	16.59 MWh	13.87 MWh
BREEAM Excellent	3 WSHP	NULL	74.29 MWh	115.92 MWh	0.00 Wh	71.7	72.00 MWh	42.48 MWh	1.88 MWh
BREEAM Excellent	4 WSHP	NULL	74.29 MWh	154.56 MWh	0.00 Wh	62.68	74.18 MWh	79.46 MWh	0.00 Wh

BREEAM Excellent	1 WSHP	5000 L	74.29 MWh	38.64 MWh	18.89 MWh	76.74	53.36 MWh	3.93 MWh	20.33 MWh
BREEAM Excellent	1 WSHP	10000 L	74.29 MWh	38.64 MWh	33.80 MWh	89.97	68.11 MWh	4.10 MWh	6.07 MWh
BREEAM Excellent	1 WSHP	15000 L	74.29 MWh	38.64 MWh	39.58 MWh	94.78	74.08 MWh	3.92 MWh	96.21 kWh
BREEAM Excellent	1 WSHP	20000 L	74.29 MWh	38.64 MWh	39.84 MWh	94.74	74.18 MWh	4.08 MWh	0.01 kWh
BREEAM Excellent	1 WSHP	25000 L	74.29 MWh	38.64 MWh	39.68 MWh	94.79	74.18 MWh	3.92 MWh	0.01 kWh
BREEAM Excellent	1 WSHP	30000 L	74.29 MWh	38.64 MWh	39.85 MWh	94.74	74.18 MWh	4.09 MWh	0.01 kWh
BREEAM Excellent	1 WSHP	35000 L	74.29 MWh	38.64 MWh	39.68 MWh	94.8	74.18 MWh	3.92 MWh	0.01 kWh
BREEAM Excellent	1 WSHP	40000 L	74.29 MWh	38.64 MWh	39.81 MWh	94.75	74.18 MWh	4.04 MWh	0.01 kWh
BREEAM Excellent	1 WSHP	45000 L	74.29 MWh	38.64 MWh	39.66 MWh	94.8	74.18 MWh	3.90 MWh	0.01 kWh
BREEAM Excellent	2 WSHP	5000 L	74.29 MWh	77.28 MWh	11.67 MWh	82.2	71.33 MWh	16.58 MWh	2.71 MWh
BREEAM Excellent	2 WSHP	10000 L	74.29 MWh	77.28 MWh	14.54 MWh	83.43	74.18 MWh	16.60 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	15000 L	74.29 MWh	77.28 MWh	14.48 MWh	83.44	74.18 MWh	17.13 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	20000 L	74.29 MWh	77.28 MWh	14.53 MWh	83.43	74.18 MWh	16.60 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	25000 L	74.29 MWh	77.28 MWh	14.46 MWh	83.45	74.18 MWh	17.13 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	30000 L	74.29 MWh	77.28 MWh	14.53 MWh	83.44	74.18 MWh	16.60 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	35000 L	74.29 MWh	77.28 MWh	14.48 MWh	83.46	74.18 MWh	17.14 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	40000 L	74.29 MWh	77.28 MWh	14.54 MWh	83.45	74.18 MWh	16.61 MWh	0.00 kWh
BREEAM Excellent	2 WSHP	45000 L	74.29 MWh	77.28 MWh	14.46 MWh	83.46	74.18 MWh	17.13 MWh	0.00 kWh
BREEAM Excellent	3 WSHP	5000 L	74.29 MWh	115.92 MWh	2.16 MWh	72.3	74.18 MWh	42.88 MWh	0.31 Wh
BREEAM Excellent	3 WSHP	10000 L	74.29 MWh	115.92 MWh	2.15 MWh	72.3	74.18 MWh	42.88 MWh	0.31 Wh
BREEAM Excellent	3 WSHP	15000 L	74.29 MWh	115.92 MWh	2.14 MWh	72.31	74.18 MWh	43.21 MWh	0.00 Wh
BREEAM Excellent	3 WSHP	20000 L	74.29 MWh	115.92 MWh	2.14 MWh	72.32	74.18 MWh	42.87 MWh	0.31 Wh
BREEAM Excellent	3 WSHP	25000 L	74.29 MWh	115.92 MWh	2.12 MWh	72.32	74.18 MWh	43.20 MWh	0.00 Wh
BREEAM Excellent	3 WSHP	30000 L	74.29 MWh	115.92 MWh	2.13 MWh	72.32	74.18 MWh	42.87 MWh	0.31 Wh
BREEAM Excellent	3 WSHP	35000 L	74.29 MWh	115.92 MWh	2.12 MWh	72.32	74.18 MWh	43.20 MWh	0.00 Wh
BREEAM Excellent	3 WSHP	40000 L	74.29 MWh	115.92 MWh	2.12 MWh	72.33	74.18 MWh	42.87 MWh	0.31 Wh

BREEAM Excellent	3 WSHP	45000 L	74.29 MWh	115.92 MWh	2.11 MWh	72.33	74.18 MWh	43.19 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	5000 L	74.29 MWh	154.56 MWh	-13722.90 Wh	62.68	74.18 MWh	79.45 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	10000 L	74.29 MWh	154.56 MWh	-27445.80 Wh	62.69	74.18 MWh	79.45 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	15000 L	74.29 MWh	154.56 MWh	-40711.27 Wh	62.7	74.18 MWh	79.44 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	20000 L	74.29 MWh	154.56 MWh	-41168.70 Wh	62.7	74.18 MWh	79.44 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	25000 L	74.29 MWh	154.56 MWh	-54205.46 Wh	62.7	74.18 MWh	79.43 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	30000 L	74.29 MWh	154.56 MWh	-54891.60 Wh	62.7	74.18 MWh	79.43 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	35000 L	74.29 MWh	154.56 MWh	-67699.64 Wh	62.71	74.18 MWh	79.43 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	40000 L	74.29 MWh	154.56 MWh	-54891.60 Wh	62.7	74.18 MWh	79.43 MWh	0.00 Wh
BREEAM Excellent	4 WSHP	45000 L	74.29 MWh	154.56 MWh	-67699.64 Wh	62.71	74.18 MWh	79.43 MWh	0.00 Wh
BREEAM Outstanding	1 WSHP	NULL	59.43 MWh	38.64 MWh	0.00 Wh	65.01	33.08 MWh	5.07 MWh	25.85 MWh
BREEAM Outstanding	2 WSHP	NULL	59.43 MWh	77.28 MWh	0.00 Wh	75.49	54.39 MWh	22.06 MWh	4.38 MWh
BREEAM Outstanding	3 WSHP	NULL	59.43 MWh	115.92 MWh	0.00 Wh	64.87	59.17 MWh	55.91 MWh	85.56 kWh
BREEAM Outstanding	4 WSHP	NULL	59.43 MWh	154.56 MWh	0.00 Wh	54.87	59.34 MWh	94.30 MWh	0.00 Wh
BREEAM Outstanding	1 WSHP	5000 L	59.43 MWh	38.64 MWh	17.16 MWh	84.25	50.26 MWh	5.28 MWh	9.08 MWh
BREEAM Outstanding	1 WSHP	10000 L	59.43 MWh	38.64 MWh	25.98 MWh	91.98	59.14 MWh	5.23 MWh	155.44 kWh
BREEAM Outstanding	1 WSHP	15000 L	59.43 MWh	38.64 MWh	26.21 MWh	92.01	59.34 MWh	5.29 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	20000 L	59.43 MWh	38.64 MWh	26.20 MWh	92.02	59.34 MWh	5.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	25000 L	59.43 MWh	38.64 MWh	26.23 MWh	92	59.34 MWh	5.30 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	30000 L	59.43 MWh	38.64 MWh	26.22 MWh	92	59.34 MWh	5.26 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	35000 L	59.43 MWh	38.64 MWh	26.16 MWh	92.05	59.34 MWh	5.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	40000 L	59.43 MWh	38.64 MWh	26.20 MWh	92.02	59.34 MWh	5.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	45000 L	59.43 MWh	38.64 MWh	26.12 MWh	92.08	59.34 MWh	5.20 MWh	0.00 kWh
BREEAM Outstanding	2 WSHP	5000 L	59.43 MWh	77.28 MWh	4.88 MWh	77.73	59.34 MWh	22.36 MWh	0.64 Wh
BREEAM Outstanding	2 WSHP	10000 L	59.43 MWh	77.28 MWh	4.91 MWh	77.74	59.34 MWh	22.38 MWh	0.64 Wh
BREEAM Outstanding	2 WSHP	15000 L	59.43 MWh	77.28 MWh	4.87 MWh	77.75	59.34 MWh	22.36 MWh	0.00 Wh

BREEAM Outstanding	2 WSHP	20000 L	59.43 MWh	77.28 MWh	4.90 MWh	77.74	59.34 MWh	22.38 MWh	0.64 Wh
BREEAM Outstanding	2 WSHP	25000 L	59.43 MWh	77.28 MWh	4.86 MWh	77.75	59.34 MWh	22.35 MWh	0.00 Wh
BREEAM Outstanding	2 WSHP	30000 L	59.43 MWh	77.28 MWh	4.90 MWh	77.75	59.34 MWh	22.38 MWh	0.64 Wh
BREEAM Outstanding	2 WSHP	35000 L	59.43 MWh	77.28 MWh	4.85 MWh	77.76	59.34 MWh	22.35 MWh	0.00 Wh
BREEAM Outstanding	2 WSHP	40000 L	59.43 MWh	77.28 MWh	4.89 MWh	77.76	59.34 MWh	22.37 MWh	0.64 Wh
BREEAM Outstanding	2 WSHP	45000 L	59.43 MWh	77.28 MWh	4.85 MWh	77.77	59.34 MWh	22.35 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	5000 L	59.43 MWh	115.92 MWh	160.91 kWh	64.92	59.34 MWh	56.05 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	10000 L	59.43 MWh	115.92 MWh	150.70 kWh	64.92	59.34 MWh	56.05 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	15000 L	59.43 MWh	115.92 MWh	140.83 kWh	64.93	59.34 MWh	56.04 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	20000 L	59.43 MWh	115.92 MWh	140.49 kWh	64.93	59.34 MWh	56.04 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	25000 L	59.43 MWh	115.92 MWh	130.78 kWh	64.94	59.34 MWh	56.04 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	30000 L	59.43 MWh	115.92 MWh	130.27 kWh	64.94	59.34 MWh	56.04 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	35000 L	59.43 MWh	115.92 MWh	120.74 kWh	64.94	59.34 MWh	56.03 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	40000 L	59.43 MWh	115.92 MWh	120.06 kWh	64.94	59.34 MWh	56.03 MWh	0.00 Wh
BREEAM Outstanding	3 WSHP	45000 L	59.43 MWh	115.92 MWh	110.70 kWh	64.95	59.34 MWh	56.03 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	5000 L	59.43 MWh	154.56 MWh	-14044.99 Wh	54.88	59.34 MWh	94.29 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	10000 L	59.43 MWh	154.56 MWh	-28089.98 Wh	54.88	59.34 MWh	94.28 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	15000 L	59.43 MWh	154.56 MWh	-41666.81 Wh	54.89	59.34 MWh	94.28 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	20000 L	59.43 MWh	154.56 MWh	-42134.98 Wh	54.89	59.34 MWh	94.28 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	25000 L	59.43 MWh	154.56 MWh	-55477.72 Wh	54.9	59.34 MWh	94.27 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	30000 L	59.43 MWh	154.56 MWh	-56179.97 Wh	54.9	59.34 MWh	94.27 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	35000 L	59.43 MWh	154.56 MWh	-69288.63 Wh	54.9	59.34 MWh	94.26 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	40000 L	59.43 MWh	154.56 MWh	-56179.97 Wh	54.9	59.34 MWh	94.27 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	45000 L	59.43 MWh	154.56 MWh	-69288.63 Wh	54.9	59.34 MWh	94.26 MWh	0.00 Wh
SE Benchmark	1 WSHP	NULL	27.96 MWh	38.64 MWh	0.00 Wh	74.48	26.16 MWh	12.01 MWh	1.53 MWh
SE Benchmark	2 WSHP	NULL	27.96 MWh	77.28 MWh	0.00 Wh	52.74	27.91 MWh	48.91 MWh	0.00 Wh

SE Benchmark	3 WSHP	NULL	27.96 MWh	115.92 MWh	0.00 Wh	39.51	27.91 MWh	87.32 MWh	0.00 Wh
SE Benchmark	4 WSHP	NULL	27.96 MWh	154.56 MWh	0.00 Wh	31.49	27.91 MWh	125.73 MWh	0.00 Wh
SE Benchmark	1 WSHP	5000 L	27.96 MWh	38.64 MWh	1.73 MWh	76.01	27.91 MWh	12.23 MWh	0.00 Wh
SE Benchmark	1 WSHP	10000 L	27.96 MWh	38.64 MWh	1.72 MWh	76.02	27.91 MWh	12.22 MWh	0.00 Wh
SE Benchmark	1 WSHP	15000 L	27.96 MWh	38.64 MWh	1.71 MWh	76.03	27.91 MWh	12.22 MWh	0.00 Wh
SE Benchmark	1 WSHP	20000 L	27.96 MWh	38.64 MWh	1.71 MWh	76.03	27.91 MWh	12.22 MWh	0.00 Wh
SE Benchmark	1 WSHP	25000 L	27.96 MWh	38.64 MWh	1.71 MWh	76.05	27.91 MWh	12.22 MWh	0.00 Wh
SE Benchmark	1 WSHP	30000 L	27.96 MWh	38.64 MWh	1.73 MWh	76.03	27.91 MWh	12.23 MWh	0.00 Wh
SE Benchmark	1 WSHP	35000 L	27.96 MWh	38.64 MWh	1.71 MWh	76.05	27.91 MWh	12.22 MWh	0.00 Wh
SE Benchmark	1 WSHP	40000 L	27.96 MWh	38.64 MWh	1.73 MWh	76.03	27.91 MWh	12.24 MWh	0.00 Wh
SE Benchmark	1 WSHP	45000 L	27.96 MWh	38.64 MWh	1.71 MWh	76.05	27.91 MWh	12.22 MWh	0.00 Wh
SE Benchmark	2 WSHP	5000 L	27.96 MWh	77.28 MWh	-14121.32 Wh	52.76	27.91 MWh	48.90 MWh	0.00 Wh
SE Benchmark	2 WSHP	10000 L	27.96 MWh	77.28 MWh	-21181.97 Wh	52.76	27.91 MWh	48.90 MWh	0.00 Wh
SE Benchmark	2 WSHP	15000 L	27.96 MWh	77.28 MWh	-34597.23 Wh	52.77	27.91 MWh	48.89 MWh	0.00 Wh
SE Benchmark	2 WSHP	20000 L	27.96 MWh	77.28 MWh	-28242.63 Wh	52.77	27.91 MWh	48.89 MWh	0.00 Wh
SE Benchmark	2 WSHP	25000 L	27.96 MWh	77.28 MWh	-41422.53 Wh	52.78	27.91 MWh	48.89 MWh	0.00 Wh
SE Benchmark	2 WSHP	30000 L	27.96 MWh	77.28 MWh	-35303.29 Wh	52.77	27.91 MWh	48.89 MWh	0.00 Wh
SE Benchmark	2 WSHP	35000 L	27.96 MWh	77.28 MWh	-48247.83 Wh	52.78	27.91 MWh	48.88 MWh	0.00 Wh
SE Benchmark	2 WSHP	40000 L	27.96 MWh	77.28 MWh	-35303.29 Wh	52.77	27.91 MWh	48.89 MWh	0.00 Wh
SE Benchmark	2 WSHP	45000 L	27.96 MWh	77.28 MWh	-48247.83 Wh	52.78	27.91 MWh	48.88 MWh	0.00 Wh
SE Benchmark	3 WSHP	5000 L	27.96 MWh	115.92 MWh	-10893.99 Wh	39.51	27.91 MWh	87.31 MWh	0.00 Wh
SE Benchmark	3 WSHP	10000 L	27.96 MWh	115.92 MWh	-21787.98 Wh	39.52	27.91 MWh	87.31 MWh	0.00 Wh
SE Benchmark	3 WSHP	15000 L	27.96 MWh	115.92 MWh	-32318.84 Wh	39.52	27.91 MWh	87.30 MWh	0.00 Wh
SE Benchmark	3 WSHP	20000 L	27.96 MWh	115.92 MWh	-32681.98 Wh	39.52	27.91 MWh	87.30 MWh	0.00 Wh
SE Benchmark	3 WSHP	25000 L	27.96 MWh	115.92 MWh	-43031.27 Wh	39.53	27.91 MWh	87.29 MWh	0.00 Wh
SE Benchmark	3 WSHP	30000 L	27.96 MWh	115.92 MWh	-43575.97 Wh	39.53	27.91 MWh	87.29 MWh	0.00 Wh

SE Benchmark	3 WSHP	35000 L	27.96 MWh	115.92 MWh	-53743.69 Wh	39.53	27.91 MWh	87.29 MWh	0.00 Wh
SE Benchmark	3 WSHP	40000 L	27.96 MWh	115.92 MWh	-54469.96 Wh	39.53	27.91 MWh	87.29 MWh	0.00 Wh
SE Benchmark	3 WSHP	45000 L	27.96 MWh	115.92 MWh	-64456.12 Wh	39.54	27.91 MWh	87.28 MWh	0.00 Wh
SE Benchmark	4 WSHP	5000 L	27.96 MWh	154.56 MWh	-14727.33 Wh	31.49	27.91 MWh	125.72 MWh	0.00 Wh
SE Benchmark	4 WSHP	10000 L	27.96 MWh	154.56 MWh	-29454.65 Wh	31.5	27.91 MWh	125.71 MWh	0.00 Wh
SE Benchmark	4 WSHP	15000 L	27.96 MWh	154.56 MWh	-43691.07 Wh	31.5	27.91 MWh	125.70 MWh	0.00 Wh
SE Benchmark	4 WSHP	20000 L	27.96 MWh	154.56 MWh	-44181.97 Wh	31.5	27.91 MWh	125.70 MWh	0.00 Wh
SE Benchmark	4 WSHP	25000 L	27.96 MWh	154.56 MWh	-58172.94 Wh	31.5	27.91 MWh	125.70 MWh	0.00 Wh
SE Benchmark	4 WSHP	30000 L	27.96 MWh	154.56 MWh	-58909.30 Wh	31.5	27.91 MWh	125.70 MWh	0.00 Wh
SE Benchmark	4 WSHP	35000 L	27.96 MWh	154.56 MWh	-72654.81 Wh	31.51	27.91 MWh	125.69 MWh	0.00 Wh
SE Benchmark	4 WSHP	40000 L	27.96 MWh	154.56 MWh	-58909.30 Wh	31.5	27.91 MWh	125.70 MWh	0.00 Wh
SE Benchmark	4 WSHP	45000 L	27.96 MWh	154.56 MWh	-72654.81 Wh	31.51	27.91 MWh	125.69 MWh	0.00 Wh

Table 4.2 below displays the thermal results from Merit for a week in August that represents the ‘high summer’ period as described in the report (15th to 21st August 1983).

Table 4.2- 'High Summer' Electrical Simulation Results from Merit

Best Matching Electrical Profile	RE Supply Name	Aux Supply Size	Demand	RE Supply	Aux Supply	Match Rate (%)	Energy Delivered	Energy Surplus	Energy Deficit
BREEAM Outstanding	1 WSHP	NULL	42.60 MWh	38.64 MWh	0.00 Wh	74.34	30.95 MWh	7.18 MWh	11.31 MWh
BREEAM Outstanding	1 WSHP	5000 L	42.60 MWh	38.64 MWh	11.01 MWh	86.14	42.00 MWh	7.21 MWh	540.20 kWh
BREEAM Outstanding	1 WSHP	10000 L	42.60 MWh	38.64 MWh	11.57 MWh	86.4	42.54 MWh	7.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	15000 L	42.60 MWh	38.64 MWh	11.52 MWh	86.43	42.54 MWh	7.41 MWh	0.00 Wh
BREEAM Outstanding	1 WSHP	20000 L	42.60 MWh	38.64 MWh	11.57 MWh	86.4	42.54 MWh	7.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	25000 L	42.60 MWh	38.64 MWh	11.52 MWh	86.43	42.54 MWh	7.41 MWh	0.00 Wh
BREEAM Outstanding	1 WSHP	30000 L	42.60 MWh	38.64 MWh	11.57 MWh	86.4	42.54 MWh	7.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	35000 L	42.60 MWh	38.64 MWh	11.52 MWh	86.43	42.54 MWh	7.41 MWh	0.00 Wh
BREEAM Outstanding	1 WSHP	40000 L	42.60 MWh	38.64 MWh	11.57 MWh	86.4	42.54 MWh	7.24 MWh	0.00 kWh
BREEAM Outstanding	1 WSHP	45000 L	42.60 MWh	38.64 MWh	11.52 MWh	86.43	42.54 MWh	7.41 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	5000 L	42.60 MWh	154.56 MWh	-14478.78 Wh	43.66	42.54 MWh	111.09 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	10000 L	42.60 MWh	154.56 MWh	-28957.57 Wh	43.66	42.54 MWh	111.09 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	15000 L	42.60 MWh	154.56 MWh	-42953.72 Wh	43.67	42.54 MWh	111.08 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	20000 L	42.60 MWh	154.56 MWh	-28957.57 Wh	43.66	42.54 MWh	111.09 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	25000 L	42.60 MWh	154.56 MWh	-42953.72 Wh	43.67	42.54 MWh	111.08 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	30000 L	42.60 MWh	154.56 MWh	-28957.57 Wh	43.66	42.54 MWh	111.09 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	35000 L	42.60 MWh	154.56 MWh	-42953.72 Wh	43.67	42.54 MWh	111.08 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	40000 L	42.60 MWh	154.56 MWh	-28957.57 Wh	43.66	42.54 MWh	111.09 MWh	0.00 Wh
BREEAM Outstanding	4 WSHP	45000 L	42.60 MWh	154.56 MWh	-42953.72 Wh	43.67	42.54 MWh	111.08 MWh	0.00 Wh

The results for the electrical simulations during the ‘winter’ week (10th to 16th January 1983) are listed below in Table 4.3 for demand combinations including either one WSHP or four WSHPs.

Table 4.3- 'Winter' Electrical Simulation Results from Merit

Electrical Profile	RE Supply Name	Aux Supply Size	Consumption	RE Supply	Aux Supply	Match Rate (%)	Energy Delivered	Energy Surplus	Energy Deficit
Average + 1 WSHP	480 YL245P	NULL	32.64 MWh	1.14 MWh	0.00 Wh	11.75	1.14 MWh	0.00 Wh	31.37 MWh
BREEAM Excellent + 1 WSHP	480 YL245P	NULL	25.67 MWh	1.14 MWh	0.00 Wh	14.54	1.14 MWh	0.00 Wh	24.42 MWh
BREEAM Outstanding + 1 WSHP	480 YL245P	NULL	21.48 MWh	1.14 MWh	0.00 Wh	16.93	1.14 MWh	0.00 Wh	20.26 MWh
SE Benchmark + 1 WSHP	480 YL245P	NULL	35.17 MWh	1.14 MWh	0.00 Wh	10.99	1.14 MWh	0.00 Wh	33.90 MWh
Average + 4 WSHP	480 YL245P	NULL	46.88 MWh	1.14 MWh	0.00 Wh	8.49	1.14 MWh	0.00 Wh	45.53 MWh
BREEAM Excellent + 4 WSHP	480 YL245P	NULL	39.90 MWh	1.14 MWh	0.00 Wh	9.83	1.14 MWh	0.00 Wh	38.58 MWh
BREEAM Outstanding + 4 WSHP	480 YL245P	NULL	35.72 MWh	1.14 MWh	0.00 Wh	10.85	1.14 MWh	0.00 Wh	34.41 MWh
SE Benchmark + 4 WSHP	480 YL245P	NULL	49.41 MWh	1.14 MWh	0.00 Wh	8.09	1.14 MWh	0.00 Wh	48.05 MWh
Average + 1 WSHP	1814 YL245P	NULL	32.64 MWh	4.30 MWh	0.00 Wh	33.4	4.20 MWh	76.61 kWh	28.29 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P	NULL	25.67 MWh	4.30 MWh	0.00 Wh	38.34	3.95 MWh	268.28 kWh	21.49 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P	NULL	21.48 MWh	4.30 MWh	0.00 Wh	41.73	3.60 MWh	597.61 kWh	17.56 MWh
SE Benchmark + 1 WSHP	1814 YL245P	NULL	35.17 MWh	4.30 MWh	0.00 Wh	31.85	4.22 MWh	40.05 kWh	30.79 MWh
Average + 4 WSHP	1814 YL245P	NULL	46.88 MWh	4.30 MWh	0.00 Wh	26.02	4.29 MWh	6.88 kWh	42.32 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P	NULL	39.90 MWh	4.30 MWh	0.00 Wh	29.04	4.24 MWh	32.18 kWh	35.45 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P	NULL	35.72 MWh	4.30 MWh	0.00 Wh	31.14	4.20 MWh	73.30 kWh	31.32 MWh
SE Benchmark + 4 WSHP	1814 YL245P	NULL	49.41 MWh	4.30 MWh	0.00 Wh	25.06	4.30 MWh	0.00 Wh	44.89 MWh
Average + 1 WSHP	12 QR5	NULL	32.64 MWh	2.77 MWh	0.00 Wh	17.22	2.76 MWh	0.00 Wh	29.75 MWh
BREEAM Excellent + 1 WSHP	12 QR5	NULL	25.67 MWh	2.77 MWh	0.00 Wh	21.23	2.76 MWh	0.00 Wh	22.80 MWh
BREEAM Outstanding + 1 WSHP	12 QR5	NULL	21.48 MWh	2.77 MWh	0.00 Wh	24.66	2.76 MWh	0.00 Wh	18.64 MWh

SE Benchmark + 1 WSHP	12 QR5	NULL	35.17 MWh	2.77 MWh	0.00 Wh	16.11	2.76 MWh	0.00 Wh	32.28 MWh
Average + 4 WSHP	12 QR5	NULL	46.88 MWh	2.77 MWh	0.00 Wh	12.94	2.76 MWh	0.00 Wh	43.91 MWh
BREEAM Excellent + 4 WSHP	12 QR5	NULL	39.90 MWh	2.77 MWh	0.00 Wh	15.06	2.76 MWh	0.00 Wh	36.96 MWh
BREEAM Outstanding + 4 WSHP	12 QR5	NULL	35.72 MWh	2.77 MWh	0.00 Wh	16.68	2.76 MWh	0.00 Wh	32.79 MWh
SE Benchmark + 4 WSHP	12 QR5	NULL	49.41 MWh	2.77 MWh	0.00 Wh	12.31	2.76 MWh	0.00 Wh	46.43 MWh
Average + 1 WSHP	1814 YL245P + 12 QR5	NULL	32.64 MWh	7.07 MWh	0.00 Wh	40.69	6.93 MWh	92.43 kWh	25.55 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 QR5	NULL	25.67 MWh	7.07 MWh	0.00 Wh	46.47	6.61 MWh	401.48 kWh	18.66 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 QR5	NULL	21.48 MWh	7.07 MWh	0.00 Wh	50.3	6.17 MWh	720.40 kWh	14.96 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 QR5	NULL	35.17 MWh	7.07 MWh	0.00 Wh	38.85	6.97 MWh	46.41 kWh	28.05 MWh
Average + 4 WSHP	1814 YL245P + 12 QR5	NULL	46.88 MWh	7.07 MWh	0.00 Wh	32.15	7.03 MWh	13.23 kWh	39.58 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 QR5	NULL	39.90 MWh	7.07 MWh	0.00 Wh	35.86	6.98 MWh	38.54 kWh	32.71 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 QR5	NULL	35.72 MWh	7.07 MWh	0.00 Wh	38.42	6.93 MWh	95.22 kWh	28.56 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 QR5	NULL	49.41 MWh	7.07 MWh	0.00 Wh	30.97	7.05 MWh	4.03 kWh	42.08 MWh
Average + 1 WSHP	1 WS110	NULL	32.64 MWh	351.49 kWh	0.00 Wh	2.41	350.17 kWh	0.00 Wh	32.16 MWh
BREEAM Excellent + 1 WSHP	1 WS110	NULL	25.67 MWh	351.49 kWh	0.00 Wh	3.07	350.17 kWh	0.00 Wh	25.21 MWh
BREEAM Outstanding + 1 WSHP	1 WS110	NULL	21.48 MWh	351.49 kWh	0.00 Wh	3.68	350.17 kWh	0.00 Wh	21.04 MWh
SE Benchmark + 1 WSHP	1 WS110	NULL	35.17 MWh	351.49 kWh	0.00 Wh	2.24	350.17 kWh	0.00 Wh	34.69 MWh
Average + 4 WSHP	1 WS110	NULL	46.88 MWh	351.49 kWh	0.00 Wh	1.75	350.17 kWh	0.00 Wh	46.31 MWh
BREEAM Excellent + 4 WSHP	1 WS110	NULL	39.90 MWh	351.49 kWh	0.00 Wh	2.07	350.17 kWh	0.00 Wh	39.37 MWh
BREEAM Outstanding + 4 WSHP	1 WS110	NULL	35.72 MWh	351.49 kWh	0.00 Wh	2.32	350.17 kWh	0.00 Wh	35.20 MWh
SE Benchmark + 4 WSHP	1 WS110	NULL	49.41 MWh	351.49 kWh	0.00 Wh	1.66	350.17 kWh	0.00 Wh	48.84 MWh
Average + 1 WSHP	12 WS110	NULL	32.64 MWh	4.22 MWh	0.00 Wh	24.19	4.20 MWh	0.00 Wh	28.31 MWh
BREEAM Excellent + 1 WSHP	12 WS110	NULL	25.67 MWh	4.22 MWh	0.00 Wh	29.38	4.17 MWh	18.30 kWh	21.36 MWh

BREEAM Outstanding + 1 WSHP	12 WS110	NULL	21.48 MWh	4.22 MWh	0.00 Wh	33.68	4.12 MWh	60.46 kWh	17.25 MWh
SE Benchmark + 1 WSHP	12 WS110	NULL	35.17 MWh	4.22 MWh	0.00 Wh	22.72	4.20 MWh	0.00 Wh	30.83 MWh
Average + 4 WSHP	12 WS110	NULL	46.88 MWh	4.22 MWh	0.00 Wh	18.44	4.20 MWh	0.00 Wh	42.46 MWh
BREEAM Excellent + 4 WSHP	12 WS110	NULL	39.90 MWh	4.22 MWh	0.00 Wh	21.3	4.20 MWh	0.00 Wh	35.51 MWh
BREEAM Outstanding + 4 WSHP	12 WS110	NULL	35.72 MWh	4.22 MWh	0.00 Wh	23.47	4.20 MWh	0.00 Wh	31.34 MWh
SE Benchmark + 4 WSHP	12 WS110	NULL	49.41 MWh	4.22 MWh	0.00 Wh	17.58	4.20 MWh	0.00 Wh	44.99 MWh
Average + 1 WSHP	2 WS138	NULL	35.17 MWh	1.41 MWh	0.00 Wh	8.55	1.40 MWh	0.00 Wh	33.64 MWh
BREEAM Excellent + 1 WSHP	2 WS138	NULL	21.48 MWh	1.41 MWh	0.00 Wh	13.62	1.40 MWh	0.00 Wh	19.99 MWh
BREEAM Outstanding + 1 WSHP	2 WS138	NULL	25.67 MWh	1.41 MWh	0.00 Wh	11.53	1.40 MWh	0.00 Wh	24.16 MWh
SE Benchmark + 1 WSHP	2 WS138	NULL	32.64 MWh	1.41 MWh	0.00 Wh	9.18	1.40 MWh	0.00 Wh	31.11 MWh
Average + 4 WSHP	2 WS138	NULL	46.88 MWh	1.41 MWh	0.00 Wh	6.75	1.40 MWh	0.00 Wh	45.26 MWh
BREEAM Excellent + 4 WSHP	2 WS138	NULL	39.90 MWh	1.41 MWh	0.00 Wh	7.92	1.40 MWh	0.00 Wh	38.32 MWh
BREEAM Outstanding + 4 WSHP	2 WS138	NULL	35.72 MWh	1.41 MWh	0.00 Wh	8.84	1.40 MWh	0.00 Wh	34.15 MWh
SE Benchmark + 4 WSHP	2 WS138	NULL	49.41 MWh	1.41 MWh	0.00 Wh	6.4	1.40 MWh	0.00 Wh	47.79 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	32.64 MWh	9.92 MWh	0.00 Wh	48.01	9.63 MWh	196.72 kWh	22.76 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	25.67 MWh	9.92 MWh	0.00 Wh	53.96	8.93 MWh	837.72 kWh	16.29 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	21.48 MWh	9.92 MWh	0.00 Wh	57.5	8.32 MWh	1.37 MWh	12.85 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	35.17 MWh	9.92 MWh	0.00 Wh	46.03	9.75 MWh	112.08 kWh	25.19 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	46.88 MWh	9.92 MWh	0.00 Wh	38.75	9.86 MWh	19.22 kWh	36.75 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	39.90 MWh	9.92 MWh	0.00 Wh	42.96	9.81 MWh	45.01 kWh	29.84 MWh

BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	35.72 MWh	9.92 MWh	0.00 Wh	45.81	9.65 MWh	193.61 kWh	25.75 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 2 WS138	NULL	49.41 MWh	9.92 MWh	0.00 Wh	37.39	9.88 MWh	10.02 kWh	39.25 MWh
Average + 1 WSHP	20 WS138	NULL	32.64 MWh	14.06 MWh	0.00 Wh	52.7	11.85 MWh	2.00 MWh	20.53 MWh
BREEAM Excellent + 1 WSHP	20 WS138	NULL	25.67 MWh	14.06 MWh	0.00 Wh	57.14	11.03 MWh	2.76 MWh	14.42 MWh
BREEAM Outstanding + 1 WSHP	20 WS138	NULL	21.48 MWh	14.06 MWh	0.00 Wh	58.98	10.34 MWh	3.56 MWh	10.94 MWh
SE Benchmark + 1 WSHP	20 WS138	NULL	35.17 MWh	14.06 MWh	0.00 Wh	51	12.07 MWh	1.80 MWh	22.82 MWh
Average + 4 WSHP	20 WS138	NULL	46.88 MWh	14.06 MWh	0.00 Wh	45.28	13.14 MWh	796.26 kWh	33.41 MWh
BREEAM Excellent + 4 WSHP	20 WS138	NULL	39.90 MWh	14.06 MWh	0.00 Wh	49.67	12.67 MWh	1.21 MWh	26.90 MWh
BREEAM Outstanding + 4 WSHP	20 WS138	NULL	35.72 MWh	14.06 MWh	0.00 Wh	52.54	12.34 MWh	1.53 MWh	23.08 MWh
SE Benchmark + 4 WSHP	20 WS138	NULL	49.41 MWh	14.06 MWh	0.00 Wh	43.82	13.24 MWh	685.93 kWh	35.90 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	32.64 MWh	23.98 MWh	0.00 Wh	63.22	18.10 MWh	5.51 MWh	14.09 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	25.67 MWh	23.98 MWh	0.00 Wh	61.98	16.08 MWh	7.53 MWh	9.12 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	21.48 MWh	23.98 MWh	0.00 Wh	59.07	14.52 MWh	9.07 MWh	6.52 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	35.17 MWh	23.98 MWh	0.00 Wh	62.9	18.66 MWh	4.92 MWh	16.02 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	46.88 MWh	23.98 MWh	0.00 Wh	59.85	20.62 MWh	3.07 MWh	25.84 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	39.90 MWh	23.98 MWh	0.00 Wh	62.4	19.58 MWh	4.03 MWh	19.76 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	35.72 MWh	23.98 MWh	0.00 Wh	63.32	18.80 MWh	4.73 MWh	16.39 MWh

SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	49.41 MWh	23.98 MWh	0.00 Wh	58.76	20.88 MWh	2.76 MWh	28.12 MWh
Average + 1 WSHP	56 WS138	NULL	32.64 MWh	39.37 MWh	0.00 Wh	53.17	21.51 MWh	17.17 MWh	10.63 MWh
BREEAM Excellent + 1 WSHP	56 WS138	NULL	25.67 MWh	39.37 MWh	0.00 Wh	47.67	18.82 MWh	19.75 MWh	6.41 MWh
BREEAM Outstanding + 1 WSHP	56 WS138	NULL	21.48 MWh	39.37 MWh	0.00 Wh	43.14	16.89 MWh	21.74 MWh	4.26 MWh
SE Benchmark + 1 WSHP	56 WS138	NULL	35.17 MWh	39.37 MWh	0.00 Wh	54.62	22.33 MWh	16.39 MWh	12.28 MWh
Average + 4 WSHP	56 WS138	NULL	46.88 MWh	39.37 MWh	0.00 Wh	59.18	26.25 MWh	12.61 MWh	19.99 MWh
BREEAM Excellent + 4 WSHP	56 WS138	NULL	39.90 MWh	39.37 MWh	0.00 Wh	57.34	24.45 MWh	14.39 MWh	14.93 MWh
BREEAM Outstanding + 4 WSHP	56 WS138	NULL	35.72 MWh	39.37 MWh	0.00 Wh	55.42	23.19 MWh	15.65 MWh	11.88 MWh
SE Benchmark + 4 WSHP	56 WS138	NULL	49.41 MWh	39.37 MWh	0.00 Wh	59.51	26.84 MWh	12.07 MWh	21.95 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	32.64 MWh	49.29 MWh	0.00 Wh	50.69	24.86 MWh	23.49 MWh	7.10 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	25.67 MWh	49.29 MWh	0.00 Wh	44.25	21.00 MWh	27.41 MWh	4.22 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	21.48 MWh	49.29 MWh	0.00 Wh	39.41	18.37 MWh	30.15 MWh	2.81 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	35.17 MWh	49.29 MWh	0.00 Wh	52.57	26.06 MWh	22.23 MWh	8.42 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	46.88 MWh	49.29 MWh	0.00 Wh	58.82	31.14 MWh	17.47 MWh	14.82 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	39.90 MWh	49.29 MWh	0.00 Wh	55.48	28.42 MWh	20.05 MWh	10.61 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 58 WS138	NULL	35.72 MWh	49.29 MWh	0.00 Wh	52.74	26.55 MWh	21.82 MWh	8.41 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 58	NULL	49.41 MWh	49.29 MWh	0.00 Wh	59.7	32.00 MWh	16.68 MWh	16.48 MWh

	WS138									
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	32.64 MWh	23.98 MWh	24.98 kWh	63.23	18.13 MWh	5.51 MWh	14.07 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	32.64 MWh	23.98 MWh	52.50 kWh	63.26	18.16 MWh	5.51 MWh	14.04 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	32.64 MWh	23.98 MWh	77.22 kWh	63.28	18.18 MWh	5.50 MWh	14.02 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	32.64 MWh	23.98 MWh	105.24 kWh	63.3	18.21 MWh	5.50 MWh	13.99 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	32.64 MWh	23.98 MWh	130.24 kWh	63.31	18.24 MWh	5.50 MWh	13.96 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	32.64 MWh	23.98 MWh	154.89 kWh	63.33	18.27 MWh	5.50 MWh	13.93 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	32.64 MWh	23.98 MWh	179.55 kWh	63.35	18.29 MWh	5.50 MWh	13.91 MWh
Average + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	32.64 MWh	23.98 MWh	207.60 kWh	63.37	18.32 MWh	5.50 MWh	13.88 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	25.67 MWh	23.98 MWh	28.90 kWh	62	16.11 MWh	7.54 MWh	9.09 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	25.67 MWh	23.98 MWh	55.84 kWh	62.02	16.14 MWh	7.54 MWh	9.06 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	25.67 MWh	23.98 MWh	81.02 kWh	62.04	16.17 MWh	7.54 MWh	9.03 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	25.67 MWh	23.98 MWh	112.90 kWh	62.06	16.20 MWh	7.53 MWh	9.00 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P +	25 iMiEV	25.67 MWh	23.98 MWh	138.04	62.08	16.23 MWh	7.53 MWh	8.97 MWh

	12 WS110 + 22 WS138				kWh				
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	25.67 MWh	23.98 MWh	170.00 kWh	62.1	16.26 MWh	7.53 MWh	8.94 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	25.67 MWh	23.98 MWh	194.97 kWh	62.13	16.29 MWh	7.53 MWh	8.91 MWh
BREEAM Excellent + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	25.67 MWh	23.98 MWh	219.95 kWh	62.17	16.32 MWh	7.53 MWh	8.89 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	21.48 MWh	23.98 MWh	25.08 kWh	59.09	14.54 MWh	9.06 MWh	6.50 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	21.48 MWh	23.98 MWh	57.01 kWh	59.11	14.58 MWh	9.06 MWh	6.47 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	21.48 MWh	23.98 MWh	89.08 kWh	59.13	14.61 MWh	9.06 MWh	6.44 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	21.48 MWh	23.98 MWh	115.20 kWh	59.15	14.64 MWh	9.06 MWh	6.41 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	21.48 MWh	23.98 MWh	140.57 kWh	59.19	14.68 MWh	9.05 MWh	6.38 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	21.48 MWh	23.98 MWh	165.53 kWh	59.21	14.71 MWh	9.05 MWh	6.36 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	21.48 MWh	23.98 MWh	197.59 kWh	59.25	14.74 MWh	9.05 MWh	6.34 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	21.48 MWh	23.98 MWh	222.56 kWh	59.28	14.76 MWh	9.04 MWh	6.31 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	35.17 MWh	23.98 MWh	24.90 kWh	62.92	18.68 MWh	4.92 MWh	16.00 MWh
SE Benchmark + 1 WSHP	1814 YL245P +	10 iMiEV	35.17 MWh	23.98 MWh	56.22 kWh	62.94	18.72 MWh	4.92 MWh	15.97 MWh

	12 WS110 + 22 WS138								
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	35.17 MWh	23.98 MWh	80.93 kWh	62.96	18.74 MWh	4.91 MWh	15.95 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	35.17 MWh	23.98 MWh	111.89 kWh	62.98	18.78 MWh	4.91 MWh	15.92 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	35.17 MWh	23.98 MWh	136.54 kWh	63	18.80 MWh	4.91 MWh	15.89 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	35.17 MWh	23.98 MWh	161.49 kWh	63.01	18.83 MWh	4.91 MWh	15.87 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	35.17 MWh	23.98 MWh	186.14 kWh	63.04	18.85 MWh	4.91 MWh	15.84 MWh
SE Benchmark + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	35.17 MWh	23.98 MWh	210.79 kWh	63.05	18.88 MWh	4.91 MWh	15.81 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	46.88 MWh	23.98 MWh	24.49 kWh	59.87	20.63 MWh	3.07 MWh	25.83 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	46.88 MWh	23.98 MWh	50.07 kWh	59.88	20.65 MWh	3.07 MWh	25.82 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	46.88 MWh	23.98 MWh	74.58 kWh	59.9	20.67 MWh	3.07 MWh	25.79 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	46.88 MWh	23.98 MWh	99.10 kWh	59.92	20.70 MWh	3.06 MWh	25.81 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	46.88 MWh	23.98 MWh	123.78 kWh	59.94	20.72 MWh	3.06 MWh	25.74 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	46.88 MWh	23.98 MWh	148.26 kWh	59.97	20.75 MWh	3.06 MWh	25.72 MWh

Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	46.88 MWh	23.98 MWh	172.75 kWh	59.99	20.77 MWh	3.06 MWh	25.69 MWh
Average + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	46.88 MWh	23.98 MWh	197.23 kWh	60.02	20.80 MWh	3.06 MWh	25.67 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	39.90 MWh	23.98 MWh	24.97 kWh	62.42	19.60 MWh	4.02 MWh	19.74 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	39.90 MWh	23.98 MWh	53.67 kWh	62.45	19.63 MWh	4.02 MWh	19.72 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	39.90 MWh	23.98 MWh	78.30 kWh	62.47	19.65 MWh	4.02 MWh	19.69 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	39.90 MWh	23.98 MWh	107.22 kWh	62.49	19.68 MWh	4.02 MWh	19.66 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	39.90 MWh	23.98 MWh	131.82 kWh	62.52	19.71 MWh	4.02 MWh	19.63 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	39.90 MWh	23.98 MWh	156.41 kWh	62.55	19.73 MWh	4.02 MWh	19.61 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	39.90 MWh	23.98 MWh	181.02 kWh	62.57	19.76 MWh	4.02 MWh	19.58 MWh
BREEAM Excellent + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	39.90 MWh	23.98 MWh	205.56 kWh	62.6	19.79 MWh	4.02 MWh	19.56 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	35.72 MWh	23.98 MWh	30.12 kWh	63.35	18.82 MWh	4.73 MWh	16.37 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	35.72 MWh	23.98 MWh	54.81 kWh	63.37	18.85 MWh	4.73 MWh	16.35 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	35.72 MWh	23.98 MWh	79.82 kWh	63.39	18.87 MWh	4.73 MWh	16.32 MWh

BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	35.72 MWh	23.98 MWh	104.48 kWh	63.42	18.90 MWh	4.72 MWh	16.29 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	35.72 MWh	23.98 MWh	129.15 kWh	63.45	18.92 MWh	4.72 MWh	16.27 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	35.72 MWh	23.98 MWh	153.82 kWh	63.47	18.95 MWh	4.72 MWh	16.24 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	35.72 MWh	23.98 MWh	178.43 kWh	63.5	18.98 MWh	4.72 MWh	16.22 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	35.72 MWh	23.98 MWh	203.03 kWh	63.53	19.00 MWh	4.72 MWh	16.19 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	49.41 MWh	23.98 MWh	24.48 kWh	58.78	20.90 MWh	2.76 MWh	28.11 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	49.41 MWh	23.98 MWh	49.12 kWh	58.79	20.91 MWh	2.76 MWh	28.09 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	49.41 MWh	23.98 MWh	73.62 kWh	58.82	20.94 MWh	2.76 MWh	28.07 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	49.41 MWh	23.98 MWh	98.13 kWh	58.84	20.96 MWh	2.76 MWh	28.04 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	49.41 MWh	23.98 MWh	122.59 kWh	58.85	20.99 MWh	2.76 MWh	28.02 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	49.41 MWh	23.98 MWh	147.04 kWh	58.88	21.01 MWh	2.76 MWh	27.99 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	49.41 MWh	23.98 MWh	171.50 kWh	58.9	21.04 MWh	2.76 MWh	27.97 MWh
SE Benchmark + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	49.41 MWh	23.98 MWh	195.95 kWh	58.92	21.06 MWh	2.76 MWh	27.94 MWh

The following, Table 4.4, includes the simulations results for the ‘BREEAM Outstanding’ profile simulations undertaken during the ‘high summer’ week period (15th to 21st August 1983).

Table 4.4- 'High Summer' Thermal Simulation Results from Merit

Best Matching Electrical Profile	RE Supply Name	Aux Supply Size	Demand	RE Supply	Aux Supply	Match Rate (%)	Energy Delivered	Energy Surplus	Energy Deficit
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	18.71 MWh	20.30 MWh	0.00 Wh	64.38	12.86 MWh	7.35 MWh	5.64 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	18.71 MWh	20.30 MWh	25.98 kWh	64.42	12.88 MWh	7.34 MWh	5.63 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	18.71 MWh	20.30 MWh	52.18 kWh	64.44	12.89 MWh	7.34 MWh	5.61 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	15 iMiEV	18.71 MWh	20.30 MWh	78.25 kWh	64.48	12.92 MWh	7.34 MWh	5.58 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	18.71 MWh	20.30 MWh	104.35 kWh	64.51	12.95 MWh	7.33 MWh	5.55 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	18.71 MWh	20.30 MWh	130.65 kWh	64.55	12.98 MWh	7.33 MWh	5.53 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	18.71 MWh	20.30 MWh	157.09 kWh	64.58	13.01 MWh	7.33 MWh	5.50 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	18.71 MWh	20.30 MWh	183.32 kWh	64.61	13.04 MWh	7.33 MWh	5.47 MWh
BREEAM Outstanding + 1 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	18.71 MWh	20.30 MWh	209.54 kWh	64.64	13.07 MWh	7.32 MWh	5.44 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	NULL	32.95 MWh	20.30 MWh	0.00 Wh	65.8	16.80 MWh	3.36 MWh	15.82 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	5 iMiEV	32.95 MWh	20.30 MWh	25.70 kWh	65.85	16.82 MWh	3.35 MWh	15.81 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	10 iMiEV	32.95 MWh	20.30 MWh	51.41 kWh	65.89	16.83 MWh	3.35 MWh	15.79 MWh
BREEAM Outstanding + 4	1814 YL245P + 12 WS110	15 iMiEV	32.95 MWh	20.30 MWh	77.11 kWh	65.93	16.85 MWh	3.35 MWh	15.78 MWh

WSHP	+ 22 WS138								
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	20 iMiEV	32.95 MWh	20.30 MWh	108.47 kWh	65.98	16.87 MWh	3.35 MWh	15.75 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	25 iMiEV	32.95 MWh	20.30 MWh	134.27 kWh	66.03	16.90 MWh	3.35 MWh	15.72 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	30 iMiEV	32.95 MWh	20.30 MWh	160.05 kWh	66.07	16.93 MWh	3.35 MWh	15.70 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	35 iMiEV	32.95 MWh	20.30 MWh	193.59 kWh	66.12	16.96 MWh	3.35 MWh	15.66 MWh
BREEAM Outstanding + 4 WSHP	1814 YL245P + 12 WS110 + 22 WS138	40 iMiEV	32.95 MWh	20.30 MWh	219.60 kWh	66.16	16.99 MWh	3.34 MWh	15.63 MWh

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