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Carron Valley- A Case Study for Community Wind Power

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the degree of Master of Science.

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In Loving Memory of

My Mother

This Dissertation is Dedicated

To

Carron Valley Community

Acknowledgements

My sincere gratitude goes to my supervisor Dr Nick Kelly- in the first place for offering me this project and exuding his confidence in me, for extending his invaluable guidance and for providing me the right direction whenever I was indecisive. I am highly indebted to Dr Andy Grant for his patience in answering my searching questions and constant encouragement and advice.

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Abstract

Carron Valley is a small remote community in Stirling Council nestled amidst picturesque surroundings. In the last few years, the residents have been facing a problem of black outs sometimes lasting for a few days. Some of the residents took initiative to explore alternatives such as wind power to overcome their problems.

This work is an attempt to look at the feasibility of such a community venture to power the village from wind energy exploring issues such as planning, grid connections, storage and economics. The central part of this work is modelling using a combination of questionnaires, ESP-r and Merit to design a wind energy system with battery storage. Various demand scenarios have been defined and using the above modelling techniques, the possibility of providing autonomy from the grid has been explored under these specific scenarios. The results have been presented at the end along with a summary of other issues studied. The modelling results indicate that required autonomy would be possible with the help of reasonably rated wind-battery combination to supply essential electric loads only. For other categories of loads, the same supply combination would leave too high a percentage of shortfalls to get the autonomy, low wind speeds for long durations being the chief reason for the short fall. Deploying wind turbines of lower cut-in speed would reduce this short fall but not to the extent of providing autonomy. The issues of local grid is another important area that can have a bearing on the decision making process of developing a small wind energy system and in the present case studies the chances of local grid up gradation look quite remote in the absence of which the proposed system may not be a worthwhile option. In the end a brief financial analysis has been provided using cash flow techniques for an investment combination of grants and loans. Elaborate results of ESP-r modelling and profiles prepared for Merit have been given in the annexure.

1 INTRODUCTION

1.1 BACKGROUND

According to Hindu Philosophy, human being derives all powers from *Panch Bhootas (Sri Chandrasekhara Saraswati)*, the Five Elements namely Earth, Wind, Fire, Space (Sun) and Water for his existence. For eons he lived simple life in harmony with nature, primarily depending on these resources. Times have changed ever since and in the 21st century, as a race man is progressing at a much faster pace than ever, thanks to the Industrial Revolution in the early 17th century *(Fordham University)* that heralded a new era. This created huge wealth and affluence in certain societies, even though the disparities between the rich and poor increased as the less privileged societies still struggle to fulfil basic needs. The additional wealth in societies, triggered human needs and so the consumption and exploitation of resources that led human being away from harmonious living with nature and started living at the cost of the nature. As a consequence, it is but ironical that with increasing progress, there is a steady deterioration of the environment, thanks to the extract, use and dump nature of the consumptions patterns of the society. Even though part of the environmental change and damage is irreversible and partly it is unavoidable, the need of the moment is to try and minimise future damage and deterioration the onus of which lies on us.

Energy is predominantly one such issue and that electrical power evolved as the most versatile form of energy- the method of production and patterns of usage continue to be detrimental to the quality of environment and responsible for its deterioration at least one in three parts. Fossil fuels such as coal and oil extracted from the earth and predominantly used in electric energy generation, contributed to the green house gases besides polluting the earth and water. All the big power stations are located either near mines or ports where it is easy access to fuels to generate electricity and transmit through long distances to supply to the end users. This has increased the transmission costs and losses, which not only means more wastage of resources but also higher emissions per unit of energy consumed. Hence the focus is increasingly towards distributed energy resources with an aim to minimise losses, costs and emissions. It goes without saying that Renewable Energy play a vital role in the distributed energy systems, more prominent among them being wind and solar. Wind is already a matured technology and enjoys cost advantage. In places with good wind resources such as Scotland, large wind farms have become the order of the day. Now the focus is slowly shifting towards medium and small wind turbines which have been already installed in some parts to serve remote and isolated communities without any access to the grid. As the shift towards distributed energy systems is increasing, such initiatives can well be extended to those communities with grid access for reasons of being able to be less reliant on grid power and able to play their role in reducing emissions.

Governments in Western Europe and USA are encouraging communities to participate in this global drive to reduce emissions and generate electricity for the communities through renewables by offering them help in the form of grants, technical know how and simplified planning approvals (*Energy Information Administration, USA*). Encouraged by such support, more and more communities are coming forward to change over to green energy. However, as this trend is yet to be established, there are certain issues such as grid connection, required to be resolved in due course. This dissertation is about designing a small wind turbine for a remote community at Carron Valley, Scotland besides focussing on some common issues in the development of community wind energy.

1.2 THE PROJECT

Carron Valley, is a small and remote community nested amidst picturesque surroundings with the magnificent Carron reservoir in the fore ground and hilly terrain all around. This village is located not very far from the famous Campsie Fells range and just 15 miles away from the city of Glasgow on the north- northeast in Central Scotland, UK.

This project attempts to explore the feasibility of a community initiative to power their village from renewables, namely from wind energy. A couple of blackouts each year and the hardships there after were enough motivation for the community to look in for alternatives. As the current trend is renewables and their area has abundant wind resource, representatives of the community Mr Bill McDonald and Mr Mac Mooney approached the University of Strathclyde to seek further assistance and the result is this project.

Though alternative options such as hydro and PV cells have been looked into, it appeared that wind energy is the most feasible option and hence the current objective is restricted to designing a wind turbine with necessary storage to satisfy the energy demands of the community consisting of 21 houses. This dissertation also attempts to look into other issues such as planning, grid connection, storage, project financing, and project costing.

1.3 BRIEF OVERVIEW

This dissertation is divided into five sections.

Section I starts with a brief introduction, provides a historical perspective of wind energy in general and community wind power in particular and moves on to introduce Carron Valley where the major focus of the current dissertation lies.

Section II outlines the literature review starting with detailed planning review for Scotland, brief review of Wind Energy technology followed by detailed review of storage technologies and practices. In the last part of this section, Scottish grid review and Carron valley distribution network information are presented.

Section III is about the energy system design, which starts with the description of methodology, planning of scenarios and advances to design a

Wind Energy System with storage options using modelling techniques such as ESP-r and Merit. It also provides critical analysis of the results.

Section IV looks into financial aspects, which includes project evaluation, various available project-financing options and provides a glimpse of cash flow analysis for a wind turbine resulting in net present value and payback periods.

Section V presents further discussions and conclusions and specifies scope for future studies.

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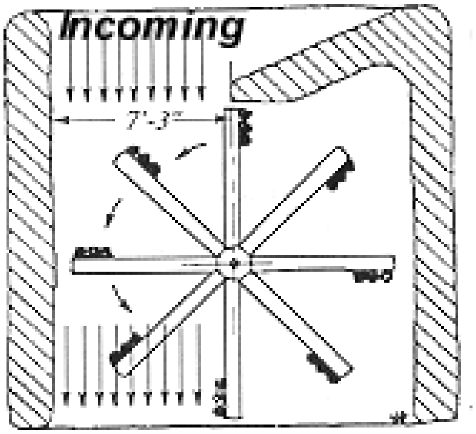
2 COMMUNITY WIND - A HISTORICAL PERSPECTIVE

2.1 WIND ENERGY HISTORY

2.1.1 Early History

Wind power has been extensively used in communities since early-recorded history. Wind energy propelled boats along the Nile River as early as 5000 B.C. In tenth century, communities used wind energy for pumping water, grinding grain and other low energy applications. The earliest known design is the vertical axis system developed in Persia about 500-900AD for pumping water. The first known documented design is also of a Persian windmill, this one with vertical sails made of bundles of reeds or wood which were attached to the central vertical shaft by horizontal struts (see Figure 2.1). Vertical-axis windmills were also used in China, which is often claimed as their birthplace. While the belief that the windmill was invented in China more than 2000 years ago is widespread and may be accurate, the earliest actual documentation of a Chinese windmill was in 1219 A.D. by the Chinese statesman Yehlu Chhu-Tshai. Here also, the primary applications were apparently grain grinding and water pumping.



Maximum efficiency of a "drag" device is obtained when the collector is pushed away from the wind, as is a simple, drag-type sail boat. In this Persian panemone design, the rotor can only harvest half of the wind striking the collection area. The panemone is one of the least efficient, but most commonly reinvented (and patented) wind turbine concepts

Figure 2.1 Drag Device *(Courtesy : http://telosnet.com/wind/)*

New ways of using the energy of the wind eventually spread around the world. By the 11th century, people in the Middle East were using windmills extensively for food production. Returning merchants and crusaders carried this idea back to Europe. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. Evidence of windmills in England dates back to the 12th century, with earlier references to "mills" (such as in the 11th century Doomsday Book) generally held to be talking about either animal or water powered mills. The 14th and 15th centuries provide evidence of what the early mills looked like, with illustrations occurring in diverse media such as memorial brasses, stained glass, and woodcarvings, as well as the expected manuscript records. These early illustrations all show the simple, all wooden, post mill structure. At the peak there were more than 100,000 windmills in Europe, most of which were installed in flat countries with no hydropower option. The use of windmills in Europe expanded until the industrial revolution, when the use of coal accelerated. In the eighteenth century there were still 10,000 community windmills in the Netherlands. As recently as the 19th century, hundreds of working windmills were scattered across the UK for community purposes and as late as in the 1930s there were some 30,000-wind mills operating on farms in Denmark. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches, and later, to generate electricity for homes and industry.

2.1.2 20th Century Developments

In early 1900's, there were several attempts to build large-scale wind powered systems to generate electricity. In 1931, the Russians built a large windmill of 100ft diameter and later it was abandoned due to low conversion efficiency. In 1945, a Vermount utility built a large wind powered generator at a cost of £1 million which lasted for 23 days before on e of the blades failed due to fatigue and the project was abandoned *(RC Bansal et al 2001*). All the early development of the current technology was focused in California in America.

The popularity of using the energy in the wind has always fluctuated with the price of fossil fuels. In the US, in the 1920s and ‘30s, farm families throughout the Midwest used wind to generate enough electricity to power their lights and electric motors. The use of wind power gradually declined with the Government subsidised construction of utility lines and fossil fuel power plants. When fuel prices fell after World War II, interest in wind turbines waned. But when the price of oil skyrocketed in the 1970s, so did worldwide interest in wind turbine generators. The wind turbine technology renaissance that followed the oil embargoes of the 1970s refined old ideas and introduced new ways of converting wind energy into useful power. Many of these approaches have been demonstrated in "wind farms" or wind power plants--groups of turbines that feed electricity into the utility grid. Since the mid eighties, the US wind turbine market has been by and large stagnant mainly owing to the removal of strong incentives that gave such rapid growth in the early eighties.

In Europe, the oil embargo triggered spectacular interest in wind energy and various Government funded programs commenced to pursue research, development and demonstration. These programmes helped gain much scientific and engineering information and the prototypes generally worked as designed. From 1988 the fastest growing market for wind power has been in Europe. Countries such as Germany, Denmark, Spain and UK are in the forefront of wind energy generation. The technology that was rediscovered and engineered as an offshoot of oil embargo is now, here to stay and expand due to its potential to help limit the climate change.

For example, Denmark, which in the early 1970s was extremely dependent on (imported) oil, pursued a very active policy of energy savings, increasing self-sufficiency, and diversification of energy sources until the mid 1980s. Since then, energy policy has increasingly promoted the use of renewable energy to ensure environmentally sustainable economic development. Since the mid 1980s, the country has had an official goal of meeting 10 per cent of Danish Electricity consumption by wind in the year 2005. Germany is also one of the early entrants into renewables. Helped by careful planning, free trading, and strong commitment to cut carbon emissions and financial incentives kick started Germany’s drive for wind energy. At the end of 1997, with 2100MWs of installed capacity, Germany became the largest wind power producing country in the world . In contrast, in UK, the discovery of North Sea oil/gas fields, paced up energy generation from fossil fuels, which along with nuclear energy almost fulfilled the country’s energy needs. Only a small percentage was shared by hydropower. As a result, until 1990 there were only a handful of wind turbines in the UK, which had no special regulations concerning purchasing of wind energy and wind energy had been economical only to firms with an ability to use the electricity themselves. (*Søren Krohn 1998)*

2.1.3 Wind Energy- Post Kyoto Protocol

In 1992, the increased use of fossil fuels and the ensuing climate change effects has forced UN to adopt a framework convention on climate change. In 1997, more than 160 countries met in the city of Kyoto, Japan and the outcome of the meeting was the Kyoto Protocol, in which the developed nations agreed to limit their greenhouse gas emissions, relative to the levels emitted in 1990. European Union called for 12% of gross energy demand of the union to be contributed from renewables by 2010. Under the new legislation, the UK will have to cut greenhouse gas emissions by 12.5% below 1990 levels by 2008 to 2012, although the Government has already set the country a far tougher target – to cut emissions by 20% by 2010. European Union identified wind energy as having a key role to play in the supply of renewable energy with a projected increase in installed wind turbine capacity from 2,5 GW in 1995 to 40GW by 2010. Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity very close in cost to the power from conventional utility generation in some locations.

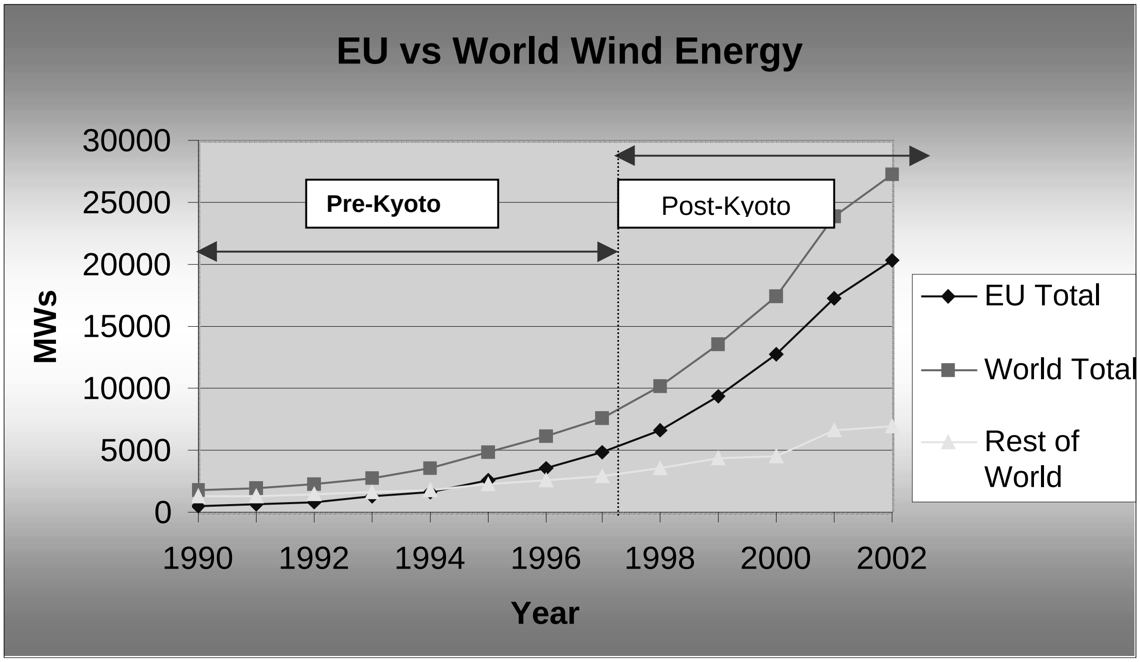


Figure 2.2 Growth of wind energy in Europe after Kyoto (Raw Data Source: European Wind Energy Association)

The above trend clearly indicates the steep rise in the installed capacity of wind power in the post-Kyoto scenario in Europe. Relatively, the rise in the same period in rest of the world is quite insignificant.

2.2 COMMUNITY WIND POWER

In the aftermath of climate change agenda, the community initiatives for wind power are on the rise across Europe and North America, the re-emergence of which was pioneered by Denmark. Currently, 80% of Denmark's wind energy is generated by community co-operatives. Community wind projects can be either small wind turbines catering to remote and isolated communities or medium scale farms for wider communities managed by co-operatives.

2.2.1 Role of Small Wind for Communities

With the advent of pioneering technological developments, small wind turbines with better conversion efficiencies have evolved. In recent years, renewed interest in small wind turbines from farmers, ranchers, homeowners, and small businesses has grown. These small turbines are rated about 40 kilowatts or less and can generate mechanical or electrical energy from the wind. In remote regions of the globe where access to electricity is limited or nonexistent, there is keen interest in generating electricity from the wind. Even small amounts of electricity can significantly improve the quality of life. Common uses for small wind electricity are lighting, running small appliances, making ice, charging batteries, and desalination.

2.2.2 Community Wind (Small) in USA

Today, communities in rural and remote locations across USA are once again examining the possibility of using wind power to provide electricity for their domestic needs *(DOE/GO-10097-374 FS135 1997)*. The US Department of Energy (DoE) has come up with a directive in 1997 aggressively advocating the benefits of such community initiatives and offered guidance, support both technical and financial in form of grants, incentives and tax concessions. Department of Energy is working with three small turbine manufacturers, selected through competitive solicitation, to improve their turbines. The goal is to develop tested small wind systems up to 40 kilowatts in size that achieve a cost/performance ratio of $0.60 per annual kilowatt-hour at sites with at least annual average wind speeds of 5.4 meters per second (12.1 miles per hour). The cost/performance ratio is the initial capital cost of the turbine divided by its annual energy capture. The companies will work with researchers to 1) design a prototype turbine, 2) complete detailed design and qualification tests of key components, 3) fabricate and field test a turbine, and 4) refine the design and perform qualification tests of the commercial prototype.

2.2.3 Community Wind Power (Small) in UK

UK is home to many remote islands and societies especially in the North in Scottish highlands and islands. Fair Isle is one of Scotland's most remote and green islands. Since 1982, the island has been powered by Europe’s very first commercial wind turbine to replace the expensive diesel generators. In 1996 a second turbine was installed on the island and in 1999 the Fair Isle Electricity Company became a community owned enterprise. Wind power now supplies 85% of winter and 50% of summer energy requirements to Fair Isle's 80 residents. Beginning with this, small wind expanded in UK first in remote islands without access to grid and expanded to communities with grid access as well. Two example projects are presented in next sections.

During the past few years, the UK Government has introduced a number of measures to encourage the uptake of renewable energy and energy efficiency by power generators and businesses. In 2002, UK Government, in partnership with DTI, DEFRA, the Forestry Commission, the Energy Savings Trust, the many industrial bodies, environmental groups and charities, launched UK's community renewables initiative aiming to allow people to create developments which reflect their own needs, fit the local environment, and bring direct local benefits. The program under which various schemes are offered is christened as clear-skies programme, which is applicable for England, Wales and Northern Ireland. With the advent of the Clear Skies initiative, the Government is aiming to encourage homeowners and community groups to take an active part in the climate change agenda and reap the benefits of renewable energy. Equivalent scheme in Scotland is Scottish Community Renewables Initiative (SCRI). These schemes provide if systems are developed through accredited installers mentioned in Clear Skies Programme.

Developing a local renewable energy project can be a detailed, involved process. A number of initiatives have been established in the United Kingdom to assist local communities through the processes, from the time that an idea is first thought of, through to actual commissioning and operation of the project.

2.3 A CASE FOR COMMUNITY WIND IN UK

Let us see how UK makes a strong case for community wind power

- UK's wind resource is 40% of that of Europe
- Potential of wind to fulfil Kyoto Protocol Obligations
- Lesser environmental impacts/effects
- Community Development and Employment Generation
- Communities' Environmental Obligations
- Remote communities without grid access

- Beginning of Distributed Generation
- Lesser Planning Obstacles
- Financial Grants
- Profits to be reinvested in community development
- Overall sustainability of communities

Community wind power in UK can be classified under two broad categories

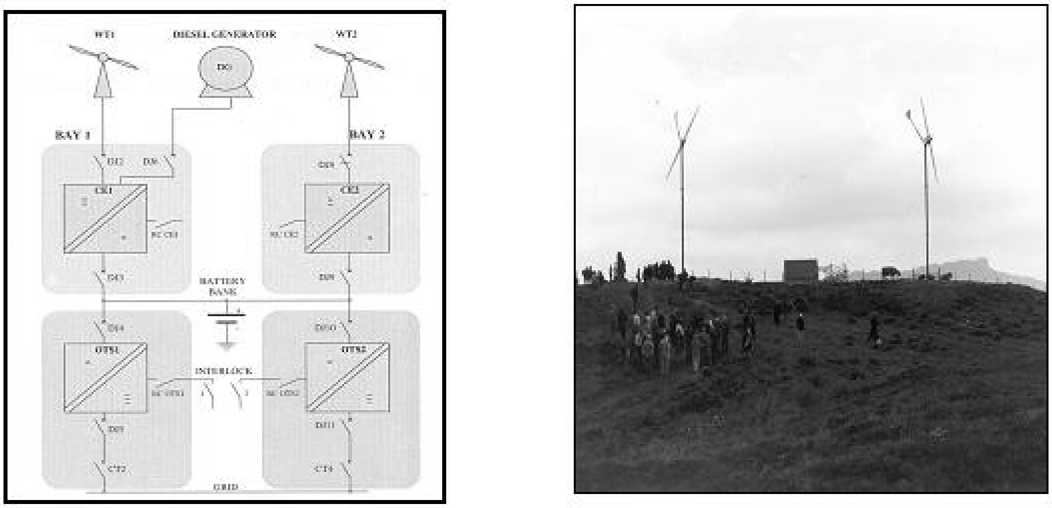
Isolated Communities without grid access: UK, especially Scotland, boasts of quite many remote islands with habitat dwellings. These islands are far off from the main land and thus extending an electricity grid is not a worthwhile proposition. The only other source of electricity in these islands is through diesel generators, which are not only expensive, but also source of emissions. Also there is little back up provisions in case of engine break down. Incidentally, these islands have huge wind potential , it is proposed to power these communities through wind energy.

Communities with Grid Access: The second category of communities fall under those with grid access. Encouraged by the phenomenon of global warming, these communities took initiative to contribute their bit in the reduction of green house gases by embracing renewables. Of course, they have other advantages such as, independence from grid, employment generation, equity participation and utilisation of profits towards other community development schemes etc.

In the following sections, we will discuss one example of each case.

2.3.1 Isolated Community -Isle Of Muck

The island of Muck is one of Lochaber's 'Small Isles', lying 10 miles off the west coast of Scotland. With a full-time population of only 38, relying on a twice weekly passenger-only ferry service, life could have been considered challenging enough without the problems posed by the poor electricity supply. The main source of energy had been diesel generators since 1968. A connection to the national grid has been ruled out because of the cost. The costs of shipping in 20,000 litres of diesel oil each year had meant electricity prices of 26 pence per unit, compared with the UK average of 6 pence.



(a) (b)

Figure 2.3 Wind at Work - The schematic and a view of the wind turbine

(Source: Sgurr Energy)

The idea of wind power was conceptualised almost 10 years ago with the help of the approved European funding, however the main contractor involved, went into bankruptcy and the project was eventually abandoned, but not before the islanders themselves had done a great deal of work in laying cables and trunking, and connecting all the properties on the island. At last, the project christened as ‘Isle Of Muck Community Wind Energy Project’, took off in 1998 which was executed by Ingenco and handed in to the Community Company in Jan 2000 and was officially opened in August 2000. The project is intended to provide reliable and cheaper electricity for the 38 islanders. Once home to the highest electricity costs in the UK, the island now houses two 60ft turbines. Residents who previously had to make toast with candlelight or individual generators are reportedly delighted at the novelty of being able to make toast at the same time as the kettle is boiling. The wind-power project means cheap and near-continuous electricity for the islanders after decades of relying on diesel generators. The two 26 kW wind turbines harness the windy conditions on the island. When the wind speed drops below the required level, diesel generators automatically ensure that the electricity supply is maintained. The electricity generated costs 4p/kWh compared with 14p/kWh for that produced from diesel.

The project has cost £238,000 with funding coming from a variety of sources. Lochaber Limited, the Local Enterprise Company, have invested £75,000 - with a further £20,000 coming from the local European LEADER partnership; the National Lottery Charities Board has provided £95,000; The Highland Council - £18,000; and private donations/trusts - £20,000.

A great deal of work and investment on the project has been provided by Glasgow-based engineering company Ingenco ltd, a new company established in May 2000 following a successful buy-out of the former Scottish Power Technology business. Ingenco's engineering expertise ensured the system was capable of meeting the islanders' needs and assisted in tackling any technical issues, which arose. The company also funded the building of the control room at the base of the turbines. Support for the project also came from the Highlands and Islands Enterprise network's expert help programme, which provided the services of an innovation and technology counsellor.

On the island the power supply is being run by Isle of Muck Power Ltd, a subsidiary of the Community Company, who meters the power used and issue bills to individual households. Wind-generated electricity will cost four pence per unit, with diesel power at 14 pence. The income from the scheme will cover repair and maintenance work and will eventually fund the replacement of the turbines when they reach the end of their useful life in about 20 years.

2.3.2 Communities with Grid Access- CAT Centre, Wales

The idea was formed in 1998 and was spread in the community through discussions and leaflets. The environmental assessment was compiled by the local community themselves and subsequently planning permission was obtained in 2001 without much difficulty for the simple reason that the project is relatively small and utilises the project revenues for the development of community. The project construction was commenced in April 2002 and was completed by June 2002.

The project is owned by an Industrial and Provident Society called Bro-Dyfi Community Renewables Initiative. Apart from individual shareholders, the 59 shareholders include the Energy Saving Trust and Baywind Energy Co-operative. Some individuals earned their shares by their physical contribution to the project either in planning or construction stages. The investment will attract an interest of 8% if left for a 15-year term. The minimum share holding is £100 and maximum is limited to £1000. This apart, other means of finance was through grants offered by various institutions. The European Regional Development Fund gave a grant of £19000, The Energy Saving Trust contributed £17500 and The Scottish Power Green Energy Trust gave £10000. Ecodyfi and Powys Energy Agency involved actively in seeing through these grants.

The capital cost was £81000 inclusive of spares and extended warranty. The construction cost was £45000, which was executed by CAT centre. The operation and maintenance cost was pegged at £2300 a year. Second hand Vestas V17 turbine and tower were bought from Denmark cost of the turbine being £15000. The turbine was installed in a forestry commission’s land at a non-commercial rent. The maximum out put of the turbine is 75KWs and at a capacity factor of 30%, it can cater to roughly to the needs of 45 households. The projected annual energy output is 163MWhs, which means prevention of 70tonnes of CO_2 into atmosphere if generated using fossil fuels.
All the electricity would be sold to CAT centre on a long-term agreement. CAT centre in turn uses 20% of this and sells the rest. This arrangement avoids community operator to involve in selling the power to different customers that is prohibitively expensive in the current regulatory regime though there is an option of supplying the electricity to grid as well, apart from CAT.

2.4 GENERAL CRITERION FOR COMMUNITY WIND POWER

Generally the following criterion and considerations are helpful for the selection of various community wind schemes.

2.4.1 Conditions for Stand Alone Systems

- Where annual wind speeds are at least 4m/s
- A grid connection is not available or only can be made through an expensive extension, as the cost of running a power line to a remote site to connect to a utility can be prohibitive depending on the terrain.
- Interest to gain energy independence from utility.
- To reduce the environment impact of electricity production
- To acknowledge the intermittent nature of wind power and have a strategy for using intermittent resources to meet the power needs.

2.4.2 Conditions for Grid Connected Systems

- Where average annual wind speeds are above 4.5m/s
- Where utility supplied electricity is expensive in the area
- Where grid connection with the utility is not prohibitively expensive
- Local regulations allow to legally erecting a wind turbine on the property
- Where long-term investments are not viewed as a risk.

2.4.3 Additional Considerations

- To research potential environmental and legal obstacles
- To obtain cost and performance information from manufactures
- To perform a complete economic analysis that accounts for a multitude of factors
- To understand the basics of small wind systems
- To review the possibility of combining the system with other energy sources, back-ups, and energy efficiency improvements.

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3 CASE STUDY- CARRON VALLEY COMMUNITY

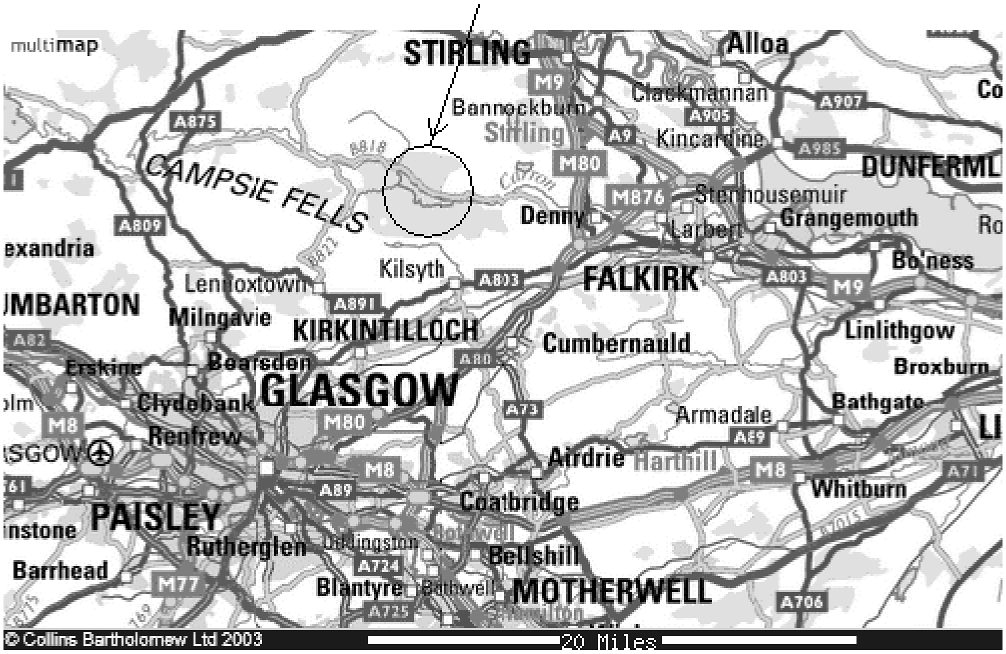
3.1 INTRODUCTION

In this chapter, a community- seeking wind power to overcome some of their hardships- is introduced. In the next few sections, we discuss about the geographical and social aspects of this community area and then move on to present the problems being faced by the community. The information presented below is gathered from a series of meetings with the community members, site visits and official web sites of Stirling council, Stirling tourism information and other relevant official web sites.

3.2 GENERAL INFORMATION

3.2.1 Geographical Information

The settlement of Carron Valley is situated on the Northeastern corner of Carron Reservoir on the B818 in central Scotland.



Carron Reservoir

Figure 3.1 Carron Reservoir with reference to Glasgow and Falkirk

The community is roughly 20 miles away on the north-northeast of the city of Glasgow. The geographical reference is 56:01N and 4:03W and UK grid reference is roughly NS7 16839. The vicinity information is as follows;

Nearest Motorway	M80 Junction 4	5.4 Miles

Nearest Train Station	Croy Train Station	5.3 Miles
Nearest Airport	Glasgow Airport	18.2 Miles

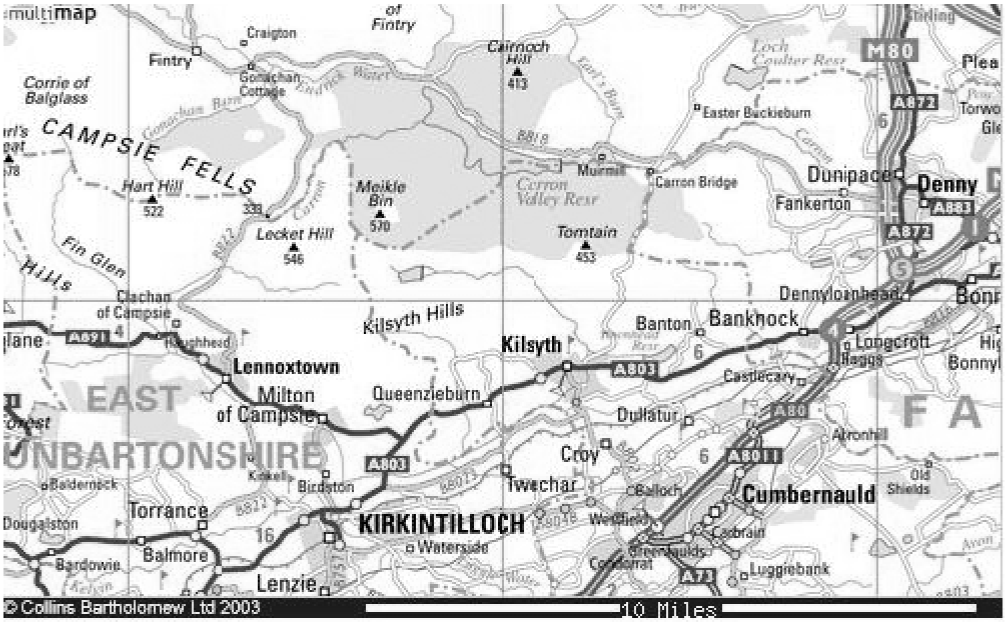


Figure 3.2 Carron Valley vicinity plan

The source of water for Carron Reservoir is Carron River, which originates in the uplands of Stirling Council area called Carron Bog and flows towards the east via Carron reservoir, Denny town and finally joins river forth at Grangemouth. The reservoir is the source of drinking water to Falkirk and Grangemouth.

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Figure 3.3 Carron Valley from Campsie Fells *(Courtesy: www.scotcolor.com)*

3.2.2 Flora and Fauna

The reservoir is abode to salmons and is also a popular fishing spot. This area is famous for great crested grebes, common sandpipers, squabbling caws, and blockheaded gulls. In summer, on the Earl's hill, one can find white rumped wheatear, short-eared owls, black grouse and some times meadow pipits *(Source: Stirling Council).* The nearby famous Campsie Fells range is part of the original wetlands and is rich in wildlife. The nearby Clackmannanshire, is a Local Nature Reserve and the winter home of thousands of migratory ducks. Further south, the town of Doune has an excellent, award-winning nature reserve with bird watching hides from which to spy on the abundant local wildlife. The following map shows the places of interest around the reservoir.

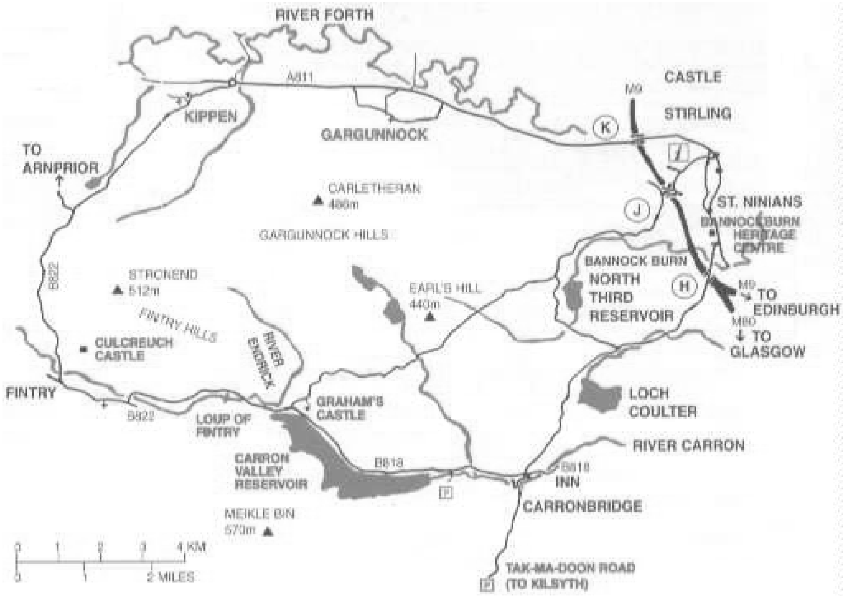

Figure 3.4 Places of Interest around Carron Reservoir *(Courtesy: Stirling Tourism)*

Figure 3.5 Imposing forest area (captured by author)

3.3 THE COMMUNITY

The Carron Valley community is flanked by the Muirmill community on the east and orients itself towards the west by almost 2 KM where the reservoir commences. The magnificent reservoir and the Caron Valley Forest are on the south and on the north of the village lay the Craigannet Hill. The community comes under Stirling Council

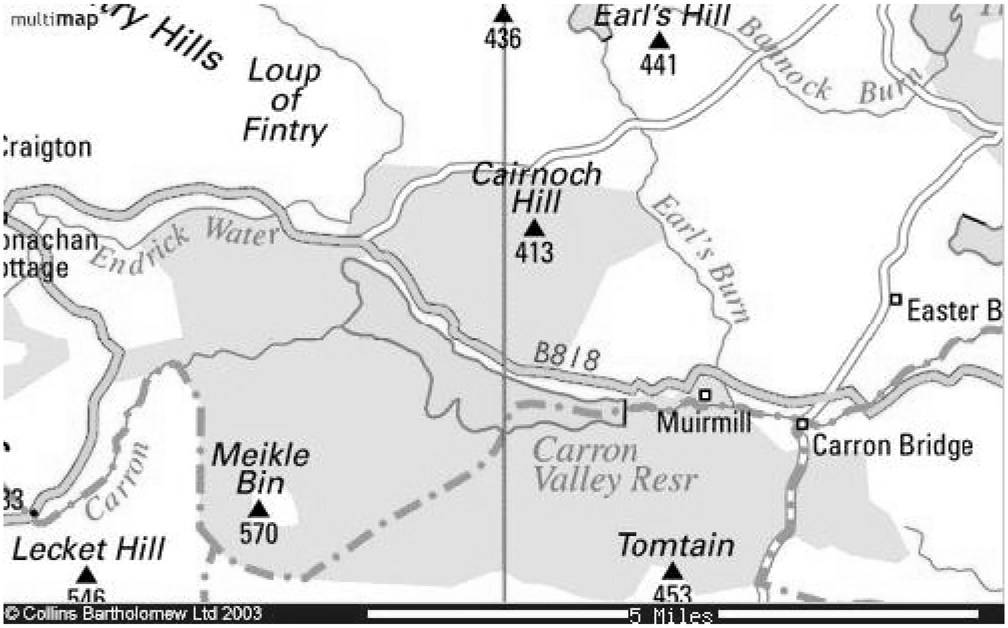

Figure 3.6 Altitudes around the Valley

The community consists of 21 houses of which one house runs a B&B and another resident runs his own fish farming. Most of the other residents are either employed or run some farm of business in nearby towns.

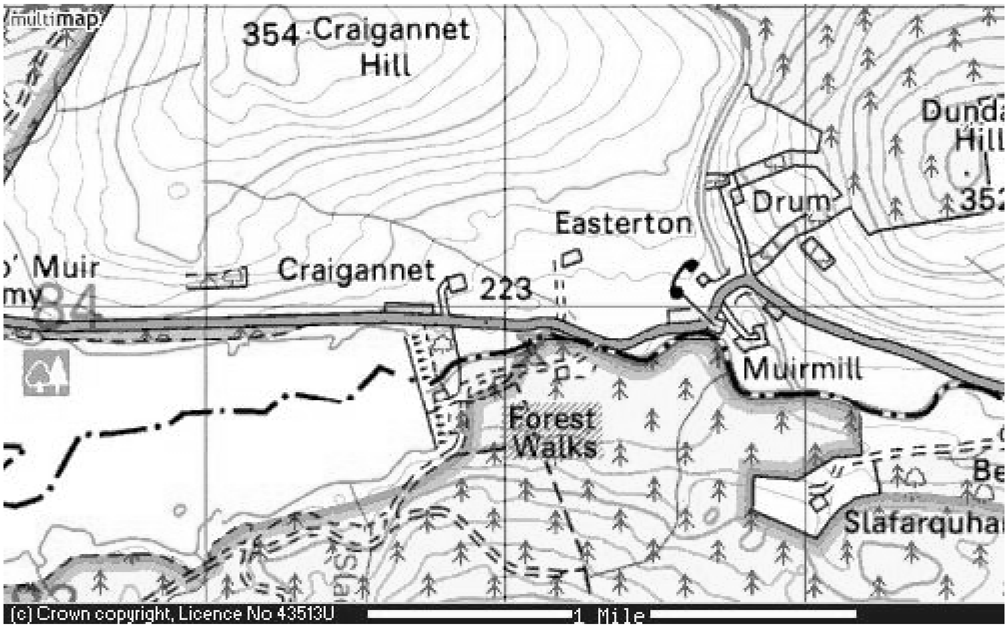

Figure 3.7 The area of Dwellings

3.3.1 Energy: All the houses are equipped with modern electric gadgets like TV, Music System, Refrigerator, and Electric Cooker etc., which need electrical power. Scottish Power is the local network operator. There is currently no piped gas supply to the village. Few of the residents attempted to get Liquefied Gas through cylinders and connect them for water heating, but the proposition appeared too expensive. Although some residents have electrical cookers, most others possess Ray-burns, which are used for cooking, hot water and space heating. Rayburns are fired by wood, coal and sometimes by oil.

Figure 3.8 A typical Rayburn used in one of the residences

3.3.2 Water: It is more obvious that the reservoir is the only source of water for the community, pumped with the help of 2 pumps for which Scottish Water Authority is responsible. Water is piped individually to all houses arranged to fill respective small overhead tanks. There is a common community overhead tank, but it is abandoned and rendered useless. No common treatment facility is available, so residents are equipped with their own purifiers.

3.4 PROBLEM DESCRIPTION

The main problem faced by the community is power interruptions when there is strong gales/ storms that cause snapping of lines. Occasionally, the lines are disrupted even by cattle, which adds to the vows of the community. Power once disrupted, can take up to 3 days to get restored. From the discussion, it also appeared that as this area is quite remote, it comes quite low on priorities for restoration purpose. The most likely period of black outs is during Christmas- New Year. The problem of black outs seem to be there since quite many years, but the frequency of blackouts is constantly on the rise since last 3 years.

When there are power interruptions, the village will be, any way, without electricity. In addition, total water supply is cut off, as the pumps would go dead in the absence of electric supply. At the moment there are no back-up systems. To escape from the hardships during such days, the villagers would migrate to various places of friends and relatives that are not hit by similar problems.

The local resident has 2 projects in mind. One is a small wind turbine that can cater to the needs of him and his immediate neighbour. Alternatively, if more residents show interest, which is the likely case, a bigger wind turbine that can be located in an open field, is proposed that can cater to the needs of whole community.

3.5 DETAILS OF SITE VISIT

A visit to the community has been made on 18th June 2003, which took roughly 45 minutes from Glasgow. Most of the information gathered is already discussed in the preceding sections and only additional information gathered along with pictures is presented below.

Figure 3.9 Reservoir at the background

Figure 3.10 Road in front of the reservoir

3.5.1 About wind

- It was one of the high wind days
- Wind blows from west or southwest generally
- More windy during winter than in summer

Figure 3.11 A view of the houses

3.5.2 Housing

- Almost all houses appear similar in construction and dimensions.
- Orientation of houses is from east to west parallel to the road running along the same direction and face the reservoir on the west end.
- While entering the village from east the first house falls on the right side of the road.
- The first house on the east and the last house on the west are separated by almost 1 mile.
- There are 6 houses in a row on the west and the reservoir starts almost opposite last 4 the house and stretches for a kilometre towards the west.

Figure 3.12 The possible location for wind turbine?

3.5.3 Possible wind turbine siting

- The reservoir dam is at 600ft above sea level. The road is slightly higher (5Ft approx.)
- The chimney top of the houses is 35ft above the road level.
- On the backside of the houses the grazing fields on a small hill, which slants down form west to east.

- The northwest corner on this hill after the last house appears to be the ideal place for a wind turbine, which is free from any obstructions, relatively on a higher altitude compared to the surroundings. These fields are left for cattle grazing.

3.5.4 Other information

- The common facilities in the village include only a pumping station supposed to have 2 pumps. Rating is unknown.
- There is a transformer, which supplies to the village located on the backside of the cluster of 6 houses. Again rating unknown.

3.6 RELEVANCE OF THIS INFORMATION

Most of this information is used and appropriately interpreted in making certain assumptions, building the model and subsequent analysis. Information such as geographical and flora and fauna will give an idea of planning issues that would possibly be involved.

With this background, in next chapters, we proceed to design a WES so the village can power itself from renewable energy.

3.7 OBJECTIVE OF THE CURRENT DISSERTATION

- To look into planning and grid aspects
- To design a Wind Energy System with storage for the valley to cater to off wind periods
- To bring out any relevant issues

3.8 REFERENCES

1 Stirling Council official web site at www.stirling.gov.uk/

2 Stirling Tourism site at www.stirling-tourism.co.uk/

3 Online map resources at www.multimap.com/ and www.ordnancesurvey.co.uk/

4 Scottish Natural Heritage site at www.snh.org.uk/

4 PLANNING REVIEW

4.1 INTRODUCTION

Obtaining planning permission is the first step forward for all projects and wind turbines are no exception. Depending on the type, size, nature and magnitude of the project, planning involves various consultations, cross-consultations, approvals, impact assessments etc. The developer is required to make consultations with different agencies typically during pre-planning stage. Local council acts as a nodal agency for all planning permissions falling in that region. Although the planning guidelines and procedures are similar throughout UK, Scotland has developed a set of planning guidelines and requirements for all projects falling in its domain. The local council in consultation with Scottish executive and other agencies accords the clearance for any proposed project.

4.2 PLANNING SERIES

Scottish Executive has devised a series of documents, which pronounce the Government's Planning Policy Framework and offers guidance and advice. These documents provide guidance about pre-planning consultations, planning permissions, development control and post developmental commitments.

-National Planning Policy Guidelines (NPPGs): These documents provide Scottish Executive Policy statements with regard to nationally important land use and other planning matters, supported where appropriate by a local framework.

-Circulars

They also provide statements of Scottish Executive Policy and extend guidance on policy implementation by way of legislation or procedural change.

-Planning Advisory Notes

These documents provide advice on good practice and other relevant information.

4.2 PLANNING GUIDANCE FOR RENEWABLE ENERGY

The Scottish Executive has compiled separate guidance notes for specific types of renewable energy, which have been issued through two main documents.

- Planning Advisory Notes PAN 45
- National Planning Policy Guidelines for Renewable Energy Development NPPG 6

Although the above two documents discuss similar issues, in fact, they compliment each other with a degree of overlap. These two documents provide guidance on a whole range of issues and advise to conform to other policy documents wherever necessary.

4.3 GUIDANCE FOR WIND ENERGY

The above documents offer advice general to all notified renewable energy developments and in addition, offer separate guidance for each of those technologies including Wind Energy development.

4.4 CRITERION FOR WIND

The range of planning permissions required for a wind turbine are mostly determined by the size (hub height, number of wind turbines, power output) and location (major and micro-siting) of the proposed development. It is relatively easy and less time consuming to obtain planning permission for, say, 2nos of 50kW turbines, as smaller size plays down the various impacts it will have on the land, environment, heritage, flight paths etc. The important criterion, the guiding documents and the agencies involved for consultation, all of which can have a bearing on the major and micro siting of the wind turbine, have been listed below.

- **Offshore:** The planning act doesn’t cover off shore wind project developments, in which case the authorisation comes within the scope of Section 36 of Electricity Act 1989 and Associated Electrical Works Regulations 2000.

- **Size, Capacity and Number**: Wind farms with proposed generation of 50MW or more have to be authorised under section 36 of Electricity Act 1989, The Electricity (Applications for consent) Regulations 1990 (Sl no 1990 No.455 and SOEnD Circular 3/1991). Size also determines the degree and depth of Environment Impact Assessment required for the development, the details of which are discussed in subsequent sections.

- **Environmental Impact Assessment** (EIA): As such wind energy projects fall under Schedule2 for the purpose of Environmental Impact Assessment, which amounts to EIA is not mandatory. If the proposed project is in a sensitive area as per Regulation 2(1), or involves more than 2 turbines or height of any turbine or structure exceeds 15 M, EIA must be considered. Also, if number of turbines is 5 or more or total generating capacity is more than 5MWs, Environmental Impact Assessment may be required for a commercial development. The proposed development would undergo screening indicated in SEDD circular 15/1999, paragraphs 36-40, which give indicative criterion where EIA is more likely to be required. PAN58 gives additional advice.

The regulation 2(1) identifies areas as sensitive, if they fall in one of the following categories in which case all the proposed scheduled 2 developments have to be screened to assess the need for EIA *(Source: The Environmental Impact Assessment (Scotland) Regulations 1999)*

- Sites of Special Scientific Interest
- Land to which Nature Conservation Orders apply
- International conservation sites
- National Scenic Areas
- Natural Heritage Areas
- World Heritage Sites

- Scheduled monuments

Even if planning Authority thinks that statutory EIA is not required, still additional environmental information can be requested under Article 133 of General development order, in which case schedule3 to 1999EIA Regulations provide useful guidance. The requirement of EIA in the form of a flow chart is shown in Figure 4.1.

- **Natural Heritage Assessment** : Certain on-shore locations may have natural and built heritage. The detailed policy issues are spelt out in the following documents. The aim is to protect Natural Scenic Areas, National Parks, Birds and Habitats, Archeological sites and to minimise visual impact of wind turbines.
  Important reference documents have been listed as under
  NPPG14: Natural Heritage
  NPPG5 : Archeology and Planning
  NPPG6 : Conservation of Habitats
  NPPG18: Planning and the Historic Environment
  The refereed documents offer further guidance in the mentioned areas. In addition, Scottish Natural Heritage (SNH) has issued guidance specific to wind farms to assess the landscape character and local authorities should provide local interpretation where necessary

- **Visual Impact:** Visual impacts are quite site specific (landscape character) and also depend on the size and number of turbines. Visual impact is assessed from within the zone of visual influence. PAN 45 gives a few detailed guidelines on how to minimise these effects. It discusses about the colour, appearance, approach roads and positioning of ancillaries and cable laying with reference to the

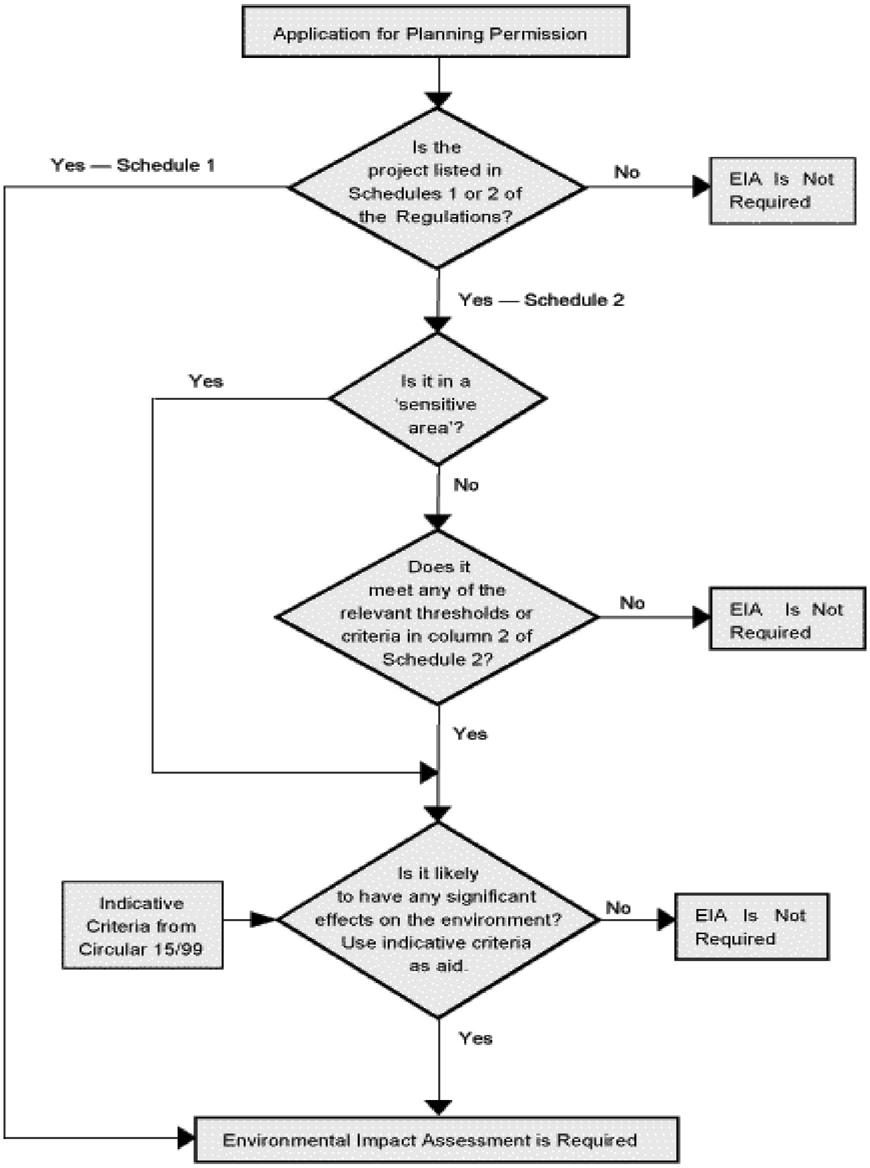

Figure 4.1: Flow chart to establish whether a proposed development needs EIA *(Source: The Environmental Impact Assessment (Scotland) Regulations 1999)*

Surroundings where the wind turbines are located. Most of these guidelines are applicable for wind farms and PAN45 acknowledges that it may be hard to conceal domestic wind turbines.

- **Noise**: Noise from wind turbines can be mechanical noise (gearbox etc) or aerodynamic noise (blade rotation). PAN45 acknowledges that modern day wind turbines are relatively quite and recommends referring to the DTI report 'The Assessment of Rating of

Noise from Wind Farms'. There is a wide spread perception that noise from wind turbines can be significant which may not be the case always. Additional advice is given under SODD circular 10/1999 and also in PAN 56.

- **Construction Disturbance**: This is mainly caused by the use of roads during construction or decommissioning phases where movement of trucks by existing roads or minor roads may cause traffic disturbance. This calls of consultations with Scottish Executive for control of traffic or reinforcement of existing roads during those phases. Also pre-planning consultations and subsequent consultations may be required with relevant road authorities, Rail track (for operational lines) and Rail track Property Board (for non-operational lines).

- **Shadow Flicker**
  During certain seasons, on certain times of a day when sun passes behind wind turbines, the rotation of blades can cause shadow flicks on and off which is known as shadow flicker. PAN 45 suggests that wind turbines be separated by at least 10 diameters so as not to cause this problem and wherever this is not possible, developer shall quantify this effect to make an assessment.

- **Safety**:
  PAN 45 gives advice on some safety aspects
  - Provision of Vibration sensors, which can sense and stop the turbine in case of icing on blades.
  - Provision of Aviation warning lights for any structures that extend 150M above ground.
  - Provision of lightning protection so that lightning is conducted to the earth harmlessly.
  - It recommends that wind turbine products and services to conform to the following standards

- IEC 16400 - Developed for wind energy equipment by International Electro-technical Commission
- BS EN 61400-1 1995- Wind Turbine Generator Systems- Safety Requirements

- **Electro Magnetic Interference for Communications**:
  The wind turbine location may cause significant electromagnetic radiation that can disrupt radio communications (sometimes-commercial or military importance) in the surrounding area. The Radio-communications Agency (RA) maintains the details of radio owners all over UK and identifies radio owners near the proposed site. The RA could itself liaison or advice the developer to have consultations with all interested parties.

- **Civil/Military Aviation**
  The location of wind turbine can cause the following effects, however the intensity can depend upon the size, shape, number and material of turbines wherever relevant.
    - Interference to Navigation systems
    - Implications to flight paths
    - Effect on Take-off and Landings if site is near airports.
    - Designated military low- flying zones

Directions for safeguarding Major Airports and Technical Sites are given under Town and Country Planning (General Development Procedure Scotland) Order 1992

The agencies involved are

Civil Aviation Authority (CAA) And Aerodromes	- For safeguarding civil sites
National Air Traffic Services Limited (NATS)	- Technical sites

Ministry of Defense (MoD) } - For safeguarding military airfields and Technical sites

The planning authorities consult the above agencies for their objections in siting a wind turbine. In case planning authority decides not to act on objections, the aforesaid agencies can request the Scottish Ministers to call in the application.

- **Television Reception**
  These effects can be minimised by installation or modification of local repeater station or some cable connection or by changing local site plans in consultation with transmitter operators.

- **Cumulative Effects**
  These are normally applicable for wind farms rather than domestic wind turbines where either a cluster of wind farms are located or a proposal to extend the existing farm or a proposed new development adjacent to the existing - in all cases the cumulative effect needs to be assessed.

- **Power Lines and Grid Connection**:
  PAN 45 gives some guidelines about Power Lines and Grid connections. Power Lines (wind turbines to sub-station) will be underground whereas grid connections (from 11kV/33kV sub-station to the nearest point of grid) will be over ground. Under ground grid connections are allowed in exceptional circumstances where visual impacts are considered more important. Consent for overhead lines must be obtained under section 36 of the Electricity Act1989 and for development consent must be sought under Section 37 of Electricity Act 1989. These consents are separate from planning permissions

4.5 SUGGESTED LIST OF DOCUMENTS FOR FURTHER REFERENCE

Planning Advisory Notes

~ Planning Advisory Note 45(Revised 2002)
~ PAN 56 on Noise
~ PAN58 on EIA

National Planning Policy Guideline for Renewable Energy Developments

~ NPPG 6: National Planning Policy Guideline for Renewable Energy Developments
~ NPPG14: Natural Heritage
~ NPPG5: Archeology and Planning
~ NPPG6: Conservation of Habitats
~ NPPG18: Planning and the Historic Environment

Other Acts/Documents

~ Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) published by SNH
~ Town and Country Planning (Scotland) Act 1997
~ Town and Country Planning (General Development Procedure Scotland) Order 1992
~ Electricity Act 1989 sections 36 and 37
~ Environment Impact Assessment Regulations 1999
~ A Guide to the EC Habitats Directive in Scotland's Terrestrial Environment ISBN 1 85397 115 4 Free
~ A Guide to the EC Habitats Directive in Scotland's Marine Environment ISBN 1 85397 116 4 Free
~ EC Habitats Directive Natura 2000 - 1992 -EC Habitats Directive series Scotland
~ Special Protection Areas ISBN 1 85397 202 9 Free
~ European Marine Sites - An Introduction to Management ISBN 1 85397 266 5 Free
~ CAP 723 Directorate Guide Directorate of Airspace Policy UK
~ The Civil Aviation Authority (Air Navigation) Directions 2001
~ SODD circular 10/1999 on Noise

- ~ SOEnD Circular 3/1991
- ~ DTI report ‘The Assessment of Rating of Noise from Wind Farms’
- ~ 1999 EIA Regulations

4.6 REFERENCES

1. National Planning Policy Guideline for Renewable Energy Developments NPPG 6
2. Planning Advisory Note 45(Revised 2002)
3. Planning Advisory Note 58 on Environment Impact Assessment
4. Scottish Natural Heritage at www.snh.org.uk
5. Scottish Environment Protection Agency www.sepa.org.uk

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5 WIND TURBINES TECHNICAL REVIEW

5.1 WIND ENERGY SYSTEMS (WES)

Under this section we are going to cover a brief technical review of wind turbine Now that WES technology is quite well established, there are numerous textbooks, journal papers that have dealt with this subject quite in depth. Hence only a brief review is presented below.

5.2 WIND ANALYSIS

The available power from wind is given by the equation
Available Power,

$$P_a = 0.5 \rho A_1 v^3$$

Where

P_a	Is available power
ρ	Is the air density (kg/m^3)
A_1	Is the area of rotor disc (m^2)
v	Is the wind speed (m/s)

From the equation, it can be seen that if the wind speed is doubled, the available power increases by eight times.

Cut-in speed: It is the speed at which wind turbines are designed to start rotating. The usual cut in speed range is 3-5m/s.

Cut-out speed: It is the speed at which the wind turbine is programmed to stop during high winds in order to avoid damage to the turbine. The normal cut-out speeds will be in the range of 20-25m/s.

Weibull Distribution: From the above equation, it is clear that wind speed is an important criterion for site selection and design of a wind turbine. But unfortunately, wind speed is never constant and as the speed varies, the power out put also varies. The changing nature of wind speed is determined by a statistical probability method known as Weibull Distribution. This method helps in the selection of appropriate and cost effective site and thus helps funds being properly utilised for Wind Energy System Operation (*Thomas Bellarmine G. et al)*.

Power Coefficient: It is the efficiency of wind turbine to convert the power in wind into useful electrical output. In other words, power coefficient at any given wind speed can be defined as the ratio of electrical power output to wind power input.

Wind Turbine Power Output

$$P_w = 0.5 C_p \rho A_1 v^3$$

Betz's limit **:** Albert Betz, the German Aero dynamist proves that the maximum value for

C_p cannot exceed 0.593

$$C_{p\max} = 0.593$$

Capacity Factor : This is the ratio of actual annual energy output to that of rated annual energy output

5.3 CLASSIFICATION OF WIND ENERGY SYSTEMS

5.3.1 Based on size

There is no hard and fast classification based on size. Some classify wind turbines less than100kW as small and above 100kW as large. Another prevalent norm of classification is small (up to 2kW), medium (2-100kW) and large (>100kW).

5.3.2 Based on Axis of Rotation

Horizontal axis**:** In this type of turbines the axis of rotation is horizontal and parallel to the direction of wind. These can again be sub classified as 'up wind' and 'down wind' (orientation of blades with respect to wind direction) and also as single bladed, double bladed etc (based on no of blades).

Powered yaw system orients the rotor facing the wind. Almost all wind turbines currently in use are horizontal.

Vertical Axis: The axis of rotation is perpendicular to the wind direction. The Savonious rotor and the Darrieus rotor are examples of vertical machines. The advantages are these machines can face wind from any direction and the generator and gearbox can be mounted on the ground. However the application of these machines is very limited in view of supporting problems.

5.3.3 Based on rotational speed *(R.Bansal et al)*

Constant speed constant frequency (CSCF): The rotor moves at constant speed by controlling blade pitch or generator characteristics. This type of wind turbines can employ either synchronous generators with rigid speed limits or induction generators with small negative slip. Advantage with synchronous generators is they can supply reactive power to the grid, but are expensive. On the other hand induction generators are far less expensive and easier to operate, control and maintain. CSCF schemes mostly tend to employ synchronous generators and hence are expensive.

Variable speed constant frequency (VSCF **):** The variable speed type can maximise the power yield as it can take advantage of higher wind speeds. This scheme mostly employs induction generator, which needs reactive power from the grid. But the generation schemes tend to be complex involving power electronics to convert variable frequency power into constant frequency power.

Variable speed variable frequency (VSVF): The major usage of this scheme is for stand-alone wind power applications. These schemes normally use self-excited induction generators.

5.4 SELECTION OF WIND ENERGY GENERATORS *(G.Thomas Bellarmine et al)*

5.4.1 DC Generators

DC generator output voltage is not constant which is proportional to both flux and speed. The DC output is converted into AC by an inverter, normally with an allowable input ratio of 2:1. Hence a voltage regulator is needed for all voltage ranges input to inverter. Speed regulation is by blade pitch control. A gearbox is used to step up the turbine rotation to generator requirements. A typical schematic is shown above.

Nowadays, DC generators are not very prevalent for WES applications. Even if DC output is needed, it is more common to use AC generators and then convert it into DC by means of simple solid-state rectifiers.

5.4.2 Synchronous Generators

This type of generators can directly be connected to the wind turbine without a gearbox. Even though speed regulation mechanism is there, the minor variations in frequency and phase prevents this system to directly connect to the grid. Hence power electronics are used to control these values in the DC phase before it is inverted back to AC to connect with the grid. Synchronous generators are expensive but capable of supplying controlled reactive power to the grid. The performance of this system depends on the efficiencies of blades, alternator, rectifier and inverter.

5.4.3 Induction Generators

Induction generator is most widely used in WES applications for advantages such as reduced size, absence of separate DC source, reduced unit cost and self-protection against severe overloads and short-circuits. However they absorb reactive power for excitation and need to be rotated slightly faster than synchronous speed. The WES efficiency is based on blades, transmission and generator.

5.5 REFERENCES

1. G.Thomas Bellarmine and J.Urquhart- Wind energy for the 1990s and beyond, Energy Conversion Management Vol37, No12, pp1741-1752, 1996
2. Bansal RC, Bhatti TS, Kothari DP- On Some of the Design Aspects of Wind Energy Systems, Energy Conversion Management 43 2175-2187 (2002)
3. Wind Energy Hand Book by Tony Burton, David Sharpe, Nick Jenkins and Ervin Bossanyi published by John Wiley & Sons, 2001
4. Wind Turbine Technology- Fundamental Concepts of Wind Turbine Engineering – Edited by David A Spera published by ASME press, New York, 1995

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6 ENERGY STORAGE OPTIONS- A REVIEW

6.1 ENERGY STORAGE- A GENERAL PERSPECTIVE

6.1.1 Why Storage?

In the context of complex electric energy networks, storage is necessitated for various reasons with the prime objective of supplying uninterrupted high quality power to the end user, which means that it is a very effective way of matching supply and demand throughout the energy network. These applications can be categorized under generation, Transmission and Distribution or customer services. J.Kondoh et al and R.M.Dell et al have listed some of the distinct applications of energy storage which are as given below.

- *System Regulation (Generation)*

  Storage can serve to meet short –term random fluctuations in demand and so avoid the need for frequency regulation by the main plant. It can also provide ride through for momentary power outages, reduce harmonic distortions and eliminate voltage sags and surges.

- *Spinning Reserve (Generation)*

  This is the generation capacity that a utility holds in reserve to readily meet any sudden and unforeseen demand and also to prevent interruption in the service to customers in the event of failure of an operating generating system/lines. Storage can potentially eliminate part-loaded main plants, which are held to respond immediately during such circumstances.

- *Peak Shaving (Generation)*

  Energy Storage accommodates the minute-hour peaks in the daily demand curve.

- *Load Levelling (Generation)*
  Storage of surplus energy generated during off- peak hours to meet the increased demand during the day.

- *Generation Capacity Deferral (Generation)*
  This is the ability of the system to postpone additional generation to a later date in view of the storage capacity the system possesses to meet the additional demand.

- *Transmission System Stability (T&D)*
  This is the ability to keep all components on a transmission line in synchronization with each other and thus prevent system collapse.

- *Transmission Voltage Regulation (T&D)*
  This refers to the ability to maintain the voltages at generation and load ends of a transmission line within 5% of each other. This encompasses the active and reactive components of power and phase angle.

- *Transmission Facility Deferral (T&D)*
  This refers to the ability of a utility to postpone installation of new transmission lines and transformers by supplementing the existing facilities with another resource, e.g. Battery Energy Storage System. In this application the battery storage acts as a fast response sources of generation at selected locations.

- *Distribution Facility Deferral (T&D)*
  This refers to the ability of a utility to postpone installation of new distribution lines and transformers by supplementing the existing facilities with another resource. Thus application defers from the transmission facility deferral only in that the storage resource is utilised along a distribution line rather than a transmission line.

- *Renewable Energy Management (Customer Service)*
  This refers to the storage of electricity by which renewable energy is made available during periods of peak utility demand at a consistent rate or level. This is more prominent when renewables operate as stand alone systems without access to the grid.

- *Customer Energy Management (Customer Service)*
  This refers to the dispatch of energy stored during the off-peak or low-cost time periods to manage demand on utility –sourced power. This also encompasses peak shaving and load leveling from a customer's point of view.

- *Power Quality and Reliability (Customer Service)*
  This refers to the use of energy storage to prevent voltage spikes, voltage sags, and power outages that last for a few cycles, from causing data and production loss for customers with demands of less than 1 MW.

6.1.2 Advantages of Energy Storage

The benefits of energy storage measures are:

- Improved power quality and reliability
- Reduced transmission and power losses
- Cost Savings due to deferral of additional generation units and system upgrading.
- Reduced environmental impacts due to lower emissions and also due to the integration of renewable distributed generation into the network.
- Strategic advantages such as greater siting and fuel flexibility.

In generating systems largely constituted by fossil fuel power stations, most of the base load demand is met by low cost generating units and peak demand by high cost units. Storage capacity is strictly limited to a few pumped hydro facilities in hilly regions, sometimes supplemented at local level by limited battery storage. Thus the pumped-hydro has emanated as the largest form of electricity storage practiced today.

6.2 STORAGE FOR DISTRIBUTED GENERATION

There is a marked difference between fossil fuels and renewables. Fossil fuels are energy stores, which can be shipped as and when needed, to generate power. On the other hand most of the renewable resources (with the exception of biomass and hydro) cannot be stored and they need to be converted into useful forms of energy. Electricity is the most preferred and versatile form of energy for most applications and hence it is not surprising that renewables and electricity generation go hand in hand. With their advent, an additional demand for storage has been created. As most of the renewables are intermittent which may range from large-scale wind farms to small community renewables such as PV or small wind (these technologies are called intermittent for the reason that they supply electricity in an intermittent manner), storage is necessitated to match the demand during lean periods. The European Union has taken a lead and set up Investire Network in 2001 funded under EC’s Fifth Framework Programme. The aim of this network is to review and assess the suitability of existing storage technologies for renewable energy applications, exchange R&D information, share experience or increase the market share of various storage systems all over the European Countries and facilitate research and technology development activities. Thus this network can potentially integrate all scattered research efforts *(S Hubert et al)*. The first report is expected to be out by October 2003.

Irrespective of the means of electricity production, small-scale storage is likely to assume greater importance in the future. As already discussed, while the pumped storage serves large storage needs, the distributed electricity networks may need medium to small-scale storage based on the size of the system. In the following discussion, we proceed to examine various possible options.

Based on the energy conversion, storage options can be divided into the following categories.

- Potential Energy (Pumped-hydro (PH), Compressed Air)
- Kinetic Energy (Flywheels)
- Thermal Energy (Hot Water, Fused Salts)
- Chemical Energy (Batteries, Hydrogen, Methanol)
- Electro-Magnetic Energy (SMES, Super Capacitors)

6.3 VARIOUS OPTIONS

6.3.1 Potential Energy -Compressed Air Energy Storage (CAES)

In compressed air energy storage, off-peak power is taken from the grid and is used to pump air into a sealed underground cavern to a high pressure. The pressurised air is then kept underground for peak use. When needed, this high pressure can drive turbines as the air in the cavern is slowly heated and released; the resulting power produced may be used at peak hours.

More often, the compressed air is mixed with natural gas and they are burnt together, in the same fashion as in a conventional turbine plant. This method is actually more efficient as the compressed air will lose less energy.

6.3.1.1 Types and requirements of CAES systems

There are many geologic formations that can be used in this scheme. These include naturally occurring aquifers, solution-mined salt caverns and constructed rock caverns. In general, rock caverns are about 60% more expensive to mine than salt caverns for CAES purposes. This is because underground rock caverns are created by excavation of solid rock formations, whereas salt caverns are created by solution mining of salt formations. Aquifer storage is by far the least expensive method and is therefore used in most of the current locations. The other approach to compressed air storage is called CAS, compressed air storage in vessels. In a CAS system, air is stored in fabricated high-pressure tanks. However, the current technology is not advanced enough to manufacture these high-pressure tanks at a feasible cost. The scales proposed are also relatively small compared to CAES systems.

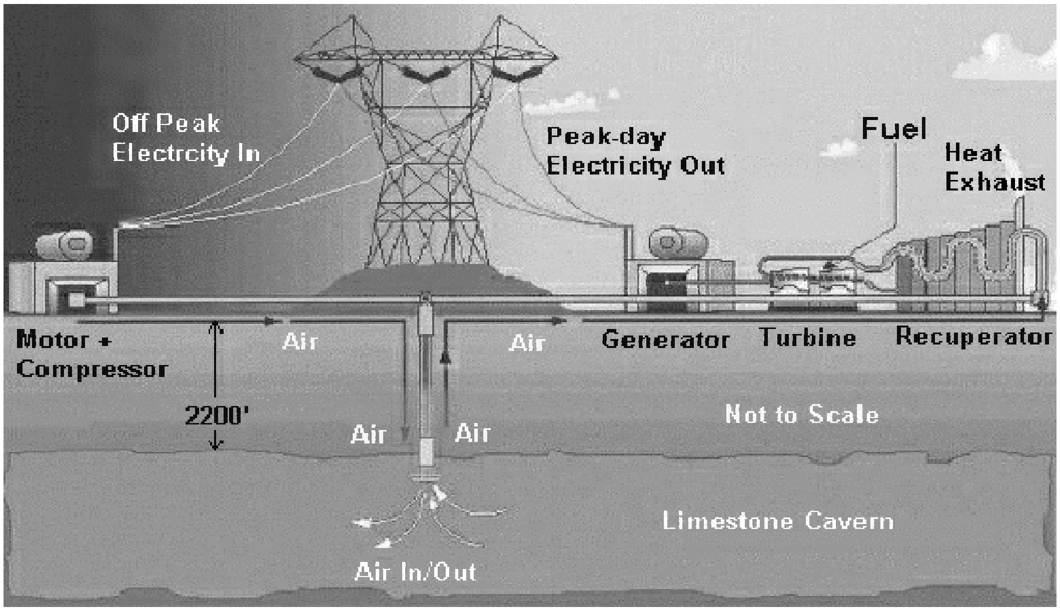

Figure 6.1 Arrangement of a CAES system

6.3.1.2 Advantages of CAES systems

- Large Scale Usage: CAES systems can be used on very large scales. Unlike other systems considered large-scale, CAES is ready to be used with entire power plants. Apart from the hydro-pump, no other storage method has a storage capacity as high as CAES. Typical capacities for a CAES system are around 50-300 MW. The storage period is also the longest due to the fact that its losses are very small. A CAES system can be used to store energy for more than a year.
- Fast start-up: A CAES plant can provide a start-up time of about 9 minutes for an emergency start, and about 12 minutes under normal conditions. By comparison, conventional combustion turbine peaking plants typically require 20 to 30 minutes for a normal start-up.
- Cost Factor: If a natural geological formation is used (rather than CAS), CAES has the advantage that it doesn't involved huge, costly installations.
- Emissions: The emission of green house gases is substantially lower than in normal gas plants.

6.3.1.3 Disadvantages

Location Limitations: The main drawback of CAES is probably the geological structure reliance. There is actually not a lot of underground cavern around, which substantially limits the usability of this storage method. However, for locations where it is suitable, it can provide a viable option for storing energy in large quantities and for long times.

6.3.1.4 Current Status

So far there are only two CAES plants in operation in the world: the 290 MW plant belonging to E.N Kraftwerk in Huntorf, Germany, and 110 MW plant of Alabama Electric Corporation in McIntosh, Alabama, USA, commissioned in 1991.

6.3.1.5 Future and planned construction of CAES

There are additional CAES plants built or planned. For example, Italy has operated a small 25 MW(e) CAES research facility based on aquifer storage. Research has been done in Israel to build a 3 100 MW CAES facility using hard rock aquifers. Similar projects have been started elsewhere to look into the possibilities of CAES systems.

Another plant currently under development is being designed by Norton Energy Storage LLC in America. Their site is a 10,000 ,000 m limestone mine 700 meters deep, in which they intend to compress air up to 100 bar before combusting it with natural gas. The first phase is expected to be between 200 and 480 MW and cost $50 to $480 million. Four more stages are planned, to develop the site to a possible capacity of 2,500 MW.

6.3.2 Kinetic Energy: Flywheel Energy Storage System (FESS)

A flywheel is an electromechanical device that couples a motor generator with a rotating mass to store energy for short durations. Conventional flywheels are "charged" and "discharged" via an integral motor/generator. The motor/generator draws power provided by the grid to spin the rotor of the flywheel. During a power outage, voltage sag, or other disturbance the motor/generator provides power. The kinetic energy stored in the rotor is transformed to DC electric energy by the generator, and the energy is delivered at a constant frequency and voltage through an inverter and a control system. Flywheel provides power during period between the loss of utility supplied power and either the return of utility power or the start of a sufficient back-up power system (i.e., diesel generator). Flywheels provide 1-30 seconds of ride-through time, and back-up generators are typically online within 5-20 seconds.

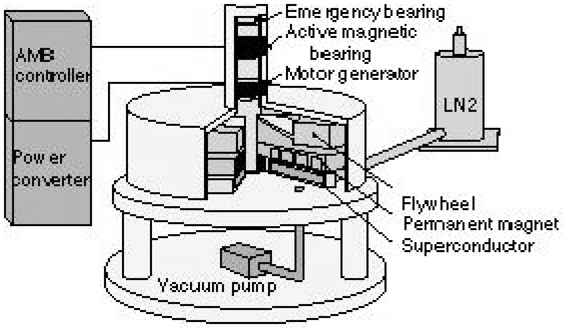

Figure 6.2: Advanced FESS arrangement *(Source:www.nedo.go.jp)*

Traditional flywheel rotors are usually constructed of steel and are limited to a spin rate of a few thousand revolutions per minute (RPM). Advanced flywheels constructed from carbon fibre materials and super conducting magnetic bearings can spin in vacuum at speeds up to 40,000 to 60,000 RPM, which are in development and testing stage. Control of rotational axis vibrations is one of the major issues associated with this technology *(N.Koshizuka et al).*

6.3.2.1 Advantages:

- Acts as high power devices which absorb and release energy at high rate
- Not associated with electrical inefficiencies as with electrochemical devices.
- Long life which is unaffected by frequency of charge discharge cycles and the amount of energy stored or released there of
- Flexibility of design and size
- Almost maintenance free
- No toxic materials used in manufacturing and hence create no environmental impact in use or in recycle

6.3.2.2 Limitations

- Relatively modest capability of energy storage
- Not suitable for long term storage
- High cost

6.3.2.3 Applications

- Best suited for applications which involve frequent charge and discharge of modest quantity of energy at high power ratings.
- Act as complimentary to batteries
- Possible application in electric and hybrid electric vehicles
- Flywheels are of potential interest in **renewables** such as wind and photovoltaics, which exhibit large, frequent and rapid fluctuations in power output. Existing applications include synchronous flywheel in a wind-diesel system, Punta Jandia, Fuerteventura, a Urenco 100kW wind system at Fuji, Japan and probably the largest of all is the wind-diesel system including flywheel energy storage at Denham in Australia is where three Enercon E-30 wind turbines have total rated power of 690kW *(Dr A.Ruddell).* Almost all existing applications of flywheels in renewable energy are meant for wind energy applications in rural area electrification or operation of desalination plant for islands and they typically use the low technology-low speed flywheels.
- A flywheel based buffer store can eliminate power electronics downstream to track fluctuations and improve overall efficiency. Rechargeable batteries are widely used to day but a battery-flywheel combination is worth a try.

6.3.2.4 State of Art:

Boeing Corporation of US has teamed up with Department of Energy to jointly develop a 2 kWh laboratory flywheel system and a 10 kWh-flywheel electricity system. Testing on the 10 kWh is continuing. Another ambitious project that was finalised in late 2002 is to develop a 35kWh-flywheel electricity system for power risk management that is presently at concept design stage.

6.3.3 Thermal Energy Storage: Hot Water

It is one of the oldest forms of energy storage commonly used. The excess electricity can be effectively utilized by heating water either through resistance heating or induction heating. The hot water in turn can be used for space heating or other hot water applications. A study by the Centre for Appropriate Technologies, Australia (CR Lloyd) showed that on an average the commercial heaters produce 22l of hot water at 60 C using 1kWh of electricity yielding efficiency levels of 80%.

Hot water storage is most commonly used in solar photovoltaic applications. The disadvantage is however, this is irreversible i.e. hot water cannot be readily convertible into electricity and hence utility scale applications are limited.

6.3.4 Chemical Energy Storage: Hydrogen Fuel Cells (EZ+FC)

Fuel cell works on the principle of electrochemical reaction between hydrogen fed to the negative electrode and oxygen or air fed to the positive electrode to produce low voltage dc current and water. Electrolysis is not an economic production of hydrogen and alternative methods are by catalytic steam reforming of naphtha or gas or by partial oxidation of heavy oils.

Fuel cells, in the future, are going to play an important role in storage applications. Fuel cells are like primary batteries and as such cannot charge and discharge to store electricity. It is an indirect way, where excess electricity is used to produce hydrogen by electrolysis, store and use via fuel cells to produce electricity. A typical fuel cell cycle is given below.

Electricity → Electrolyser → Hydrogen Store → Fuel Cell →
Electricity *(RM Dell et al, Journal of Power Sources 100 (2001)2-17)*

The major impediment in this technology is storing hydrogen mainly due to cost considerations and handling problems. Also what matters, is whether hydrogen is produced using electricity generated from renewable resources or not. For renewable energy storage applications, the requirements are to size the electrolyser to accommodate excess electricity, but the problem remains in the control of hydrogen production with changing loads and usage of fuel cells to meet variable demand requirements. Experts predict solid hydrides can be a solution, but the technology is still under development

6.3.5 Chemical Energy: Batteries Energy Storage System (BESS)

Utilities typically use batteries to provide an uninterruptible supply of electricity to power substation switchgear and to start backup power systems. However, there is an interest to go beyond these applications by performing load levelling and peak shaving with battery systems that can store and dispatch power over a period of many hours. Batteries also increase power quality and reliability for residential, commercial, and industrial customers by providing backup and ride-through during power outages (*Carl D Parker*).

Now batteries are widely used medium for storage of renewables also especially in wind and photovoltaic systems. The standard battery used in energy storage applications is the lead-acid battery. A lead-acid battery reaction is reversible, allowing the battery to be reused. There are also some advanced sodium/sulphur, zinc/bromine, and lithium/air batteries that are nearing commercial readiness and offer promise for future utility application. In this section, we discuss five categories of batteries, which are the possible candidates for renewable storage applications.

6.3.5.1 Lead Acid Batteries

Today, several types of lead acid batteries are manufactured for different applications. For example, automotive batteries are widely used in cars, vehicles etc. for start up power and other duties. They are not often subjected to deep discharge and under these circumstances have a life of several years. Tubular type traction batteries are used to power electric vehicles. Finally valve regulated lead acid batteries are assuming increasing importance as they do not need water top ups and may be used in any orientation.

Applications: These are invariably chosen for wind or solar power installations on account of their range of sizes and the acceptable cost.

Disadvantages:

- Periodical maintenance
- Relatively poor performance at low and high ambient temperatures
- Limited charge discharge cycle-life.

Future: The advances in valve regulated gel type batteries look promising in overcoming some of the disadvantages.

6.3.5.2 Other Types of Batteries

The following are other forms of batteries being extensively used and further developed for various small to medium storage applications typically from electronics to utility scale applications.

- Alkaline Batteries
- Flow Batteries Regenerative Fuel Cells
- High Temperature Batteries
- Lithium Batteries
- Electric and Hybrid Electric Vehicles

6.3.6 Super-Conducting Magnetic Energy Storage (SMES)

Super-conducting Magnetic Energy Storage (SMES) systems store energy in the magnetic field created by the flow of direct current in a coil of super conducting material that has been cryogenically cooled.

How It Works

A super conducting material enhances storage capacity. In low-temperature super conducting materials, electric currents encounter almost no resistance. The challenge is to maintain that characteristic without having to keep the systems quite so cold.

Advantages

Power is available almost instantaneously, and very high power output is provided for a brief period of time. There is no loss of power, and there are no moving parts.

Disadvantages

The energy content of SMES systems is small and short-lived, and the cryogenics (cold temperature technology) can be a challenge.

Applications

Already dramatically used in such applications as high-speed, magnetic-levitated trains, superconductors are also being developed for use in microelectronics and communications.

6.3.7 Advanced Electrochemical Capacitors (S-CP)

Super capacitors (also known as ultra capacitors or super capacitors) are in the earliest stages of development as an energy storage technology for electric utility applications. An electrochemical capacitor has components related to both a battery and a capacitor. Consequently, cell voltage is limited to a few volts. Specifically, the charge is stored by ions as in a battery. But, as in a conventional capacitor, no chemical reaction takes place in energy delivery. An electrochemical capacitor consists of two oppositely charged electrodes, a separator, electrolyte and current collectors. Presently, very small super capacitors in the range of seven to ten watts are widely available commercially for consumer power quality applications and are commonly found in household electrical devices. Development of larger-scale capacitors has been focused on electric vehicles. Currently, small-scale power quality (<250 kW) is considered to be the most promising utility use for advanced capacitors.

6.4 Comparison of Storage Technologies

According to J.Kondoh et al, an ideal storage system is one, which is inexpensive, provides long life, good power densities and conversion efficiencies and has least environmental impacts. But no single storage technology meets the criterion. Hence the above-discussed Storage Technologies can be compared on the basis of technology development/maturity, cost, conversion efficiencies, output power, energy densities, long life and environmental concerns.

In view of their rapid response capabilities (<5ms)(but varying degrees of power and energy capabilities), Batteries, SMES, Flywheels and Super-Capacitors are best suited for power quality related responses *(C.D.Parker)*.

At the moment Capacitors and SMES are still under developmental stage to be suitable for renewable applications and as such these technologies are expensive.

Thermal Energy storage cannot be converted to electricity directly without going through thermodynamic cycles again and so keeping in view the conversion efficiencies it is an impractical option. However, in the absence of other possibilities, this is a useful way to dissipate excess power in the form of hot water, which can be used for residence services.

Compressed air and pumped storage are helpful for large storage needs where rapid response is not an issue. The limitation is these technologies are applicable for particular geographical locations.

That leaves us with battery storage (flooded and valve regulated lead acid), fuel cells and flywheel storage for small-scale renewable applications.

Fuel cells and flywheel storage options at the moment are not cost effective where as battery storage is a proven and mature technology with better versions in the offing. From environmental point of view, batteries pose a big problem of disposal after its active life and can create environmental problems. Though lead acid batteries are reliable, one problem is the need to top up with water regularly. Thus sealed batteries have been developed which potentially eliminate the need for water top-up. Fuel cells and flywheel score better on the environmental front although fuel cells do emit negligible quantities of CO2. On the storage front batteries can cater to long hours where as flywheels with conventional bearings can be very effective for shaving momentary fluctuations on a 10-minute cycle period since it has a large idling loss. Flywheels with levitation bearings are promising for the decrease of idling loss, but the cost of levitation bearings is pretty high at the moment. For flywheels, there is no limit on the number of charge discharge cycles unlike battery and thus enjoy longer life. Hence the selection of storage really depends on the storage scenario requirements. However, in future combination of flywheel and battery storage can serve variety of requirements in small renewables applications.

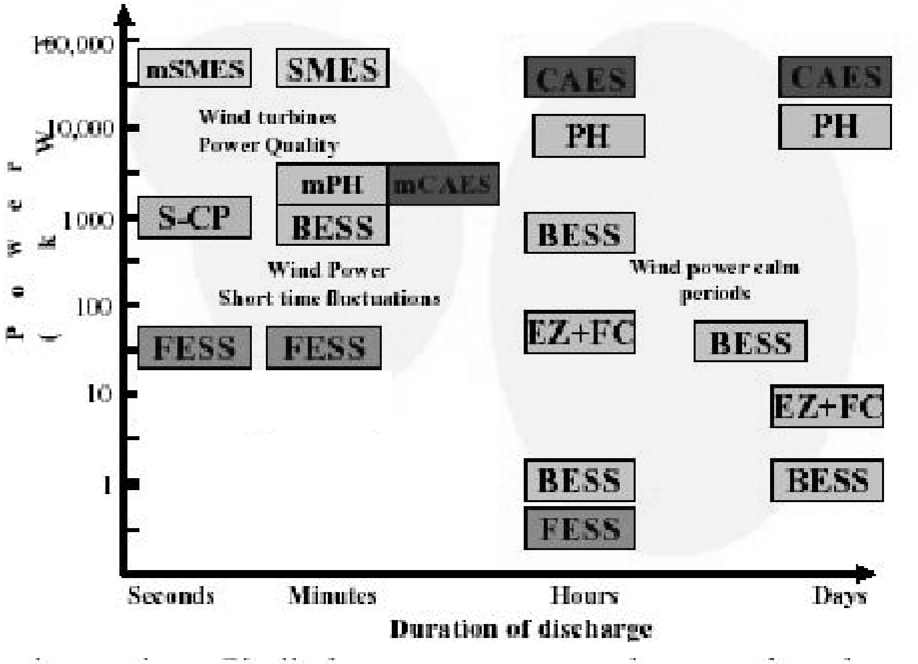

Figure 6.3: Comparison of Storage Technologies for WES applications

(Source: I. Cruz et al)

6.5 STORAGE IN THE CONTEXT OF SMALL WIND POWER

As mentioned before, as all renewables are intermittent and more so with wind, storage assumes paramount importance. The type of storage really depends on the autonomy required and economics involved there of. For example, for a stand alone wind turbine without grid back up, there may be few days in a year without good wind, which means wind turbine effectively can not produce any electric power. In such a case, only a back up diesel generator can provide several days of autonomy. Think about a wind turbine in a remote community with grid connection and imagine a situation of grid failure for days and a low wind period at the same time. Again other storage technologies cannot supply to meet the complete needs of the people during such periods and only a diesel generator can come to the rescue. A bank of batteries can provide storage for few hours and these can effectively plug the gaps between supply and demand during load as well as wind speed fluctuations. Alternatively, a flywheel can provide very effective back up in case of heavy surges both due to load and wind fluctuations but lasting for only a few minutes. The other cheapest option is to use the excess generation when there is high wind and low demand, for thermal storage in the form of hot water, which can be used for services and space heating.

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7 GRID NETWORK REVIEW

7.1 SCOTLAND OVERVIEW

Knowledge of existing grid, its capacity, operator, area distributor, voltage, current and fault levels is required to assess grid connection issues. Since the proposed wind turbine is to be located in Scotland, a review of the Scottish Grid would be most appropriate. There are two transmission system operators in Scotland

- Scottish and Southern Energy in the North
- Scottish Power in the central and South

The bulk transmission system consists of

- 400kV
- 275kv
- 132kV

Scottish Power operates 3 Inter-connectors with Scottish and Southern Energy, National Grid Company and Northern Ireland Electricity. Scottish Power and Scottish and Southern energy carried out a network study in October 2001 on behalf of Scottish Executive to assess the impact of renewables on Scottish Transmission Network. The group considered that there would be an increase of around 1500MW across Scottish Network by way of additional capacity by renewables *(Scottish network study report)*.

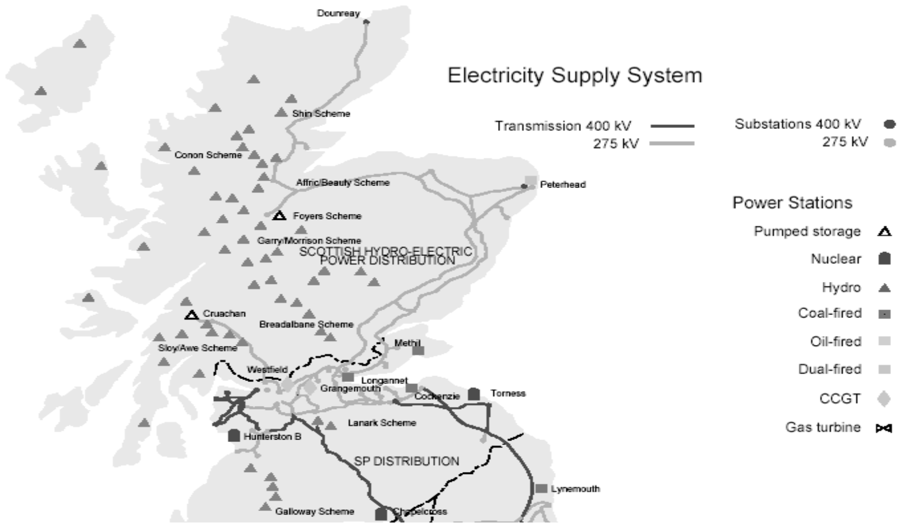

Figure 7.1 Scottish Grid Network

7.2 SCOTTISH AND SOUTHERN ENERGY

This network consists of 275kV and 132kV overhead line as well as cable transmission systems, which cover the North of Scotland. The 275kV connects Dounreay(on the North Coast), Beauly, Blackhillock, Foyers(pumped storage), Peterhead (Coal Station) on the North East. Two double circuit lines to Tealing near Dundee connect with Scottish Power's network at Kincardine, Glenrothes and Westfield. The 132kV system, which runs almost parallel to the 275kV in the North of Scotland, collects majority of hydropower and supplies to the 132/33kV and 132/11kV systems. Around3GWs of generation is connected to this network and the peak indigenous load demand is in the order of 1.7GW. The approximate cost of connecting a new generation to the 33kV network is £55/kW based on 2001 estimates.

7.3 SCOTTISH POWER

This also comprises of overhead lines and underground cables at 132kV, 275kV and 400kV levels. Scottish power operates three interconnection networks with Scottish and Southern Energy in the North, Northern Island Electricity in the west and National Grid Company in the south. Approximately 7.1GWs of generation are connected to this network and with an average peak of 4.2GW. The approximate cost of connecting a new generation to the 33kV network is £33/kW based on 2001 estimates.

The study was based on limitations of thermal and fault levels. The impact on the network depends not only on the capacity and location of new generation to be connected but also on the additional margins available on the existing transmission groups and grid supply points, which is based on the above limitations. Based on the additional capacity levels the impact can be at local, transmission or interconnectors level. At some points the existing network can accommodate the new generation while at other points, system reinforcement is needed. One interesting observation is that wind energy projects are clustering around those areas where network is weak for obvious reasons.

Wind power tends to concentrate in those areas with high wind resource, which happen to be the hilly regions that also have weak networks. The study identifies all areas those capable of accommodating additional generation and those needing reinforcement.

There are many other issues to be considered in connecting large volumes of renewables.

- Effects on the system transient and voltage stability. For example the induction generators used wind turbines can have a detrimental effect on the transient stability reducing the transmission capacity of an existing line.
- Effects on the interconnectors
- Drastic change in the grid response characteristics to maintain grid integrity which is otherwise predominantly supplied by conventional generation
- Effect on power supply quality
- Impact on the control and operation of the system
- Effects on characteristics of the transmission network planning and operation. For example systemic understanding of effects on the local and wider transmission networks with the introduction of wind energy in an existing network.

7.4 CARRON VALLEY

The area of Carron Valley comes under Stirling Council, which is under Scottish Power network. As seen in the map the main source of supply to the village is by a 2-wire single-phase 11kV overhead line (16mm ^{2} copper). This overhead line powers as many as 3 single-phase transformers in the valley. The 3 transformers (Figure 7.2) are located at Easterton Cottage (25kVA), Carron Valley Forestry area (25kVA) and Muirland school (50kVA). The nearest 11kV 3phase transformer is 3 km away. If wind turbine has to produce power, the need of the hour is to have a 3-phase network in the vicinity, which means the existing facility is not suitable and has to be suitably upgraded.

·•—•· 11kV 2 wire 1 phase

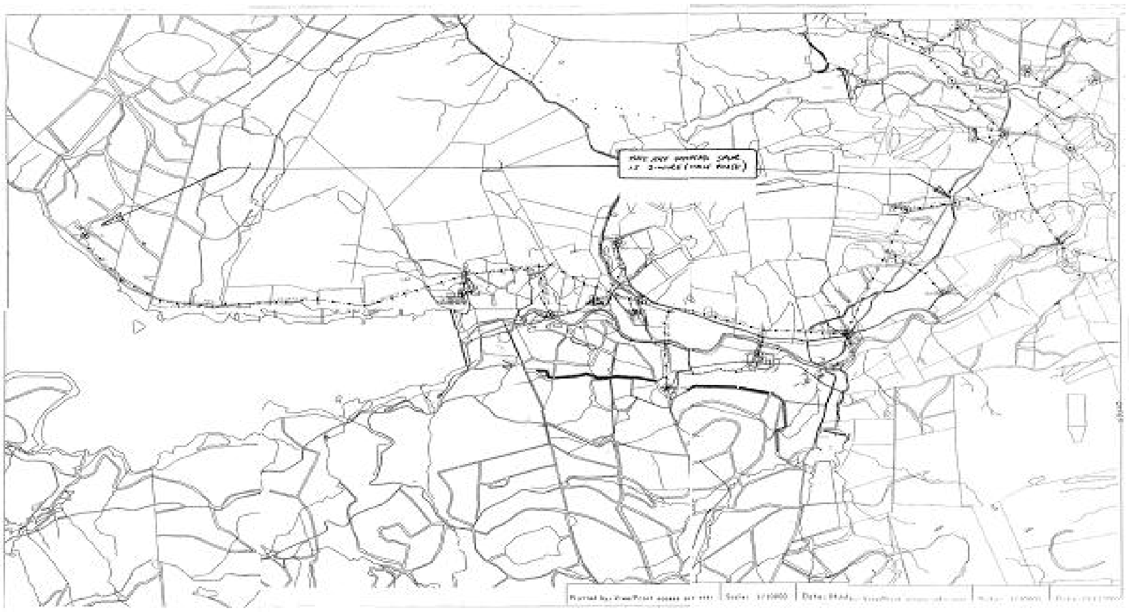

Figure 7.2: A 2-wire single-phase 11kV distribution line powering the village

(Source: SP Power Systems)

7.4.1 Modes of Operation

The wind turbine can be operated in 3 possible modes.

<u>Stand-alone</u>:

This is one possible mode of operation. But the house-to-house distribution network belongs to Scottish Power and the community has to either install its own network or take permission from Scottish Power to use its network. This is quite a complicated situation involving huge costs, safety issues and administrative issues.

<u>Grid Connected</u>

The next possibility is to go for grid connection. This is a common practice and based on the available network rating and proposed addition, the network would be reinforced. Based on the expenses incurred, a fee would be charged for grid connection. The advantage of this option is that the entire power can be sold to the grid at prevailing prices. Technically and commercially this is the most attractive option, but incapable of providing security of supply during grid failures.

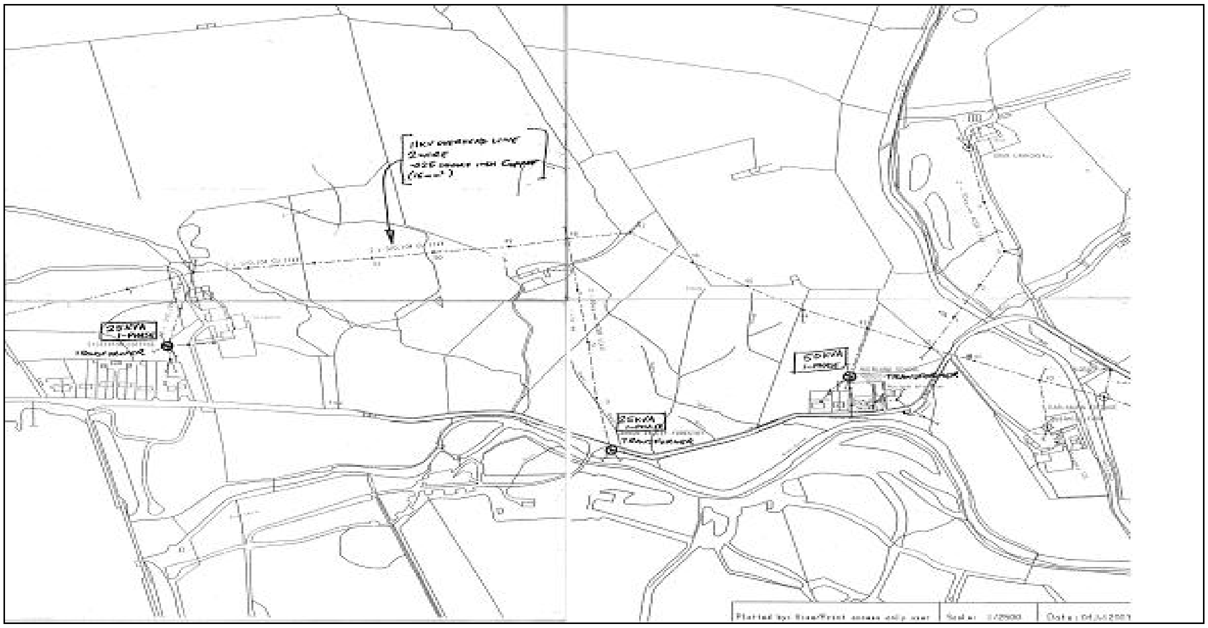

Figure 7.3: Arrangement of Transformers in the valley *(Source: SP Power Systems)*

Switching between stand-alone and grid connected

This arrangement is the most complicated one, and in view of safety issues involved, it needs sophisticated switching, isolation and protection arrangements that incur lot of expenditure. Also two-way metering arrangements are needed to account for import and export.

Commercially this is the least attractive option as the residents pay higher for import and get meager rates in the absence of **net metering**. To encourage small renewables, the US has introduced the concept known as 'net metering' by law and regulation in 23 states *(Ackerman et al)*. Under this arrangement, there will be one single energy meter, which rotates forward while importing from the grid and rotate in the reverse while exporting to the grid. If import is higher than export, the customer has to pay for the balance based on the tariff plans and if vice versa, he will be paid a nominal amount. In 2001, California State raised the limitation for net-metered wind/solar power form 10kW to 1MW. In the UK, the Government is not very keen to the introduction of this arrangement siting reasons that it would attract double subsidy *(UK parliament)*. Hence in the absence of net metering, this would be commercially non-viable option.

However, as far as energy security is concerned, this provides by far the best possible security as well as flexibility. During the periods of low wind, power can be drawn from the grid, during moderate wind power can be drawn simultaneously from grid and wind turbine and during good wind conditions power can not only be supplied to the community but also exported to the grid. All these operations can be automated with the currently available technology.

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8 GENERAL METHODOLOGY AND ELECTRIC LOADS COMPUTATION

8.1 INTRODUCTION

Devising an appropriate methodology is a key to the validity of any feasibility studies. The general obstacles in devising a strategy are time constraints and lack of valid data required for creating a model with reasonable accuracy. A combination of raw data and modelling techniques within certain assumptions improves the efficacy of the model. The current evaluation too, involves a combination of raw data compiled through site visits and questionnaires as well as employing modelling techniques to simulate certain actual conditions to the extent possible to run a model and yield results and make a base for critical evaluation. Although it is impossible to devise a perfect model, effort is made to integrate as much of actual data as possible while emphasis is given on keeping the model as simple as possible or else the focus of the studies might drift in a different direction. Also the main agenda is on the technical analysis of different scenarios and the final validity would be based on an elaborate economical analysis, which is not the focus of this studies, though a chapter is included on the economics to just provide a flavour.

In the current methodology two software tools-ESP-r and Merit (introduced at appropriate stages) have been extensively used. The current objective is to devise a wind energy system suitable for different demand scenarios, which includes typical demand profiles during the problem periods of the year (usually December when blackouts occur in the community). Hence the first step involved is to identify and define various demand scenarios, which is followed by compiling the required demand data with seasonal variations wherever applicable. The various demand scenarios are arrived based on demand side management (DSM). Generally demand side management is a combination of energy efficiency measures and modifying the demand curve such that existing supply can become adequate to meet the demand. The

DSM techniques followed in the present case are modification of demand profiles. The compiled demand profiles will be considered one by one for weighing against supply and storage profiles and back-up systems. The match scenario is analysed and evaluated to give an insight into various issues involved. The tool used for this part of the exercise is in-house developed software called MERIT.

8.1 SITE SURVEY

As mentioned in Chapter 3, a site visit is made to get an actual feel of the area, to gather first hand information, and then proceed to devise a method to elicit more information. Also the survey would be useful to broadly look into siting aspects involving planning and land ownership issues.

8.2 DEMAND PROFILES EVALUATION

As the community do not have any common facilities barring a water pumping station, the major demand profiles are reduced to just two categories. Reasonable margin is incorporated for future demands such as electrical heating and addition of few more electrical appliances. Possible major future demands are kept out of current purview, as this needs a major revamp of existing local grid perhaps involving vast sums of money.

The demands are broadly classified into two major categories

- Electric loads involving present and possible future loads consisting of Lighting, Appliances and pumps
- Heating loads, which is a future demand involving space and water heating. (At present the residents are using a combination of wood and coal to fire their Ray-burns to generate hot water, which is also used for space heating)

8.2.1 Electric Loads- Methodology

Since no records are available which can confirm the demand patterns, it is decided to circulate a questionnaire amongst the residents to yield a reasonable demand pattern, which consists of only electricity component as the residents are using mix of coal and wood for hot water and space heating.

The questionnaire is designed such a way that the usage hours of various electric appliances including lighting are established in a typical winter and summer day. These hours for different appliances are assigned with respective kW rating to calculate the kWh of consumption. These results are extrapolated to yield an annual pattern of electric loads.

8.2.2 Heating Loads- Methodology

Heating loads have been established in a separate section by running simulations in ESP-r under 2 climate profiles namely Eskdalemuir and Glasgow of which the former represents an extreme whether condition whereas the latter represents moderate case. The profiles generated under ESP-r are taken as heating load inputs in the next section.

8.3 DEMAND SCENARIO PLANNING

Based on the demand data, possible scenarios have been identified for comparison and analysis and have been categorised as below.

- Electrical + Heating Load
- Essential Electrical + Heating Load
- Only Electrical Load
- Essential Electrical Load

Electrical + Heating Load

In this case the electrical loads obtained from questionnaires are arithmetically added to the heating loads obtained from ESP-r modelling. This is the ideal case scenario, where theoretically, the supply system would meet overall energy demand of the community.

The rest of the scenarios are formulated based on the principles of **demand side management** and represent gradually reducing demand.

Essential Electrical + Heating Load

This is the second scenario where the essential electrical loads obtained under scenario 4 are added to the heating loads obtained by ESP-r modelling.

Only Electrical Load

This scenario considers total electrical loads obtained from the questionnaires profiled for whole year and the supply will be sized based on electrical loads only.

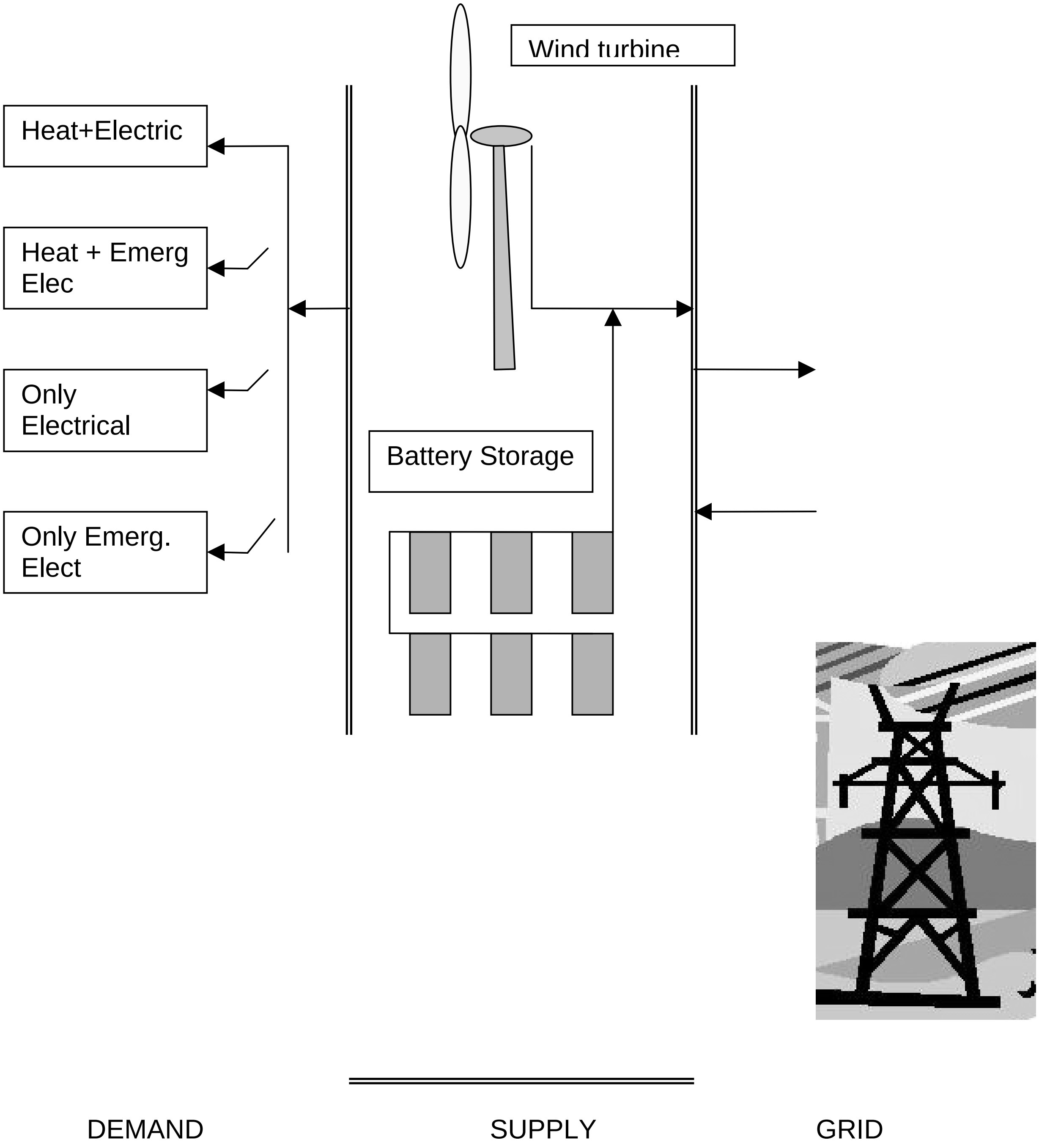

Figure 8.1 Demand Side Management

Essential Electrical Load

Essential loads are arrived at using the data obtained from the questionnaires. Under essential loads only part of the electrical loads are considered based on common reasoning keeping in view the important requirements of the residents in case of loss of grid. These loads consist of some lighting, electric cooker, refrigerator, hot water pump and television. Other appliances such as music systems, computers, washing machines, and dishwashers have been omitted from this list. One important assumption made is that the essential load remains constant throughout irrespective of summer and winter months.

After listing the scenarios, demand profiles would be built using the feature Profile Designer in Merit software

8.4 SUPPLY SPECIFICATION

Using the peak demand profiles under various scenarios, suitable supplies would be assigned in the form of wind turbine systems. Again some inherent features of Merit would be used to evaluate various supplies. The power produced by wind turbine is largely inconsistent and depends on two important criterions. The first criterion is wind resource in terms of speed and the second issue is turbine technical specifications- cut-in and cut-out speeds, type of control- stall or variable pitch and so on. Hence storage or back up is needed which may be battery/flywheel storage or back up by diesel engine or grid connection.

8.5 Storage Profiles

Again, Merit database houses dozens of specifications of different storage technologies namely battery, pumped storage etc. However, the database for flywheels is still in infancy and it would be made available in the near future. Hence for matching purposes, flywheel storage has been excluded.

8.6 Matching and Result Analysis

Using the feature ‘Matching’ available in Merit, demand sets would be matched against supply and storage profiles and results obtained under various scenarios. These results would be critically analysed and conclusions drawn for different scenarios.

8.7 VALIDATION OF ESP-r AND MERIT

ESP-r is an established tool by any standards which has been proved time and again and the validity is best exhibited by the example of Lighthouse Building, Glasgow where embedded systems for building applications have been modelled using ESP-r *(Clarke et al)* . In contrast Merit is a recent development and the validity has been adequately demonstrated on numerous occasions and one such example is the case study of a hypothetical island *(FJ Born et al).*

The next sections deal with using ESP-r and Merit tools and present the results obtained.

8.8 COMPUTATION OF ELECTRICAL LOADS BY QUESTIONNAIRES

Before design of any supply system, it is essential to gather a deep insight of the demand profiles. Almost all the electric loads are from the appliances used by the residents. There are no other common facilities including street lighting. The questionnaires should help obtain only the overall consumption, daily peaks, and seasonal variations. On the negative side, the information obtained from questionnaires is not necessarily be accurate and sometimes the data has to be reinterpreted to convert it into usable form.

8.8.1 Objectives

- To know the list of various appliances used by the residents
- To know about the lighting levels
- To know about other systems such as pumps etc.
- To know what times of the day they are typically used

- To know any common community areas that needs electric power
- To get the above data for a typical summer day and a typical winter day.
- To have an idea of overall daily/monthly kWh consumption, based on records, if any

8.8.2 Methodology

- Design of Questionnaire: Keeping the above objectives in mind, a questionnaire is designed and circulated. A part of the questionnaire is given below (see Annexure for full questionnaire). The questionnaire also includes general questions about the mix of fuels they are using, weather they are in favour of a wind turbine etc.

Usage Habits of Electric Appliances

NAME	MONTHS	NO OF HOURS OF USAGE BETWEEN			
		6-12 hrs	12-18 hrs	18-24hrs	24-6 hrs
Electric Cooker	April-Sept				
	Oct- Mar				
Lighting No of Bulbs:___	April-Sept				
	Oct- Mar				
Hot Water Pump	April-Sept				
	Oct- Mar				
TV	April-Sept				
	Oct- Mar				
Refrigerator	April-Sept				
	Oct- Mar				
Music System	April-Sept				
	Oct- Mar				
Washing Machine	April-Sept				
	Oct- Mar				
Iron	April-Sept				
	Oct- Mar				
Dish Washer	April-Sept				
	Oct- Mar				
Microwave	April-Sept				
	Oct- Mar				
PC/Laptop	April-Sept				
	Oct- Mar				
Others 1	April-				

	Sept				
	Oct- Mar				
2	April- Sept				
	Oct- Mar				

Table 8.1: Sample questionnaire

- Once the range of appliances is known, next stage is to find out the electric ratings of the appliances. These ratings are gathered from the web sites of standard appliances companies such as Phillips, Whirlpool etc that are shown in the following table.

APPLIANCE NAME	RATING
Philips HD4603 Stainless Steel Kettle	2800-3100W 220-240V, 50-60Hz
Philips GC4018 Azur 4000 Steam Iron	2200W
Philips HR7140/6 Cucina Duo Coffee Maker	550W 10-130V, 220-240V and 100V
Philips HR7600 Comfort Compact Food Processor	350W
KitchenAid KSM150 BNK Artisan Food Mixer Brushed Nickel	325 W
Russell Hobbs 10007 Juice Lady Commercial Quality Juice Extractor	700W motor
Kenwood RC310 Rice Cooker	Wattage: 640-760 Voltage: 220/240
Philips HD4432 Contact Grill	1600W
Philips FC9006 Universe Cylinder Vacuum Cleaner Soft Red	1500W IEC/1700W Max
Sony KV21LS30 21" Nicam 4:3 TV	60 W / 0.5 W
Philips LX3000D Home Cinema System	200 Watts
Refrigerator Zanussi ZF4A	368.65 KWHr/year
Washing Machines Zanussi TLE1116W	1.15kWh/Cycle
Tumble Dryers ZanussiTDE4234W	4.5 kWh/Cycle
Dish Washer ZanussiDE6544	1.24kWh/cycle
Zanussi Electric Cooker ZCE700X	1 x .2kW (Dual zone) 1 x 2.0kW (Fish kettle) 2 x 1.2kW and 1 x 0.12kW
Electric Bulbs	60 W
PC/ Laptop	250W
Hot water pump	1000W

Table 8.2: Electrical Rating of Standard Appliances *(Source: Various web sites)*

	POWER CONSUMPTION IN KW BETWEEN HOURS					
	7h-8h	8h-9h	9h-10h	10h-11h	11h-12h	12h-13h
Refrigerator	0.06	0.06	0.06	0.06	0.06	0.06
Elec Cooker	0.62					0.12
Bulbs	0.12	0.12	0.12	0.12	0.12	0.3
Hwpump	0.5	0.5				
Television	0.06	0.06				
Music Sys	0.05	0.05	0.05			0.05
Wm/C	1.15	1.15	4.5	4.5		
Iron		2.2				
Dish Wash						
Mw		1.2				
Pc				0.25		
Total	2.56	5.34	4.73	4.93	0.18	0.53

- The third stage is to link the data from the questionnaires to that of the ratings to arrive at the power consumption on a typical summer day and winter day (Table 8.3 and Figure 8.2).

- This exercise is repeated to all the houses for which the data is available in the form of questionnaires.

Table8.3: Power Consumption of a B&B during the fore noon session in a typical winter day

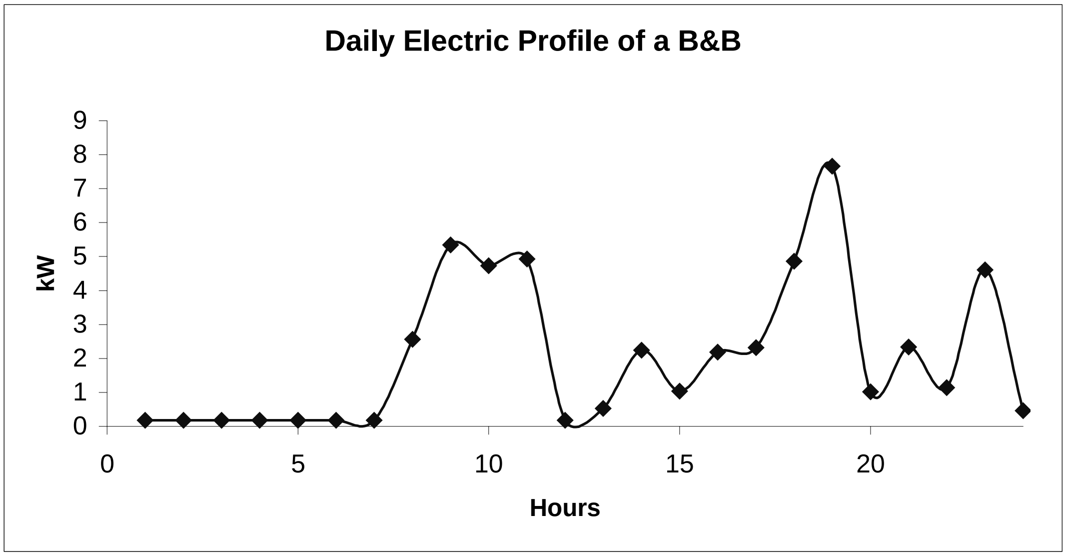

Figure 8.2: Daily Power Consumption Profile for the B&B Accommodation

- All consumption is summed up for winter and summer days respectively. A multiplication factor is used to accommodate for the balance of houses those have not responded to the questionnaires.

- The only common facility requiring electric power is the water pump house and this lone facility is accommodated in the residential electric data.

- Now we are ready with the total electrical demand data of the community for a typical winter day and also for a typical summer day.

- This total electric demand would be scaled down later under Merit profile designer by applying consumption at the rate of 15-17kWh/day/house based on actual measurements in some households.

In the next Chapter, it is discussed how heating loads are calculated using the simulation tool called ESP-r

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9 COMPUTATION OF HEATING LOADS BY ESP-r

9.1 AIMS

The main objective of using ESP-r is to determine energy consumption for space heating for a typical residential building at Carron Valley Community.

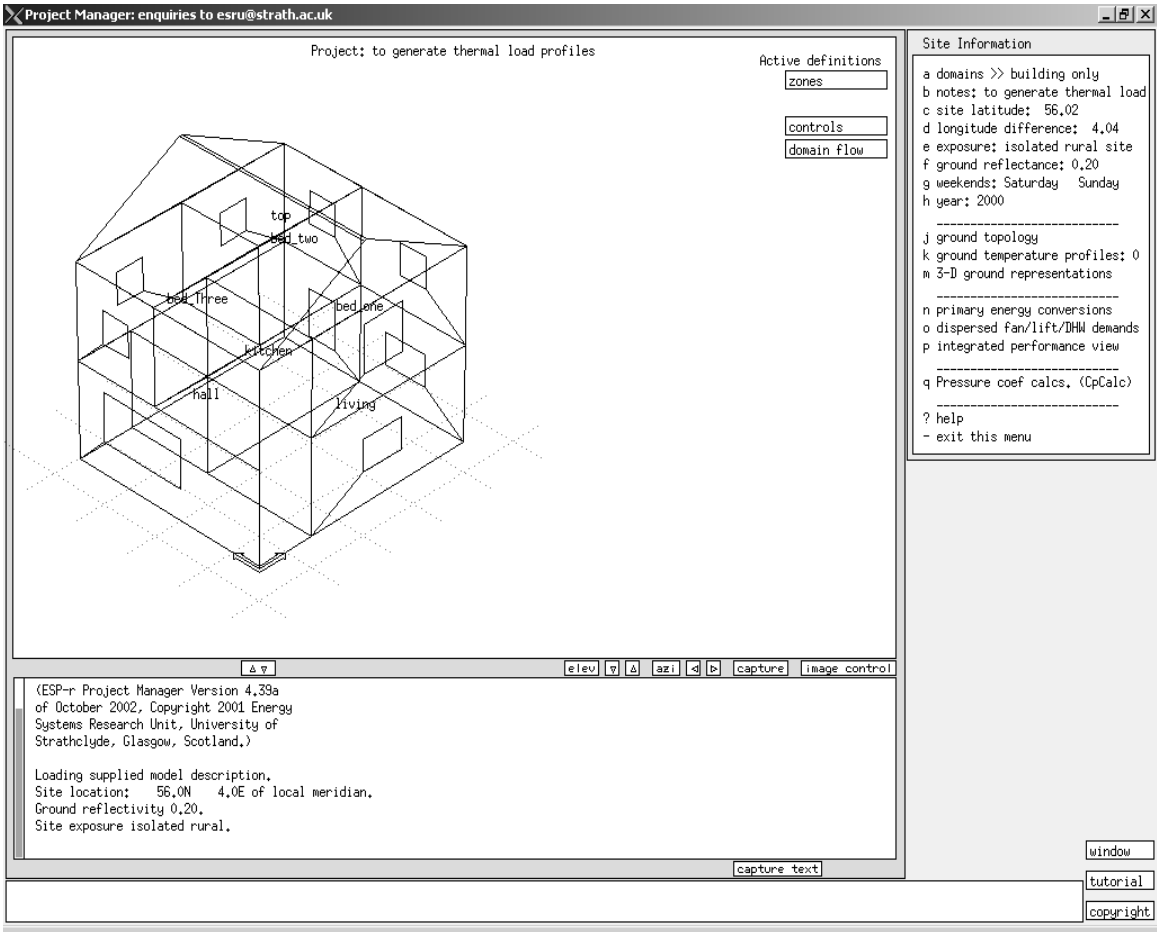
9.2 ASSUMPTIONS

The required assumptions have been specified at different stages as and when the case arises.

9.3 INPUTS

Building Model : Developed based on the measured dimensions of the dwelling at Carron Valley.

Site Location : The locational details selected are 56.0N 4.0E with ground reflectivity of 0.20 and typical isolated rural exposure.



Project: to generate thermal load profiles

```
Site Information
a domains >> building only
b notes: to generate thermal load
c site latitude:  56.02
d longitude difference:  4.04
e exposure: isolated rural site
f ground reflectance: 0.20
g weekends: Saturday   Sunday
h year: 2000
  ----------------------------
j ground topology
k ground temperature profiles: 0
m 3-D ground representations
  ----------------------------
n primary energy conversions
o dispersed fan/lift/DHW demands
p integrated performance view
  ----------------------------
q Pressure coef calcs. (CpCalc)
  ----------------------------
? help
- exit this menu
```

```
(ESP-r Project Manager Version 4.39a
of October 2002, Copyright 2001 Energy
Systems Research Unit, University of
Strathclyde, Glasgow, Scotland.)

Loading supplied model description.
Site location:    56.0N    4.0E of local meridian.
Ground reflectivity 0.20.
Site exposure isolated rural.
```

Figure 9.1 Building Model in ESP-r

Climate Files

Two numbers of climate files have been used to carry out two sets of simulations. They are 1) Glasgow 2) Eskdalemuir. Since actual annual climate details are not available, it is assumed that the actual climate falls between the above two climate profiles. For comparison, the average annual temperatures for Eskdalemuir and Glasgow are 6.93 ^{o}C and 8.91 ^{o}C respectively.

9.4 MODEL DESCRIPTION

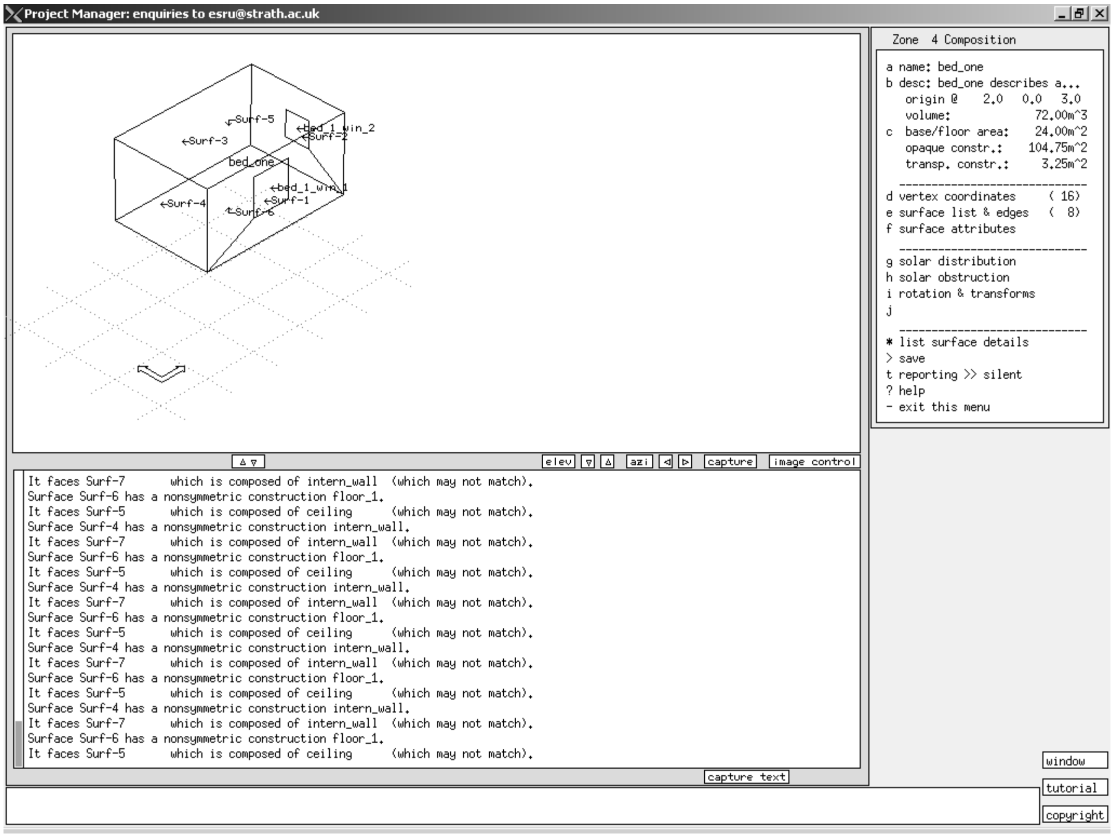
9.4.1 Zones

The building is designed based on the actual dimensions of the dwellings at Carron Valley. The model differs from the actual building only to that extent that finer details such as toilets, passage and terrace have been omitted to keep the model simple.

The model is built with 7 zones consisting of hall, living and kitchen in the ground floor and bed_one, bed_two, bed_three and 'top' on the first floor. The top simply represents the canopied roof space, which is not meant for occupation.

9.4.2 Composition-Construction and Attribution

All outside surfaces have been designated as external_walls and inside surfaces as internal_walls, all windows have been assumed to have double-glazing. The following screen shot gives the geometry and attributes of a typical zone bed_one



```
 Zone  4 Composition
a name: bed_one
b desc: bed_one describes a...
   origin @    2.0   0.0   3.0
   volume:              72.00m^3
c  base/floor area:    24.00m^2
   opaque constr.:    104.75m^2
   transp. constr.:     3.25m^2
   -----------------------------
d vertex coordinates     ( 16)
e surface list & edges   (  8)
f surface attributes
   -----------------------------
g solar distribution
h solar obstruction
i rotation & transforms
j
   -----------------------------
* list surface details
> save
t reporting >> silent
? help
- exit this menu
```

```
It faces Surf-7       which is composed of intern_wall  (which may not match).
Surface Surf-6 has a nonsymmetric construction floor_1.
It faces Surf-5       which is composed of ceiling      (which may not match).
Surface Surf-4 has a nonsymmetric construction intern_wall.
It faces Surf-7       which is composed of intern_wall  (which may not match).
Surface Surf-6 has a nonsymmetric construction floor_1.
It faces Surf-5       which is composed of ceiling      (which may not match).
Surface Surf-4 has a nonsymmetric construction intern_wall.
It faces Surf-7       which is composed of intern_wall  (which may not match).
Surface Surf-6 has a nonsymmetric construction floor_1.
It faces Surf-5       which is composed of ceiling      (which may not match).
Surface Surf-4 has a nonsymmetric construction intern_wall.
It faces Surf-7       which is composed of intern_wall  (which may not match).
Surface Surf-6 has a nonsymmetric construction floor_1.
It faces Surf-5       which is composed of ceiling      (which may not match).
Surface Surf-4 has a nonsymmetric construction intern_wall.
It faces Surf-7       which is composed of intern_wall  (which may not match).
Surface Surf-6 has a nonsymmetric construction floor_1.
It faces Surf-5       which is composed of ceiling      (which may not match).
```

Figure 9.2   Zone descriptions for bed_one

To present an example, all construction details of bed_one (zone_4) are captured in a text file, which is given below.

Zone bed_one (4) is composed of 8 surfaces and 16 vertices. It encloses a volume of 72.0m^3 of space, with a total surface area of 108.00m^2 & approx floor area of 24.00m^2 bed_one describes a...

```
 A summary of the surfaces in bed_one( 4) follows:

 Sur| Area  |Azim|Elev| surface    |geometry| multilayer   |environment
    | m^2   |deg |deg | name       |type|loc| constr name  |other side
  1    15.75 180.   0. Surf-1       OPAQ VERT extern_wall  ||< external
  2    11.00  90.   0. Surf-2       OPAQ VERT extern_wall  ||< external
  3    18.00   0.   0. Surf-3       OPAQ VERT intern_wall  ||< identical environment
  4    12.00 270.   0. Surf-4       OPAQ VERT intern_wall  ||< Surf-7:hall
  5    24.00   0.  90. Surf-5       OPAQ CEIL ceiling      ||< adiabatic
  6    24.00   0. -90. Surf-6       OPAQ FLOR floor_1      ||< Surf-5:living
  7     2.25 180.   0. bed_1_win_1  TRAN VERT d_glz        ||< external
  8     1.00  90.   0. bed_1_win_2  TRAN VERT d_glz        ||< external

All surfaces will receive diffuse insolation.
```

```
Surface Surf-4 has a nonsymmetric construction intern_wall.
It faces Surf-7       which is composed of intern_wall  (which may not match).
Surface Surf-6 has a nonsymmetric construction floor_1.
It faces Surf-5       which is composed of ceiling      (which may not match

 Zone construction details for bed_one ( 4)

Surface    |Layer|Mat|Thick  |Conduc-|Density |Specif|IR  |Solr| Description
           |     |db | (m)   |tivity |        |heat  |emis|abs |
Surf-1         1    4 0.1500    0.960  2000.0   650.0 0.90 0.93 Outer leaf brick
               2  211 0.0370    0.040   250.0   840.0           Glasswool
               3    0 0.0500    0.000     0.0     0.0           air gap (R= 0.170)
               4    2 0.1500    0.440  1500.0   650.0 0.90 0.65 Breeze block
            Standard U value for construction extern_wall is   0.56
Surf-2         1    4 0.1500    0.960  2000.0   650.0 0.90 0.93 Outer leaf brick
               2  211 0.0370    0.040   250.0   840.0           Glasswool
               3    0 0.0500    0.000     0.0     0.0           air gap (R= 0.170)
               4    2 0.1500    0.440  1500.0   650.0 0.90 0.65 Breeze block
            Standard U value for construction extern_wall is   0.56
Surf-3         1    2 0.1500    0.440  1500.0   650.0 0.90 0.65 Breeze block
               2  103 0.0120    0.180   800.0   837.0 0.91 0.60 Perlite plasterboard
            Standard U value for construction intern_wall is   1.71
Surf-4         1    2 0.1500    0.440  1500.0   650.0 0.90 0.65 Breeze block
               2  103 0.0120    0.180   800.0   837.0 0.91 0.60 Perlite plasterboard
            Standard U value for construction intern_wall is   1.71
Surf-5         1  211 0.1000    0.040   250.0   840.0 0.90 0.30 Glasswool
               2  150 0.0100    0.030   290.0  2000.0 0.90 0.60 Ceiling (mineral)
            Standard U value for construction ceiling is   0.33
Surf-6         1  263 0.1000    1.280  1460.0   879.0 0.90 0.85 Common earch
               2   82 0.1000    2.900  2650.0   900.0           Red granite
               3   32 0.0500    1.400  2100.0   653.0           Heavy mix concrete
               4  124 0.0500    1.400  2100.0   650.0 0.91 0.65 Cement screed
            Standard U value for construction floor_1 is   2.76
bed_1_win_1    1  242 0.0060    0.760  2710.0   837.0 0.83 0.05 Plate glass
               2    0 0.0120    0.000     0.0     0.0           air gap (R= 0.170)
               3  242 0.0060    0.760  2710.0   837.0 0.83 0.05 Plate glass
            Standard U value for construction d_glz is   2.75
bed_1_win_2    1  242 0.0060    0.760  2710.0   837.0 0.83 0.05 Plate glass
               2    0 0.0120    0.000     0.0     0.0           air gap (R= 0.170)
               3  242 0.0060    0.760  2710.0   837.0 0.83 0.05 Plate glass
            Standard U value for construction d_glz is   2.75
```

9.4.3 Operation:

Under operation, casual gains from human beings, lighting and some appliances have been included and assumed to be similar in all occupancy zones, the summary of which for one zone (bed_two) is given below. No casual gain controls have been defined.

```
  Description : nil_operations
 Number of Weekday Sat Sun casual gains=  5  5  5
Day Gain Type     Period Sensible  Latent     Radiant    Convec
    No.  labl     Hours  Magn.(W)  Magn. (W)  Frac       Frac
Wkd  1 OccuptW    7 -  8     20.0     20.0       0.50       0.50
Wkd  2 OccuptW    8 - 11     10.0     10.0       0.50       0.50
Wkd  3 OccuptW   11 - 18     30.0     30.0       0.50       0.50
Wkd  4 OccuptW   18 - 23     50.0     50.0       0.50       0.50
Wkd  5 LightsW   20 - 24     30.0     30.0       0.50       0.50
Sat  1 OccuptW    7 -  8     20.0     20.0       0.50       0.50
Sat  2 OccuptW    8 - 11     10.0     10.0       0.50       0.50
Sat  3 OccuptW   11 - 18     30.0     30.0       0.50       0.50
Sat  4 OccuptW   18 - 23     50.0     50.0       0.50       0.50
Sat  5 LightsW   20 - 24     30.0     30.0       0.50       0.50
Sun  1 OccuptW    7 -  8     20.0     20.0       0.50       0.50
Sun  2 OccuptW    8 - 11     10.0     10.0       0.50       0.50
Sun  3 OccuptW   11 - 18     30.0     30.0       0.50       0.50
Sun  4 OccuptW   18 - 23     50.0     50.0       0.50       0.50
Sun  5 LightsW   20 - 24     30.0     30.0       0.50       0.50
```

9.4.4 Controls

- Only single day type is assumed which is a typical weekday. As the actual community is in a remote area, most likely they either spend relaxing on weekends or they may go for an outing for the weekends, which gives us, on an average, a typical weekday profile.
- The occupancy hours for hall assumed to be between 4 PM to 10 AM, for living 10AM to 4PM and for all bedrooms from 7PM to 7AM.
- No heating considered for kitchen because it is assumed that the casual gains from appliances are sufficient enough to keep the occupants comfortable during the hours of occupancy.
- No heating assumed for roof.
- Basic control is assumed for the above zones during occupancy hours and during other periods, it is taken as free floating. Full details are given in the appendices.
- Heating temperature set point is given as 21 C, which means all the living areas receive heating for a temperature below 21 C.

- Sine no cooling is envisaged, the cooling set point is kept high at 100C.

The control loop summary is:

```
Zone to contol loop linkages:
 zone ( 1) hall         << control  1
 zone ( 2) living       << control  2
 zone ( 3) kitchen      << control  0
 zone ( 4) bed_one      << control  3
 zone ( 5) bed_Three    << control  3
 zone ( 6) bed_two      << control  3
 zone ( 7) top          << control  0
```

9.4.5 Plant and Systems

No plant and systems have been assumed since the current aim is only to calculate heating loads neglecting the efficiency criterion of various systems providing the space heat.

9.5 SIMULATION

The model building is complete with above assigned input variables and attributes. The next step is to run the simulation. Some of the highlights have been presented below.

Period of simulation : 1st January to 31st December
Time steps : 2/hour
Climate files : Glasgow and Eskdalemuir

Respective system configuration file and control file have been assigned and results stored in library files.

9.6 RESULTS SETS

Two sets of results for each input climate file have been sought. The first result set is about total sensible + latent heating load in all defined zones. This is matched against second result set consisting of comfort factors in % of ppd for the occupied hours in each zone. A range between 0-25% with default clothing levels is assumed comfortable. The result sets are as given below

1. Heating load with Glasgow Climate
2. %PPD for the above heating.
3. Heating load with Glasgow Climate
4. %PPD for the above heating

9.6 RESULTS ANALYSIS

1. Ambient Temperature Profiles of both Eskdalemuir and Glasgow have been generated from respective Climate files. Using the climate files and the simulation results of ESP-r, a comparative table is presented.

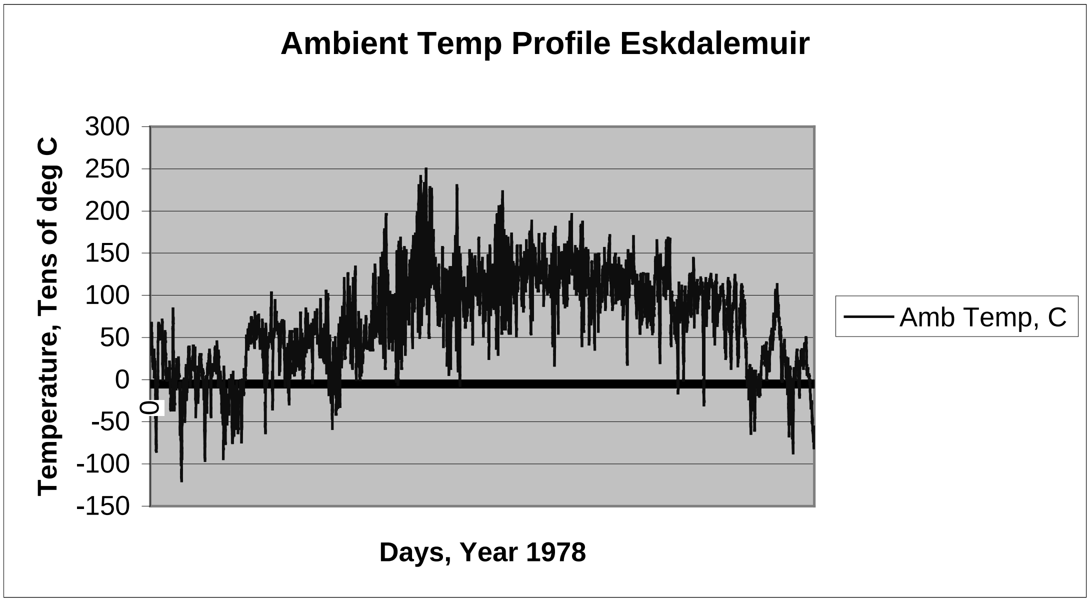


Figure 9.3 Ambient temperature profiles for Eskdalemuir

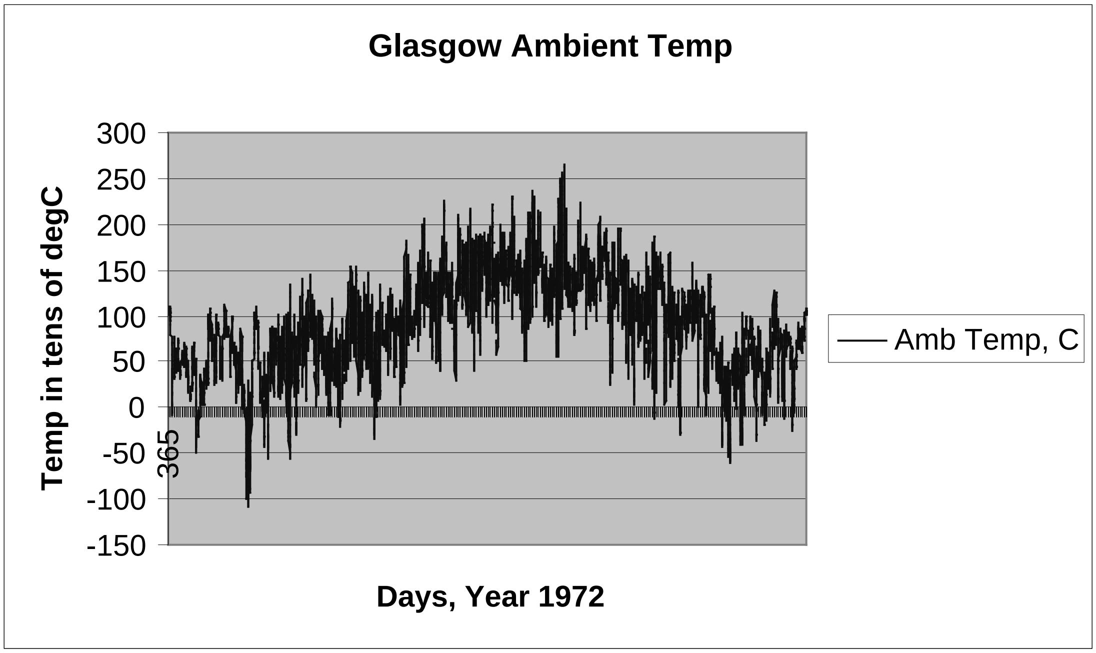


Figure 9.4 Ambient temperature profiles for Glasgow

Comparison of Eskdalemuir and Glasgow

	Mean Amb Temp, C	Mean Wind speed, m/s	Tmin C	Tmax C	Mean Heat Power, kW
Eskdalemuir	6.93	4.55	-12	25	1.179
Glasgow	8.91	4.57	-11	27	1.025

Table 9.1: Comparison of Eskdalemuir and Glasgow

2. Above table 9.1, indicates that the mean ambient temperature at Eskdalemuir is much lower than that of Glasgow. Also the lowest/highest temperatures reached in Eskdalemuir in a year are lower than that of Glasgow. It is evident that Eskdalemuir is much colder place and thus consumes more energy for space heating and thus the mean power consumption for space heating in Eskdalemuir is higher than that of Glasgow.

3. Eskdalemuir Climate- Heating and PPD for a typical week (15th Jan – 21st Jan)

Based on the simulation results, the following graph is presented for the coldest period of Eskdalemuir climate. The purpose of the graph is to show that the heating power is sufficient to maintain good comfort factor during occupancy hours in the respective zones.

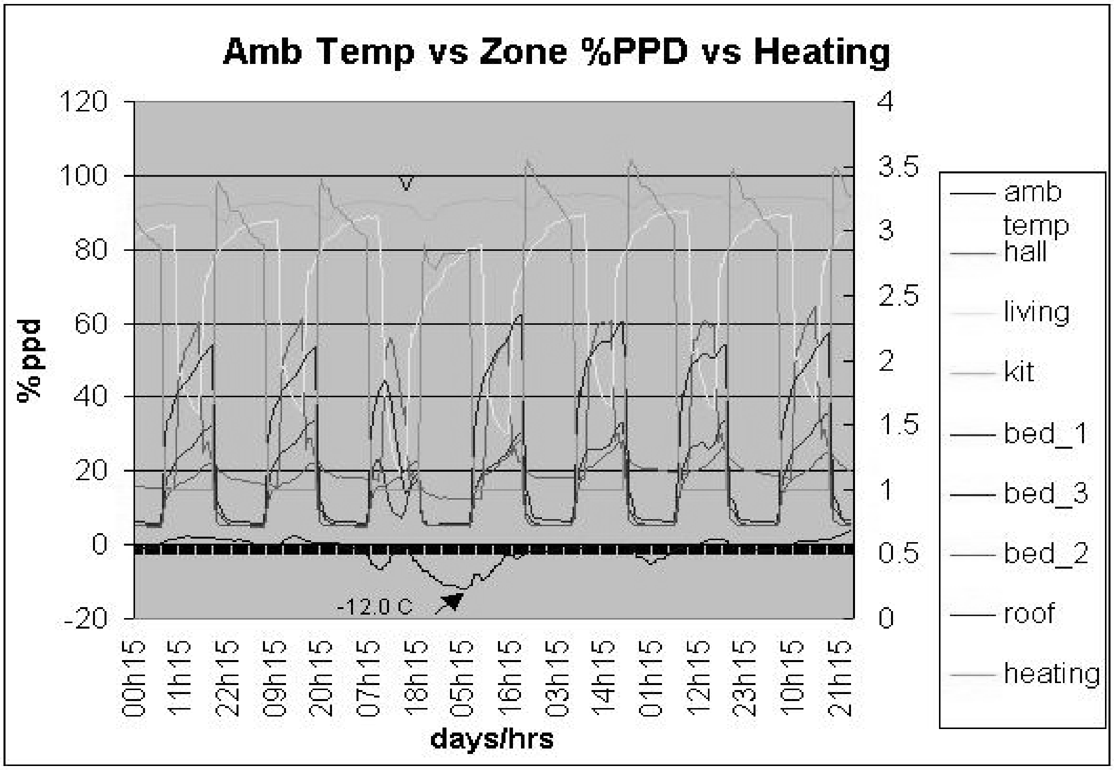


Figure 9.5 Zone Comfort Matrices for Eskadalemuir Climate

In the above graph (Fig 9.5), the comfort levels in terms of % ppd with respect to climate and heating loads based on occupancy hours have been compared. For example, in all bedrooms, occupancy has been defined between 19 hrs and 7hrs and it can be seen the %ppd between those hours is below 10 while during these hours, the heating demand is at its peak. As day hour occupancy is defined only for living room between 10am to 4 pm, the % ppds for this zone are low only during these hours. As no occupancy and heating envisaged for kitchen and roof, their ppd levels are consistently above 90%. These results prove that the selected controls are validated.

4 Similar result set is produced for Glasgow climate as well and the heating loads of these respective sets are taken as input for subsequent analysis using Merit software tool. A snapshot of % ppd result trends for Glasgow climate for the period between 1 st Jan to 15th Jan is presented below (Fig 9.6). Similar reasoning, discussed before is applicable for this graph also.

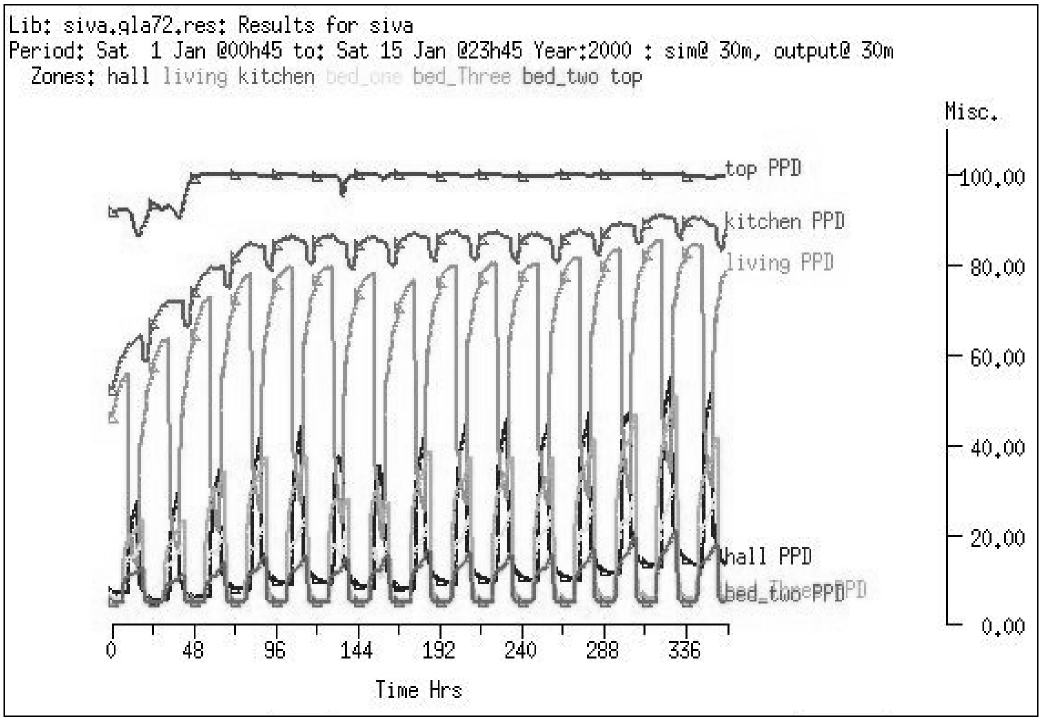


Figure 9.6 Zone wise % ppd for Glasgow Climate

5 And finally, the annual heating profiles for one dwelling with respective climates are given below (Fig 9.7 and Fig 9.8). These profiles have been used as inputs to Merit Tool to design the Wind Energy System.

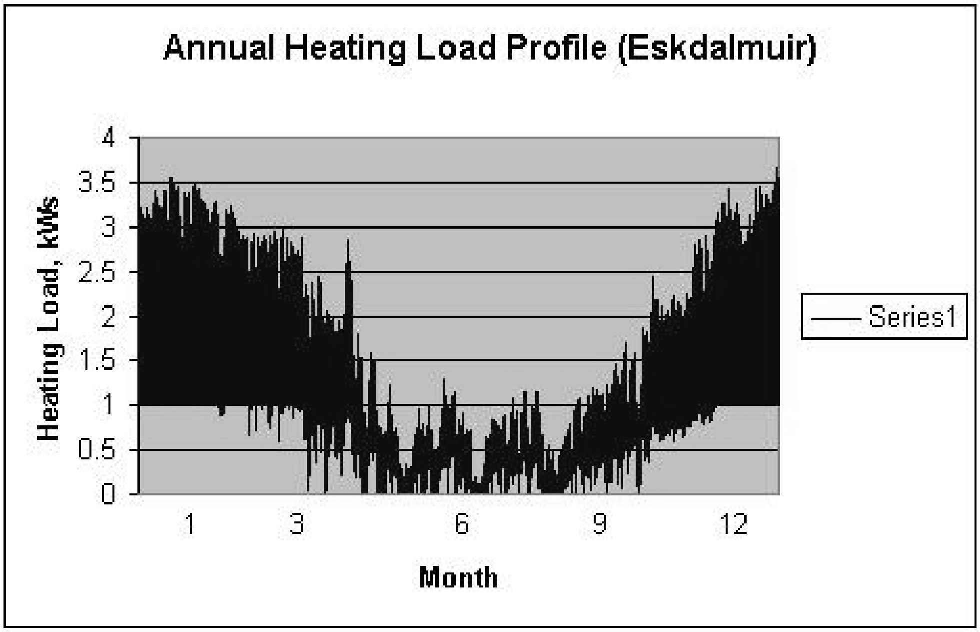


Figure 9.7 Require Heating Loads of the building for Eskdalemuir Climate

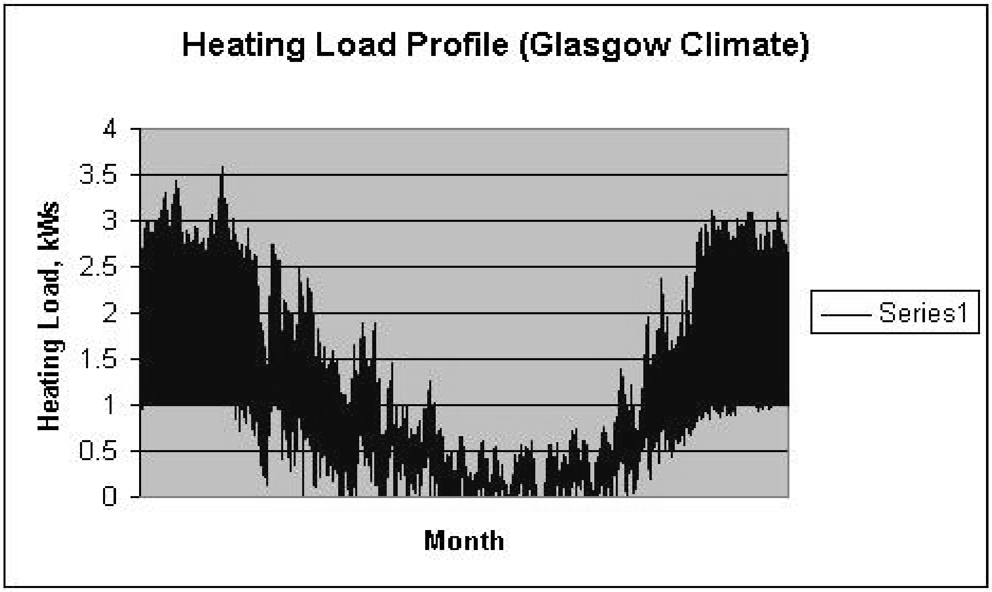


Figure 9.8 Require Heating Loads of the building for Glasgow Climate

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10. DESIGN AND ANALYSIS USING MERIT

10.1 MERIT- THE ULTIMATE RENEWABLES MATCHING TOOL

The idea of developing an integrated renewables matching tool was conceived by Ms F.Born while she was doing her doctorate and in due course the tool was evolved leading to her Ph.D. in the year 2001. The objective of developing this tool is to facilitate optimum matching of energy demands using energy from renewables with different forms of back up. Later this tool was further developed by Nicola Smith as part of her PhD thesis.

10.2 COMPONENTS OF MERIT

The various components of Merit are very briefly examined in the following paragraphs. It consists of 5 stages.

- Boundary Conditions Specification

- Demand Specification
- Renewables Supply Specification
- Storage/Grid connection Specification
- Matching

10.2.1 Boundary Conditions Specification : Under boundary conditions, one needs to specify the climate file, number of time steps per hour and period of simulation. The significance of the boundary conditions is that the climate files are appropriately interpreted in next stages wherever necessary. For example, the annual wind energy output in supply stage is based on the wind speed input through the climate file.

10.2.2 Demand Specification

This section is designed to input the demand profiles. These profiles can either be selected from the standard demand sets available in the database or user defined profiles can be prepared using the profile designer feature. We can specify any number of demand profiles. The number of profiles can be treated as each single profile or all profiles combined into one.

10.2.3 Supply Specification

As already mentioned before, in this section various supplies will be defined either from the options available in the database or by designing new supply profiles. Again any number of supplies can be defined. Like demand profiles, number of supply profiles can be specified as each single profile or all profiles combined into one. The database of Merit consists of variety of supply profiles ranging from Combined Heat and Power, PV cells, to hydropower and of course winds turbines. The wind turbine database consists of turbines of different specifications of various manufacturers’. During the course of matching, additional wind turbine profiles have been added to the existing database as the occasion demands, which we will examine in detail in subsequent sections.

10.2.4 Storage/Grid connection Specification

Now we move onto the next section where the storage or grid connection options are defined. Again the database consists of various storage options such as battery and pumped storage each of them in turn containing a number of specification sets. Also grid connection option is available under different tariff plans from which any one plan can be selected.

10.2.5 Matching

The last and most important section is matching where in the demand profiles defined are pitted against the selected supplies and storage specifications. All sets selected in the previous sections would appear on the Matching screen. The current aim is to try and match in different combinations and see which gives the best match. The best match is the one, which has least correlation factor. In other words the best match is the one where demand is provided by matching supply not only by the quantity but also by the timing of supply, which amounts to supplying the right quantity at the right time. The out of phase demand/supply is reflected in terms of excess and/ or deficit energy.

In next sections, it is demonstrated how various solutions have been arrived using the tool Merit.

10.3 APPLICATION OF MERIT FOR CARRON VALLEY

10.3.1 Boundary Conditions Specification- Selection of climate files

While computing the heating loads using ESP-r, two climate files have been used namely- Glasgow 1972 (a 30 years average profile) and Eskdalemuir 1978 for reasons already mentioned. But these two climate files yield average wind speed of 4.55 m/s and 4.57 m/s respectively. These speeds as such are quite low and not ideal for wind turbines. Since the elevation reference is unknown, these values cannot be corrected for the required heights. The next option is to look into the weather database available in Merit. Few sets are examined and the Glasgow set gives an average wind speed of 6.5 m/s at a standard observation height of 10M. This time series is corrected to the required height based on the hub heights available for turbines specified in the manufacturer's data sheet by using the formula

$$\boxed{V/V_0 = (Z/Z_0)^{1/7}}$$ *(RC Bansal et al)*

Where

V is predicted wind speed at height Z
V_0 is the wind speed at height Z_0

Other boundary conditions are as follows
Time steps: 2/hour
Period of simulation: Two periods considered
1st January 2003 to 31st December – Typical year
16th December to 31st December – Typical Winter

10.3.2 Demand Specification

Please refer to the demand scenarios from which we can see that there are 3 primary demand sets - Regular Electrical demand, essential electrical demand and heating demand. The listed scenarios are formed by different combinations of these primary sets. The idea now is to integrate these 3 primary sets into Merit demand database since none of them belong to the existing demand sets available in Merit database.

For integrating electrical demand, the key is to use profile designer, which involve the following steps.

- To define number of week days/weekends and in this case only two-day types (summer and winter) are defined treating week days and weekends similarly for the sake of simplicity. Corresponding data is entered in the profile designer against each day type, which is followed by the preparation of templates. Two templates have been obtained for two-day types, validity period having been defined for each day type.
- Next step is to assign Profile effects. In this case, ambient temperature effect is assumed at the rate of 10W/degree C rise of temperature. No % variability is assumed.

- Now the task is to combine different day types along with validity period to generate the annual profile. The annual profile can be scaled by applying consumption and in the present case it is scaled down by 3:1 based on an average consumption of 15kWhrs/house/day (which is a measured feed back from the questionnaires). The profile thus generated is saved under Merit Demand Database.
- Similar procedure is followed for essential electrical demand except that, in this case only one day type is defined.

In comparison, it is rather simple to integrate the heating demand because it is already available as a time series. The only manipulation to be done in case of heating profiles is to convert this single column time series as a .csv file and it is ready for use in Merit.

Now the primary demand sets are combined in such a way we get one set for each demand scenario defined in the previous section. Henceforth, supply and storage specification and matching are considered on case-by-case basis to relate various demand scenarios with supply and storage that gives best match.

10.3.3 CASE IA: Electrical + Heating for whole year

To design the wind turbine and storage to supply total annual electricity demand and heating demand which are 150000 kWh and 188608 kWh respectively.

Boundary Conditions:

Time steps 2/hr and period of simulation is from 1st January to 31st December.

Demand specification:

The profiles are assigned under demand specification feature of Merit by importing them from respective folders.

Supply Specification:

Specifying supply is based on trial and error. The existing profiles consist of wind turbines either too low rated (10kW) or too high rated (150kW). Hence it is decided to build new profiles in the range of 50-60kWs. The most suitable turbines in this range are found to be manufactured by Vergnet, France. The supply profile is built and stored for this turbine with the help of data available in the manufacturer’s data sheet. Then using this saved supply profile, two different supplies have been specified consisting of 1 turbine and 2 turbines respectively. Also the existing 10kW rated LMW wind turbines are considered in convenient multiples.

Specifications of Wind Turbines used in modelling

	Vergnet GEV 15/60	LMW
Rated Power	60 kW	10 kW
Diameter	15m	3.5 m
Control	Pitch Regulated	Stall Regulated
Cut-in wind speed	5 m/s	3
Rated wind speed	15 m/s	12
Maximum wind speed	50 m/s	16

(Source: http://www.vergnet.fr/)

The summary of wind turbines used

- 1x 60kW Vergnet Turbine
- 2x60kW Vergnet Turbine
- 10kW LMW turbine in various multiples

These 3 sets of profiles have been standardised for all subsequent cases.

Match and dispatch

Once demand and supply have been specified, the next exercise is matching. Matching the specified demands with one number of Vergnet turbine yielded a poor result with a match rating of 5/10 resulting in an excess of 78043/2 kWh and a deficit of 434071/2 kWh.

Next attempt is made connecting 2 Vergnet wind turbines of 50kWs and the results are analysed. This time the result is not any better. Match rating has not improved (5/10), but of course creating lower deficit (317139/2), and higher excess (409694/2).

Storage Specification: Battery Storage

The next attempt involves assigning battery storage by trial and error and to check if better match can be obtained.

- Computing the required overall battery voltage: Assuming that the wind generator AC output is used to charge a battery bank, the relationship between rectifier input AC voltage (V_{AC}) and rectifier DC output voltage (V_{DC}) is given by

$$\boxed{V_{AC} = (\pi / 3\sqrt{6})V_{DC}}$$ *(Stephen Drouilhet et al)*

  In the present case considering the alternator terminal voltage for Vergnet 60kW wind generator which is 400V (V_{AC}),

  Overall Battery Voltage V_{DC}=935V and this is taken as a guideline for battery specification in the current analysis.

- Computing the required overall battery rating : The required battery kW rating is based on the envisaged period of autonomy and peak power required to be supplied during that period assuming no wind conditions.

Required Battery Energy in Wh, E_B = (Period of Autonomy in hours x Peak Power Demand)

*= (Battery Overall Rating in Ah * V_{DC})*

in the present case, considering 3 days autonomy at a peak demand of 116kW, the maximum battery energy required,

$$E_{B,max} = 3*24*116.1 = 8361kWh.$$

Hence, required battery rating in Ah = $E_{B,max} / V_{DC}$

Where $E_{B,max}$ is the maximum battery energy required.

Therefore in the present case,
Required maximum battery rating= $8361x10^3/935$ = 8942Ah

This is the maximum battery storage required. However starting from lower storage energy requirement, 3 sets have been considered for matching purpose using different series and parallel arrangements of the *6V-335 Ah* standard battery set available under battery profiles in Merit database. The 3 sets thus produced are

- 512kWh (Minimum storage)
- 2785kWh (Moderate Storage)
- 8361kWh (Maximum Storage)

The above battery storage sets have been standardised for all subsequent analysis.

Diesel Generator Specification:

A diesel generator also has been incorporated, as a back up measure in some of the matching exercises and this generator is already available in the Merit standard database. The specification of the said diesel generator is Cummins C275 rated at 168kW with a torque of 1070Nm at 1500 rpm. Further matching exercises have been carried out using battery storage/ diesel generator as backup and all the results have been tabulated.

Legend for all Tables

DG: Diesel Generator; Figures in ( ) : Supply capacity in kWh; Bat: Battery
* marked figures show the fuel consumption of DG; # marked figures tell the cost of grid power under green tariff ; kl : Kilo Litres

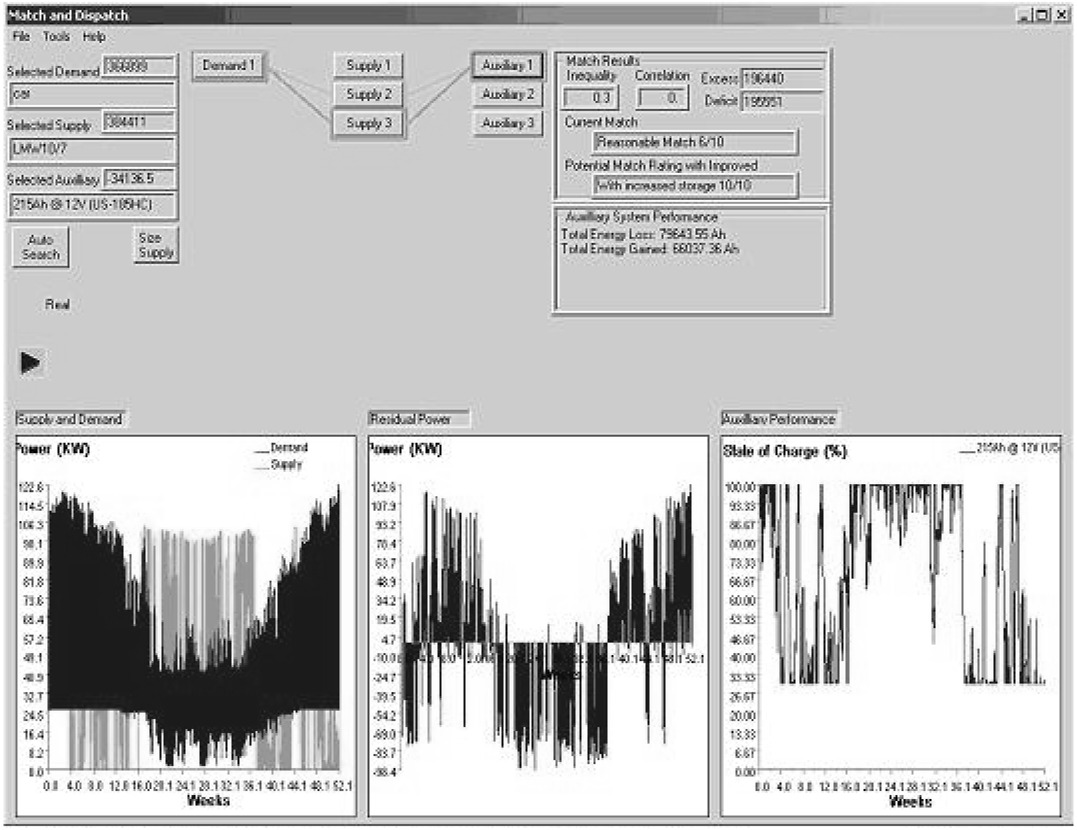
Selected Demand : 366899kWh

Period: Whole year

Trial No	Supply		Results				Comments (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequ-altiy	Excess kWh	Deficit kWh	

1	1x60kW (160597)	DG	8/10	0.1	34935	37	10/10 *345kl
2	2x60kW	512	5/10	0.4	99847	174257	7/10
3	2x60kW	2785	6/10	0.3	72573	136830	9/10
4	2x60kW (321195)	DG	6/10	0.3	151031	33	10/10 *282kl
5	2x60	Bat+ grid	7/10	0.2	126537	0	# £44881
6	10x10kW (384411)	512	6/10	0.3	118736	132204	10/10
7	10x10kW	2785	6/10	0.3	98220	97775	10/10
8	10x10kW	8361	6/10	0.3	87744	105515	10/10
9	10x10	Grid (green)	7/10	0.2	175823	0	10/10 24949
10	10x10	Bat +grid	7/10	0.2	149240	0	10/10 # £35338
11	10x10kW	DG	7/10	0.2	175823	28	10/10 *227kl

Table 10.1: Matching Results for Case IA

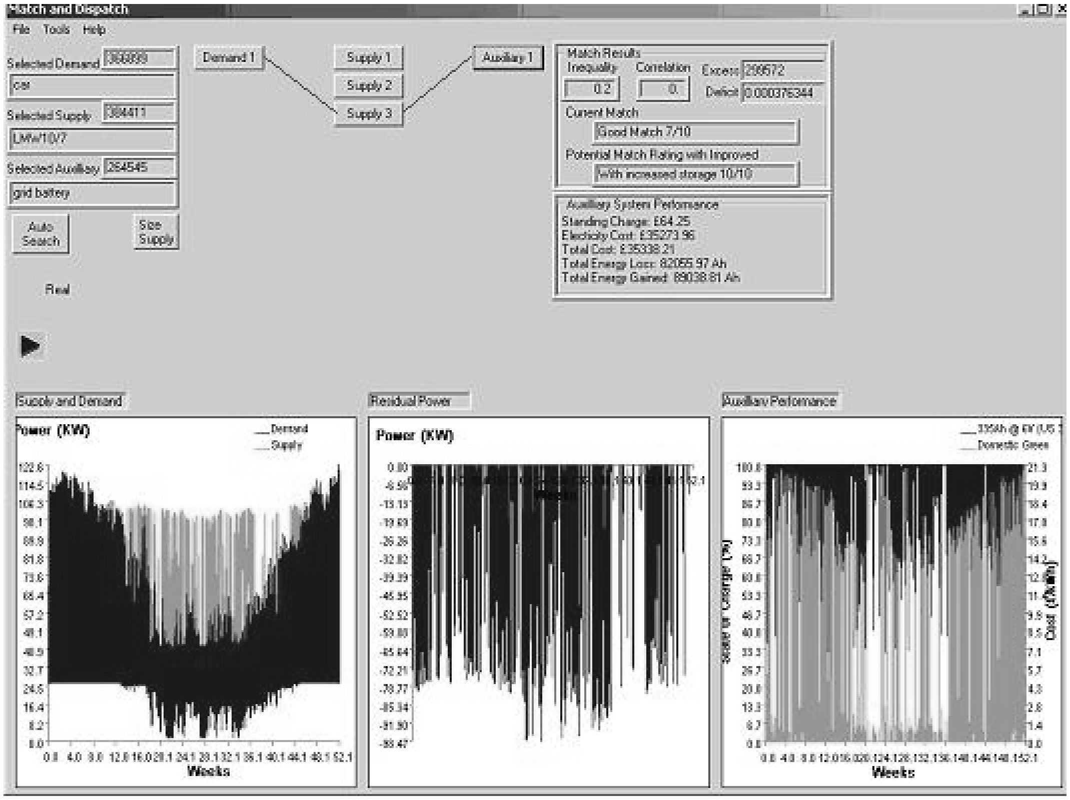


Selected Demand: 366899
car
Selected Supply: 384411
LMW/10/7
Selected Auxiliary: -34136.5
215Ah @ 12V (US-105HC)

Match Results
Inequality: 0.3
Correlation: 0.
Excess: 196440
Deficit: 195551
Current Match: Reasonable Match 6/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Total Energy Loss: 79643.55 Ah
Total Energy Gained: 68037.36 Ah

Figure10.1: Matching Template-Case IA / Trial Number 7



Selected Demand: 366899
car
Selected Supply: 384411
LMW/10/7
Selected Auxiliary: 264545
grid battery

Match Results
Inequality: 0.2
Correlation: 0.
Excess: 299572
Deficit: 0.000376344
Current Match: Good Match 7/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Standing Charge: £64.25
Electricity Cost: £35273.96
Total Cost: £35338.21
Total Energy Loss: 82055.97 Ah
Total Energy Gained: 89038.81 Ah

Figure10.2: Matching Template-Case IA / Trial Number 10

Comments

- The best match rating without back up from diesel generator or grid connection appears to be 6/10 in trial numbers 2 and 7.
- 10 numbers of 10kW turbines in comparison with 2x60kW turbines, produce lower excess and lower deficit in the whole year. The reason for this is the 10kW wind turbine has a lower cut-in speed and so produces more power in comparison to 60kW wind turbine during low wind conditions.
- In both these cases, the deficit indicates that a wind energy system alone with moderate storage cannot meet the demands of the community. Even increasing the storage to the Maximum limit (8760kWh) did not improve the rating nor diminished the deficit.
- When a diesel generator backup (or) grid connection (or) combination of low battery storage and grid are attached to the 10x10kW wind, the rating improves to 7/10, but the deficit totally disappears. The not so good rating is due to the amount of excess energy generated.
- Hence the ideal situation would be to install 2x60kW or slightly lower rated wind turbines with moderate storage and grid connection where the grid would supplement large deficits and excess can be sold back to the grid.

10.3.4 CASE 1B: Electrical +Heating during winter

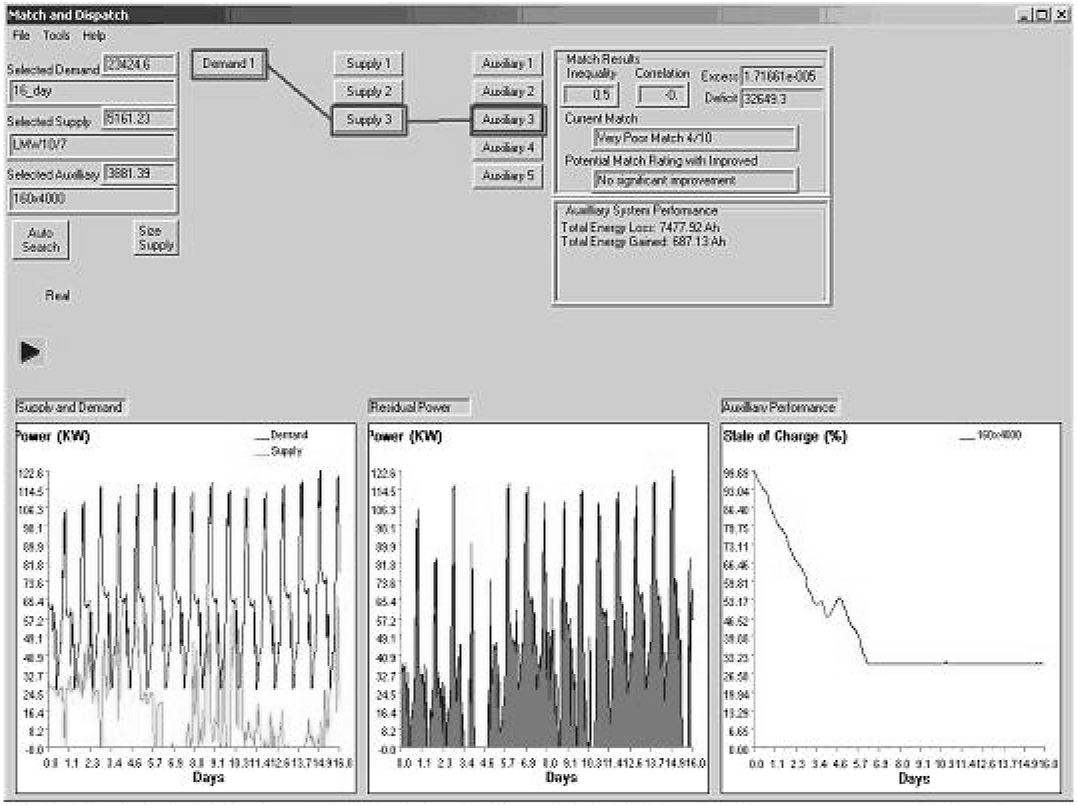
The objective is same as case 1A, but the focus is on typical winter period when the chronic black outs occur. Using the same supply and storage profiles defined in the previous case, the results are tabulated.

Selected Demand: 23424 kWh

Simulation Period: Typical Winter, 16th Dec- 31st Dec

Trial No.	SUPPLY		RESULTS				COMMENTS
	Wind	Storage kWh	Match Rating	Inequ-altiy	Excess kWh	Deficit kWh	
1	1x60kW (1430)	512	1/10	0.8	0	2289	
2	1x60kW (2860.92)	DG (or) grid	9/10	0	46	0	
3	2x60kW	512	2/10	0.7	82	20800	
4	2x60kW	8361	3/10	0.6	0	18584	
5	2x60kW	DG (or)grid	9/10	0	529	0	
6	10x10kW (5161)	8361	4/10	0.5	0	16325	
7	10x10kW (5161)	DG (or) grid	9/10	0.0	856	0	

Table 10.2: Matching Results for Case IB



Selected Demand 23424.6

16_day

Selected Supply 5161.23

LMW10/7

Selected Auxiliary 3881.39

160x4000

Match Results

Inequality 0.5

Correlation -0.

Excess 1.71661e+005

Deficit 32649.3

Current Match: Very Poor Match 4/10

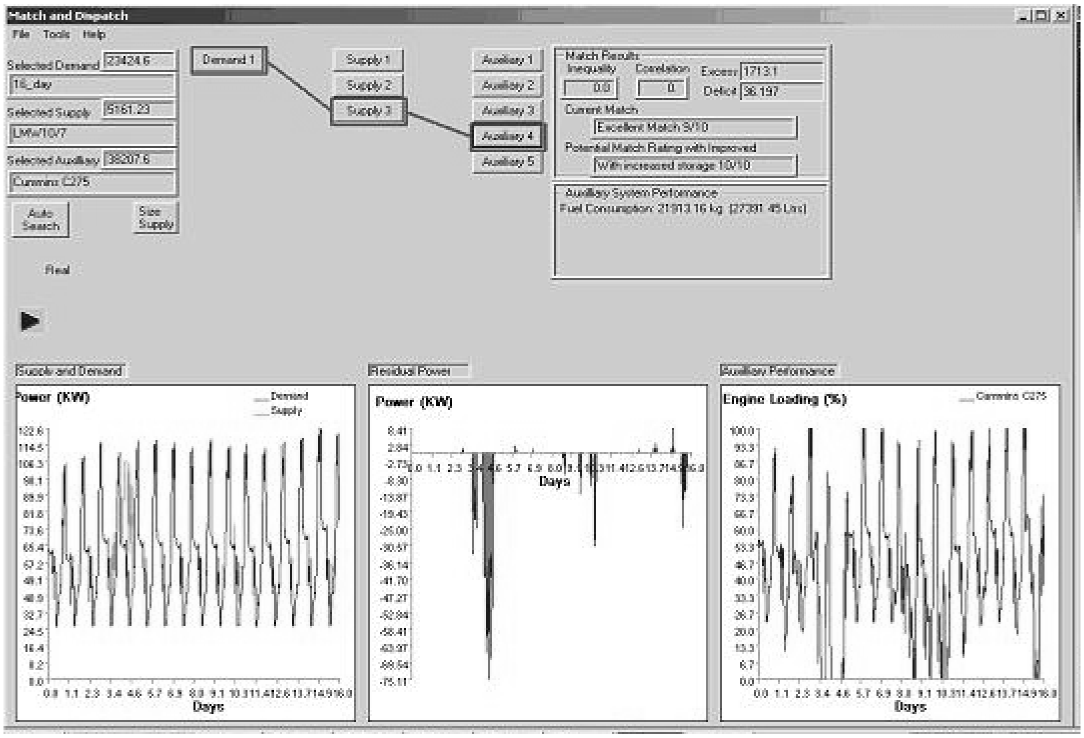
Potential Match Rating with Improved: No significant improvement

Auxiliary System Performance

Total Energy Loss: 7477.92 Ah

Total Energy Gained: 687.13 Ah

Figure10.3: Matching Template-Case IB / Trial Number 6



Selected Demand 23424.6

16_day

Selected Supply 5161.23

LMW10/7

Selected Auxiliary 38207.6

Cummins C275

Match Results

Inequality 0.0

Correlation 0

Excess 1713.1

Deficit 36.197

Current Match: Excellent Match 9/10

Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance

Fuel Consumption: 21913.16 kg (27391.45 Ltrs)

Figure10.4: Matching Template-Case IB / Trial Number 7

Comments:

- The best match rating obtained without diesel generator or grid back up is a meagre 4/10 with 10x10kW wind turbines and maximum battery storage of 8361kWh that produces no excess energy, but leaves a whopping deficit of 16325kWh
- Add a diesel or grid back up without battery storage, the rating dramatically rises to 9/10 totally nullifying the deficit and producing an excess of 856kWh.
- This proves a point that it is not possible to get autonomy from grid during low wind conditions with wind turbine and battery storage alone. Autonomy is possible only with a back up diesel generator.
- This also establishes that if black out period falls in winter when low wind conditions also persist, only a diesel generator is capable of meeting the total heating and electricity demands.

The above observations lead to demand side management, on which the subsequent cases are based.

10.3.5 CASE IIA : Essential Electrical +Heating for whole year

Wind energy System to supply only Essential Electrical Demand and regular heating Demand.

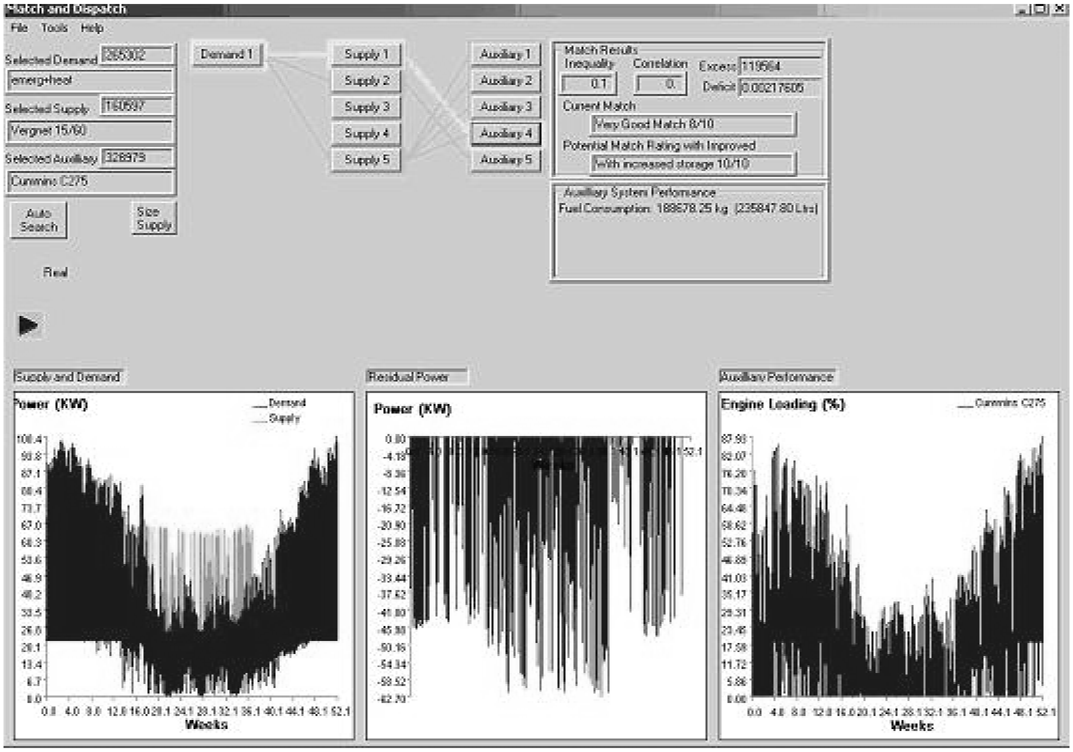
Selected Demand: 255302kWh

Simulation Period : Whole Year

Trial No	SUPPLY		RESULTS				COMMENTS (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequ-altiy	Excess kWh	Deficit kWh	
1	1x60kW (160597)	512	5/10	0.4	26582	145164	
2	1x60kW	2785	5/10	0.4	14011	132203	
3	1x60kW	8361	5/10	0.4	9667	122199	

4	1x60kW	Grid (or) DG	8/10	0.1	59782	0	*23.58kl # £25856
5	2x60kW (321195)	512	5/10	0.4	142702	112023	8/10
6	2x60kW	2785	5/10	0.4	116919	93733	8/10
7	2x60kW	8361	5/10	0.4	106190	81907	8/10
8	2x60	Grid /DG	5/10	0.4	192581	0	196kl # £21486
9	10x10kW (384411)	512	5/10	0.4	177072	83109	7/10
10	10x10kW	2785	5/10	0.4	152738	66308	7/10
11	10x10kW	8361	5/10	0.4	141605	52670	7/10
12	10x10kW	DG/grid	5/10	0.4	227093	0	Nil

Table 10.3: Matching Results for Case IIA



Selected Demand 265302

emerg+heat

Selected Supply 160597

Vergnet 15/60

Selected Auxiliary 328979

Cummins C275

Match Results

Inequality 0.1

Correlation 0.

Excess 119564

Deficit 0.00217605

Current Match: Very Good Match 8/10

Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance

Fuel Consumption: 188678.25 kg (235847.80 Ltrs)

Figure10.5: Matching Template-Case IIA / Trial Number 4

Comments

- Similar attempts repeated as in earlier cases, to see the effect of reduced overall demand
- The best match obtained by single 60kW turbine and moderate storage is 5/10 amounting to both excess and deficit which is not a suitable solution
- At the same time single 60kW turbine with grid connection nullifies the deficit and the result is an improved 8/10
- 2 numbers of 60kW turbines or 10nos of 10kW turbines without grid connection give a match rating of 5/10.
- If a grid connection /diesel back up is given to the above configuration, it clears up the deficit and the rating still remains the same due to excess, which indicates a small rated turbine would be sufficient.

10.3.6 CASE IIB: Essential Electrical +Heating during winter

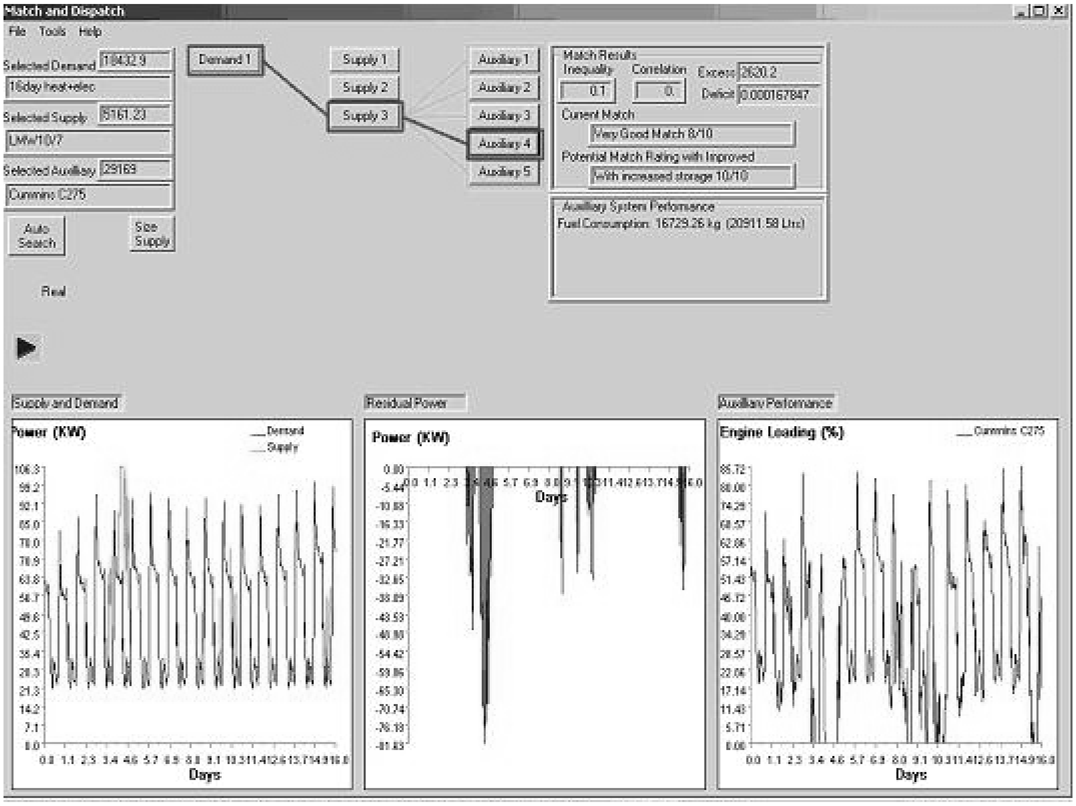
Selected Demand 18433 kWh

Simulation Period: 16th Dec to 31st Dec

Trial No	SUPPLY		RESULTS				COMMENTS (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequ-altiy	Excess kWh	Deficit kWh	
1	1x60kW (1430)	512	1/10	0.8	0	16927	nil
2	1x60kW (1430)	2785	2/10	0.7	0	16071	nil
3	1x60kW (1430)	8361	3/10	0.6	0	14148	nil
4	1x60kW (1430)	Grid (or) DG	9/10	0	116	0	# £2693/ *24kl
5	2x60kW	512	2/10	0.7	193	15990	nil
6	2x60kW	2785	3/10	0.6	0	15062	nil
7	2x60kW	8361	4/10	0.5	0	13029	nil

8	2x60 (2860)	Grid/ DG	9/10	0	747	0	# £2565 * 23kl
9	10x10kW	512	3/10	0.6	385	14065	nil
10	10x10kW	2785	4/10	0.5	0	13037	nil
11	10x10kW	8361	5/10	0.4	0	10723	nil
12	10x10kW	Dg/grid	8/10	0.1	1310	0	*21kl/ # £2295

Table 10.4: Matching Results for Case IIB



Selected Demand 18432.9

16day heat+elec

Selected Supply 8161.23

LMW10/7

Selected Auxiliary 29169

Cummins C275

Match Results

Inequality 0.1

Correlation 0.

Excess 2620.2

Deficit 0.000167847

Current Match: Very Good Match 8/10

Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance

Fuel Consumption: 16729.26 kg (20911.58 Ltrs)

Figure10.6: Matching Template-Case IIB / Trial Number 12

Comments

- The match ratings have generally been poorer in comparison to the ratings for whole year. The reason for this is the wind turbine output has fallen owing to low wind regime during the selected period. This is also substantiated by the fact that there is hardly any excess generation in almost all trials.

- Again the best Match rating of 9/10 is obtained by back up diesel or grid connection and highlights that battery storage is not sufficient to ride through the low wind regime.

It is already described in previous sections, how essential electrical loads have been arrived at for the purpose of this analysis. This is the basic electrical requirement in case of electricity crisis. Another profile assigned is regular heating demand, which is same as the one considered in Case I.

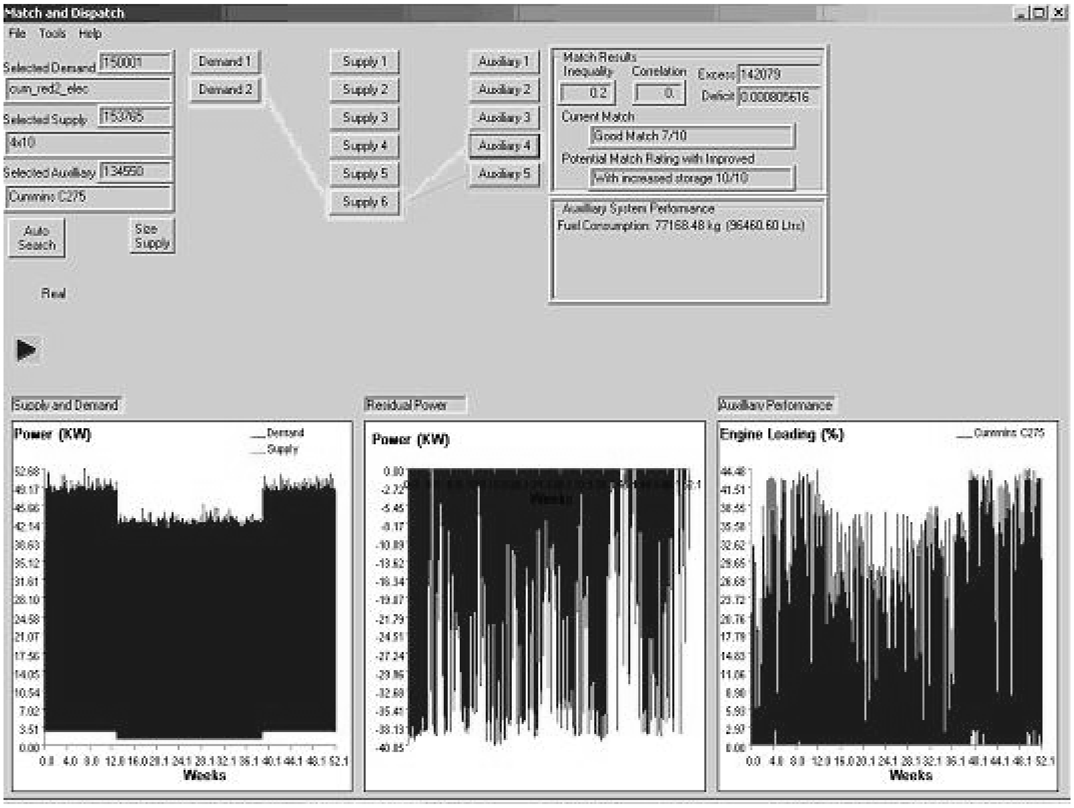
10.3.7 CASE III A: Only Electrical for whole year

Selected Demand 150001

Simulation Period Whole Year

Trial No	SUPPLY		RESULTS				COMMENTS (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequ-altiy	Excess kWh	Deficit kWh	
1	1x60kW (160597)	512	5/10	0.4	51790	54944	9/10
2	1x60kW	2785	6/10	0.3	33143	35664	10/10
3	1x60kW	8361	5/10	0.3	30263	24274	10/10
4	1x60kW	Grid (or) DG	6/10	0.3	89286	0	10/10
5	2x60kW (321195)	512	4/10	0.5	192424	39205	Nil
6	2x60kW	2785	4/10	0.5	177906	23650	Nil
7	2x60kW	8361	4/10	0.5	178536	15196	nil
8	3x10kW	512	6/10	0.3	33418	42593	10/10
9	3x10kW	2785	7/10	0.2	21708	27150	10/10
10	3x10kW	8361	7/10	0.2	23554	19538	10/10
11	3x10kW	Grid/dg	7/10	0.2	71039	0	*96.4kl # £10575

Table 10.5: Matching Results for Case IIIA



Selected Demand: T50001
cum_red2_elec
Selected Supply: T53765
4x10
Selected Auxiliary: T34550
Cummins C275

Match Results
Inequality: 0.2
Correlation: 0.
Excess: 142079
Deficit: 0.000805616
Current Match: Good Match 7/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Fuel Consumption: 77168.48 kg (96460.60 Ltrs)

Figure10.7: Matching Template-Case IIIA / Trial Number

Comments

The demand is further reduced by removing the heating profiles from consideration.

- Single number of 60kW wind turbine with moderate storage gives an acceptable match of 6/10. Even a grid/diesel addition to this configuration in place of battery doesn't improve the match rating.
- Lower multiples of 10kW turbines (3nos) with moderate storage present a better match rating of 7/10. This is due to the fact that lower rated turbine account for lower excess values in view of reduced demand. Still it leaves a deficit of 27150kWh (Trial no 9).
- Again a grid connection to the above configuration doesn't improve the rating, but eliminates the deficit power.

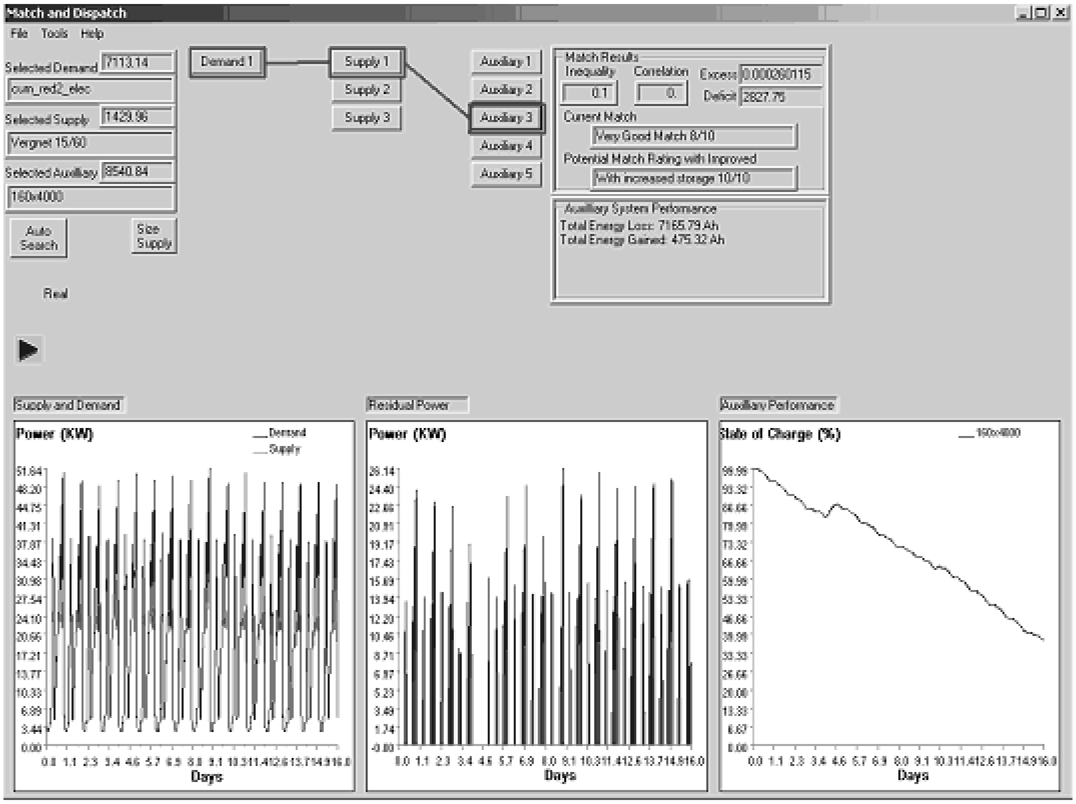
10.3.8 CASE IIIB Electrical Demand during winter

Selected Demand : 7113.14 kWh/Peak 52kW

Simulation Period: 16th Dec to 31st Dec

Trial No	SUPPLY		RESULTS				COMMENTS (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequ-altiy	Excess kWh	Deficit kWh	
1	1x60kW (1430)	512	3/10	0.6	30	5691	nil
2	1x60kW (1430)	2785	4/10	0.5	0	4487	5/10
3	1x60kW (1430)	8361	8/10	0.1	0	1414	8/10
4	1x60kW (1430)	Grid (or) DG	8/10	0.1	578	0	*8.9kl/ # £987
5	2x60kW	512	4/10	0.5	610	5058	nil
6	2x60kW	2785	5/10	0.4	0	3452	7/10
7	2x60kW	8361	8/10	0.1	0	1297	10/10
8	10x10kW	512	5/10	0.4	958	3657	6/10
9	10x10kW	2785	7/10	0.2	17	1616	10/10
10	10x10kW	8361	8/10	0.1	213	978	10/10

Table 10.6: Matching Results for Case IIIB

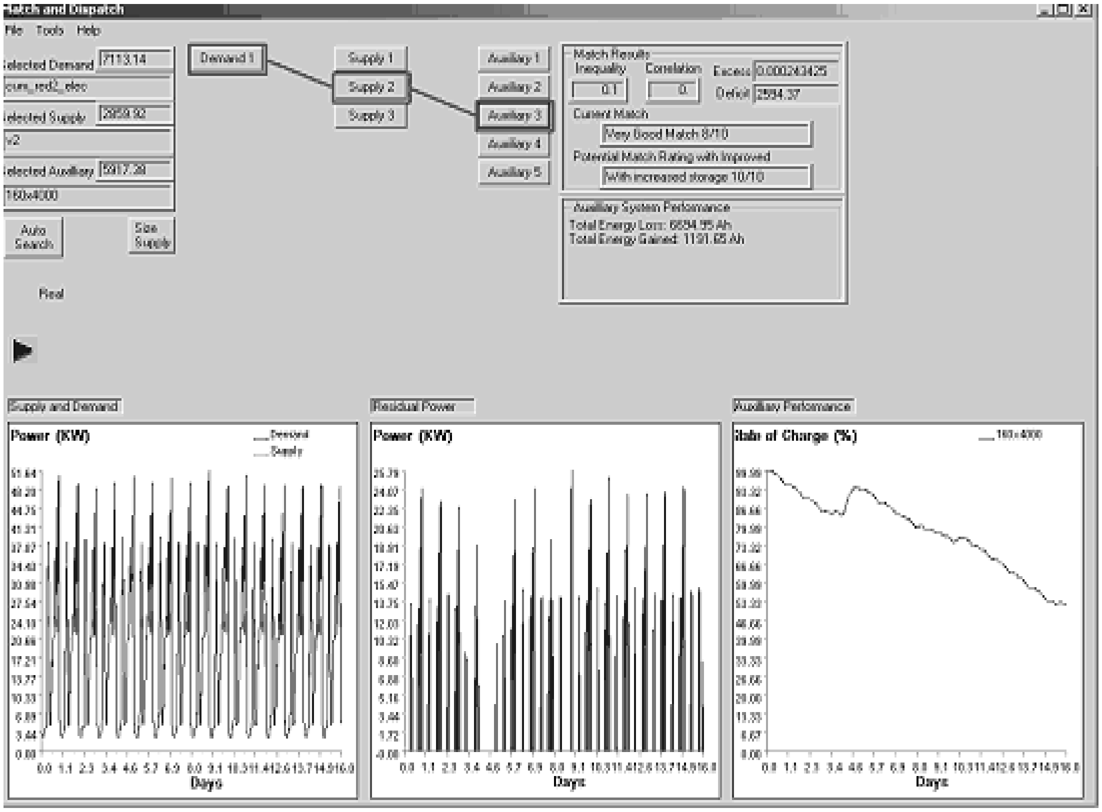


Selected Demand 7113.14
cum_red2_elec
Selected Supply 1429.96
Vergnet 15/60
Selected Auxiliary 8540.84
160x4000

Match Results
Inequality 0.1
Correlation 0.
Excess 0.000260115
Deficit 2827.75
Current Match: Very Good Match 8/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Total Energy Loss: 7165.79 Ah
Total Energy Gained: 475.32 Ah

Figure 10.8: Matching Template-Case IIIB / Trial Number 4

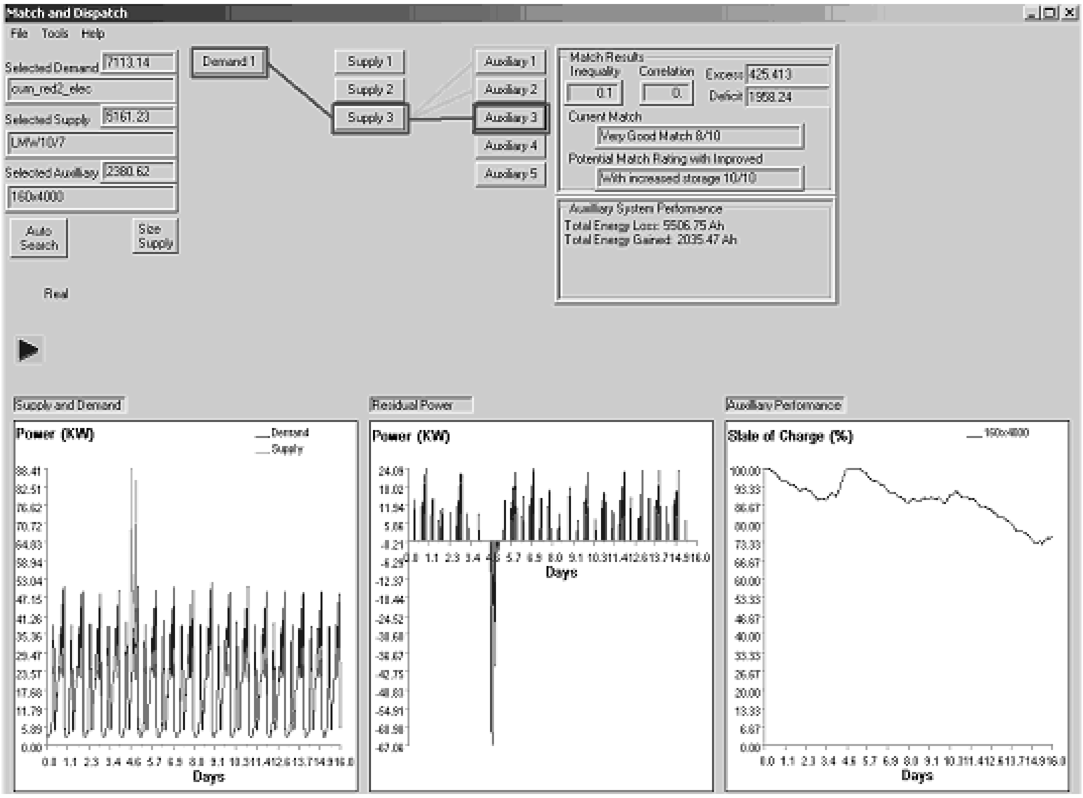


Selected Demand 7113.14
cum_red2_elec
Selected Supply 2859.92
v2
Selected Auxiliary 5917.28
160x4000

Match Results
Inequality 0.1
Correlation 0.
Excess 0.000243425
Deficit 2594.37
Current Match: Very Good Match 8/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Total Energy Loss: 6694.95 Ah
Total Energy Gained: 1191.65 Ah

Figure 10.9: Matching Template-Case IIIB/ Trial Number 7



Selected Demand 7113.14
cum_red2_elec
Selected Supply 5161.23
LMW10/7
Selected Auxiliary 2380.62
160x4000

Match Results
Inequality 0.1
Correlation 0.
Excess 425.413
Deficit 1958.24
Current Match: Very Good Match 8/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Total Energy Loss: 5506.75 Ah
Total Energy Gained: 2035.47 Ah

Figure10.10: Matching Template-Case IIIB / Trial Number 10

Comments

- The matching exercise is repeated for the winter period and in this case one 60kW turbine in combination with maximum storage appears to provide the best match (Trial No 3) which do not leave any excess, but there is still some shortfall to be taken care of. But the amount of storage warranted would have severe cost implications.
- The next alternative good match is 10numbers of 10kW turbines with moderate storage that gives a match rating of 7/10 (Trial No 9) leaving a shortfall of 1616kWh.

10.3.9 CASE IV A Essential Electrical Demand for whole year

This is the last case scenario under consideration and supplies would be sized based on the essential loads in the community.

Selected Demand 48402

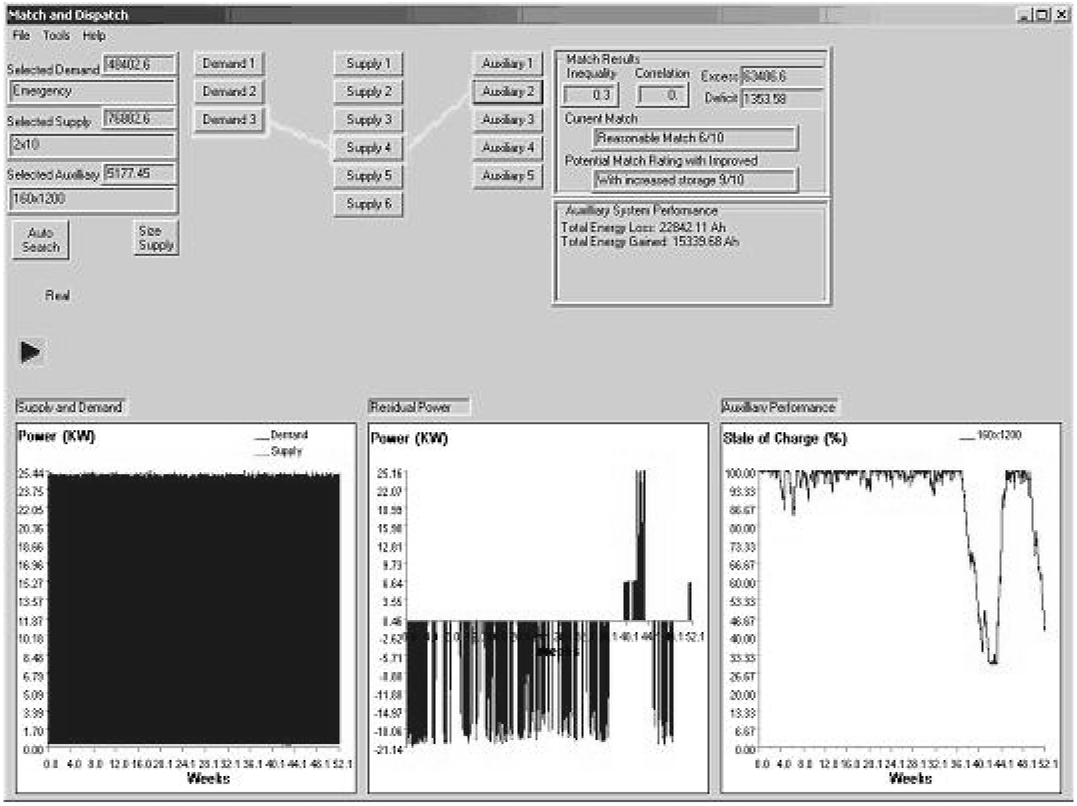
Simulation Period Whole Year

Trial No	SUPPLY		RESULTS				COMMENTS (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequaltiy	Excess kWh	Deficit kWh	
1	1x60kW (160597)	512	3/10	0.6	112161	4135	Nil
2	1x60kW	2785	3/10	0.6	113179	93	Nil
3	1x60kW	8361	3/10	0.6	115313	0	Nil
4	1x60kW	Grid (or) DG	3/10	0.6			*29kl/ # £3183
5	2x60kW (321195)	512	1/10	0.8	269810	2234	Nil
6	2x60kW	2785	1/10	0.8	272028	0	Nil
7	2x60kW	8361	1/10	0.8	274477	0	Nil
8	2x60 (2860)	Grid /DG	1/10	0.8	291172	0	*23kl # £2890
9	3x10kW 115323	512	4/10	0.5	65096	2856	5/10
10	2x10kW 76882	512	6/10	0.3	30506	4598	10/10
11	2x10kW 76882	2784	6/10	0.3	31743	676	9/10
12	1x10kW 38441	512	7/10	0.2	1621	13322	10/10
13	1x10kW	2785	7/10	0.2	1486	8409	10/10
14	1x10kW	8361	8/10	0.1	1601	1345	10/10
15	1x10kW	Grid/dg	7/10	0.2	16815	0	*38.4kl # £4209

Table 10.7: Matching Results for Case IVA

- This exercise produced some interesting results.

- The first half of the trials has been conducted using 1x60kW or 2x60kW wind turbines with different storage/back-up combinations. Though the resulting ratings are not significant, the important observation is that there is hardly any deficit in most of the cases. Obviously the poor ratings are because of the additional power generated, which indicates that lower rated turbines would be sufficient to meet the current demand.
- The exercises repeated using lower multiples of 10kW turbines to produce another set of interesting results. Though the ratings are vastly improved (7/10), there are large amounts of energy shortfall unless there is a grid connection and this indicates that high-rated turbines (60kW) are necessary in the absence of grid to minimise the shortfall.



Selected Demand 48402.6
Emergency
Selected Supply 76802.6
2x10
Selected Auxiliary 5177.45
160x1200

Match Results
Inequality 0.3
Correlation 0.
Excess 63406.6
Deficit 1353.58
Current Match: Reasonable Match 6/10
Potential Match Rating with Improved: With increased storage 9/10

Auxiliary System Performance
Total Energy Loss: 22842.11 Ah
Total Energy Gained: 15339.68 Ah

Figure10.11: Matching Template-Case IVA / Trial Number 11

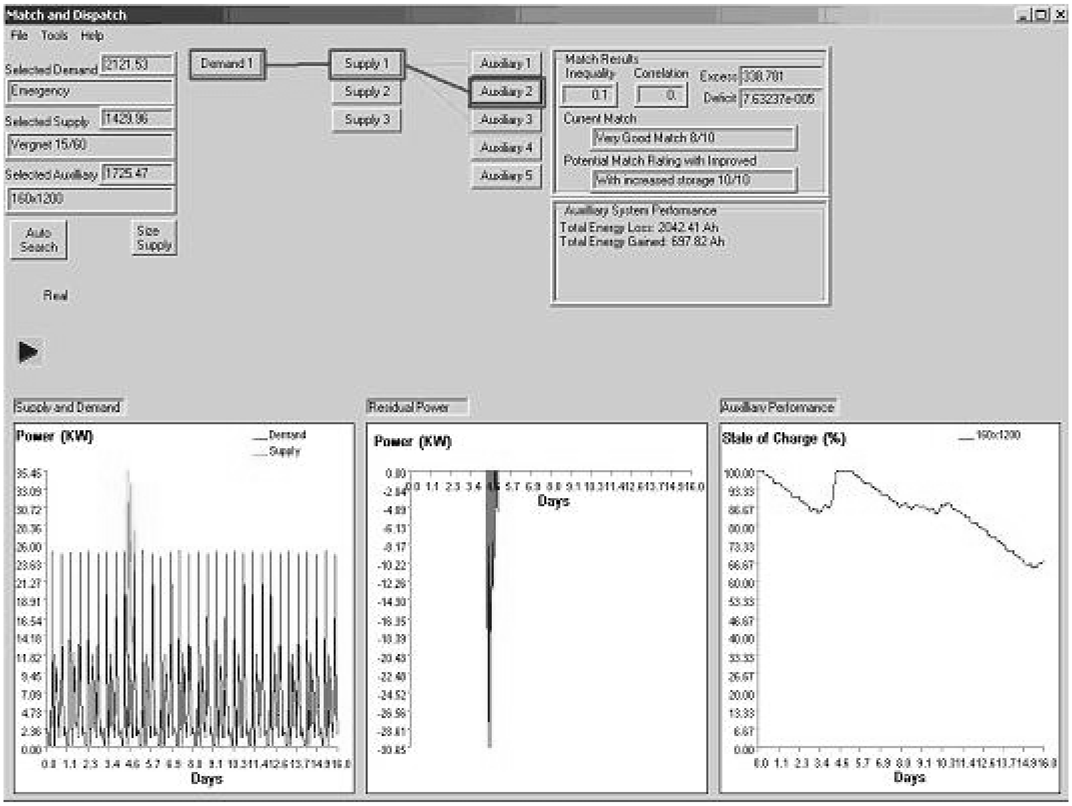
10.3.10 CASE IV B: Essential Electrical Demand during winter

Selected Demand **:** 2121 kWh

Simulation Period: 16th Dec to 31st Dec

Trial No	SUPPLY		RESULTS				COMMENTS (Max.possible rating)
	Wind	Storage kWh	Match Rating	Inequaltiy	Excess kWh	Deficit kWh	
1	1x60kW (1430)	512	6/10	0.3	226	826	10/10
2	1x60kW (1430)	2785	8/10	0.1	169	0	10/10
3	1x60kW (1430)	8361	7/10	0.2	239	0	10/10
4	1x60kW (1430)	Grid (or) DG	5/10	0.4	1011	0	9/10
5	2x60kW	512	3/10	0.6	1598	530	5/10
6	2x60kW	2785	4/10	0.5	1568	0	6/10
7	2x60kW	8361	4/10	0.5	1203	0	6/10
8	3x10kW	512	7/10	0.2	75	550	10/10
9	3x10kW	2785	8/10	0.1	236	0	10/10
10	4x10kW	512	6/10	0.3	295	355	10/10
11	4x10kW	2785	7/10	0.2	755	0	nil
12	10x10kW	8361	3/10	0.6	3172	0	nil

Table 10.8: Matching Results for Case IVB

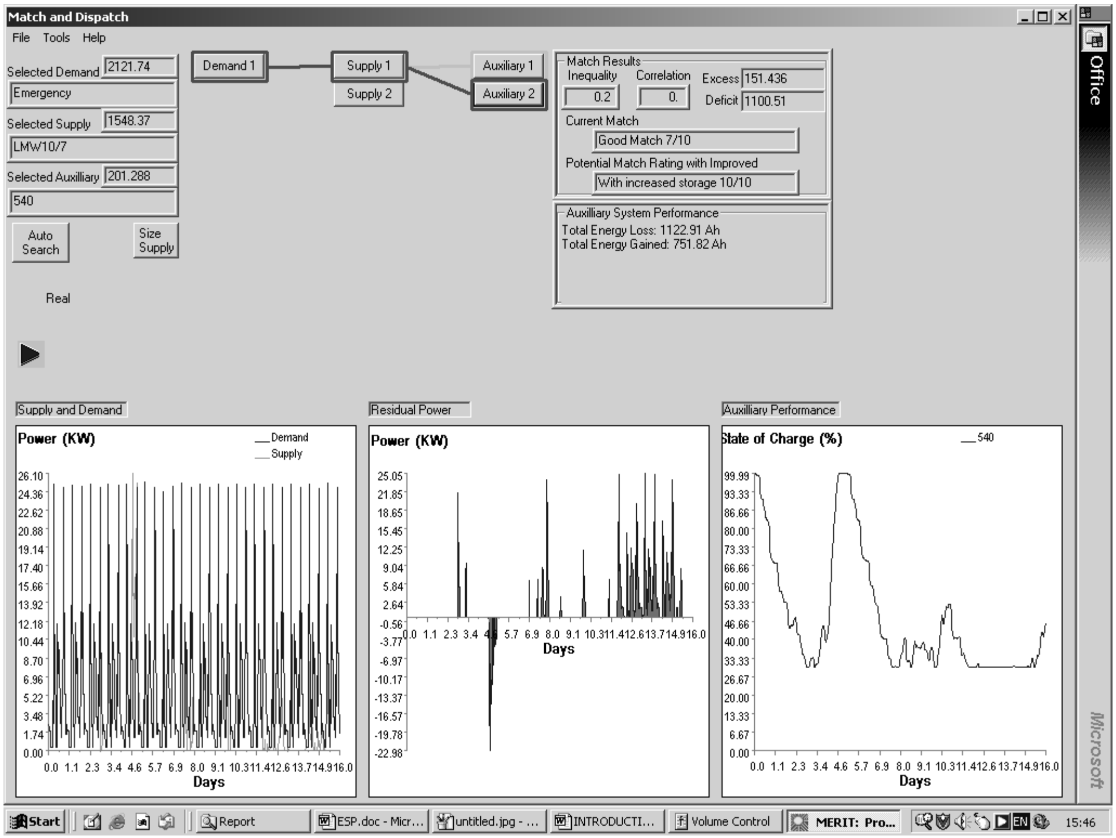


Selected Demand 2121.53
Emergency
Selected Supply 1429.96
Vergnet 15/60
Selected Auxiliary 1725.47
160x1200

Match Results
Inequality 0.1
Correlation 0.
Excess 338.701
Deficit 7.63237e-005
Current Match: Very Good Match 8/10
Potential Match Rating with Improved: With increased storage 10/10

Auxiliary System Performance
Total Energy Loss: 2042.41 Ah
Total Energy Gained: 697.82 Ah

Figure10.12: Matching Template-Case IVB / Trial Number 2

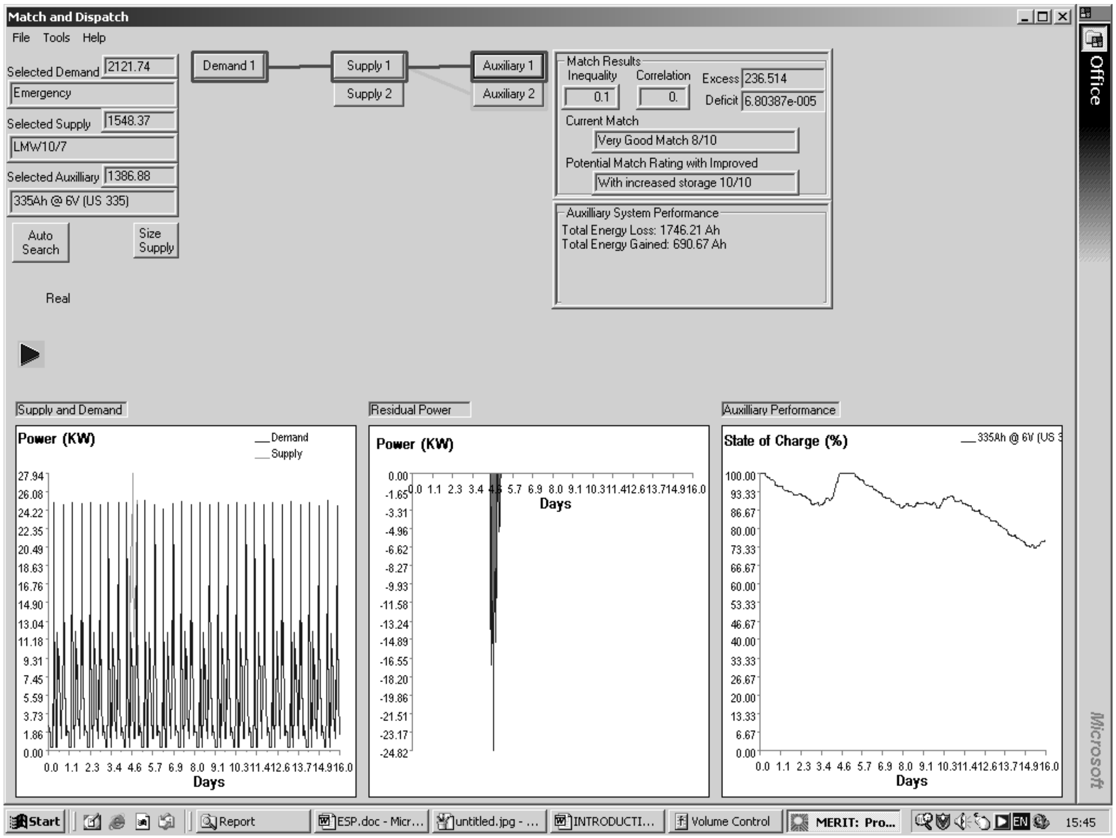


Selected Demand 2121.74
Emergency
Selected Supply 1548.37
LMW10/7
Selected Auxilliary 201.288
540

Match Results
Inequality 0.2
Correlation 0.
Excess 151.436
Deficit 1100.51
Current Match: Good Match 7/10
Potential Match Rating with Improved: With increased storage 10/10

Auxilliary System Performance
Total Energy Loss: 1122.91 Ah
Total Energy Gained: 751.82 Ah

Figure10.13: Matching Template-Case IVB / Trial Number 8



Selected Demand 2121.74
Emergency
Selected Supply 1548.37
LMW10/7
Selected Auxilliary 1386.88
335Ah @ 6V (US 335)

Match Results
Inequality 0.1
Correlation 0.
Excess 236.514
Deficit 6.80387e-005
Current Match: Very Good Match 8/10
Potential Match Rating with Improved: With increased storage 10/10

Auxilliary System Performance
Total Energy Loss: 1746.21 Ah
Total Energy Gained: 690.67 Ah

Figure10.14: Matching Template-Case IVB / Trial Number 9

Comments

- This scenario is the ultimate focus of attention because this tells us whether the community can manage to survive the essential loads with a wind scheme during grid failure in typical winter days.
- The combination of 1x60kW wind turbine with moderate storage gives an excellent match rating of 8/10 totally wiping out the deficit and creating some surplus.
- Surprisingly grid or diesel back up has not produced a better match rating because of more surpluses the scheme generates.
- Increasing the wind turbine capacity from 60kW also looks pointless and so the capacity reduced to 3x 10 kW and 4x10kW. The results are quite encouraging
- 3x10kW gives an excellent match rating of 8/10 and 0 deficit when the storage is upgraded from minimum to moderate.
- These results once again confirm that moderate battery storage with wind turbine is very effective to meet reduced demands.

10.4 DISCUSSION OF RESULTS

The main criterion for results analysis is based on two aspects. One is a good match rating (7-10) in Merit. Second is the deficit shall be as minimum as possible without back up from grid or diesel generator. Good match rating provides overall optimum demand-supply –storage scenario. Minimum deficit without back up gives more autonomy from grid. The results obtained under various scenarios lead to the following discussions.

Under Scenario I, it is impossible to obtain autonomy from grid without the help of a diesel generator if the wind-battery scheme has to supply the requirements of electric and heating loads throughout the year. The poor match rating and also large shortfalls in supply make this finding more vivid. Though 2 number of 60kW wind turbines with 2785kWh of battery storage in place of 1 number 60kW turbine, reduce the annual shortfall from 58% to 33% of total demand, the shortfall is still too high to get autonomy from grid. However, still a wind battery scheme can save import of grid power and prevents release of CO_2 emissions and saving of primary fuel used to produce the avoided grid power.

The scenario is no better even during typical winter period when power blackouts are expected in the community. 60kW wind turbine and 2785kWh battery storage could supply only 13% of the total demand leaving a whopping 87% as deficit. An addition of another 60kW turbine only marginally reduces this deficit to 80%. The reason for higher short falls in winter in comparison to shortfall over a year is that the selected climate file has a typically low wind regime during the selected period. Here too only a diesel back up is capable of providing the necessary autonomy.

In the next Scenario, the demand is reduced by considering only essential electrical power and heating. The best possible trial is obtained by deploying 10 numbers of 10kW turbines with medium storage (2785kWh), which leaves the overall deficit at 25% of total demand. Another important observation is that 10X 10kW +2785 kWh storage presents a better configuration than 2x60kW + 2785kWh (37% deficit) storage for the simple reason that the cut-in wind speed for 10kW wind turbine (3m/s) is less than that of 60kW turbine

(5m/s). In any case, a deficit of 25% still cannot give the required autonomy from the grid and again the inclusion of a back up diesel generator wipes out the deficit to give complete autonomy from the grid. The winter results for this scenario deploying 1x60kW, 2x60kW and 10x10kW turbines with 2785kWh storage produce a deficit of 87%, 81% and 71% respectively which are far higher than the deficits generated for the whole year. Again a diesel generator gives the required autonomy. Very high battery storage of 8361kWh along with 10x10kW wind scheme manage to reduce the deficit to 58%, but the cost implications of providing such high battery storage may be far reaching and hence this may not be a viable option.

In the third Scenario, the demand is further reduced to see the impact on the results. The demands chosen is only electrical loads. Between one 60kW wind turbines and two 60kW turbines, the deficit reduces from 23% to 16% of total electrical demand, which can be regarded reasonable. But further reduction of supply by configuring 2 or 3 -10kW turbines with the existing storage increases the deficit, though gives a better match rating, as there is shortfall in generation and so lower configuration is not recommended. The winter scenario for the current demand profile, results in a deficit of 63% and 48% respectively for 1x60kW and 2x60kW wind turbines with 2785kWh storage, which prompts the need of diesel back up or grid connection to meet the demand considered.

In the final scenario, the demand is kept at minimum possible level by considering only essential electrical demands of the community. The demand considered is 48402kWh annually. A 60kW wind turbine with 512kWh of battery storage reduces the deficit to fewer than 10% (8.5% only) for the whole year and increasing the storage to 2785kW marginalizes the deficit to less than 1%, which is the best result by far. Of course there is a lot of excess power generated that can always be used for water heating and charging of Electrically Operated Vehicles (EOVs) etc. Now if we shift the focus to the winter weeks with the same demand scenario and supply profiles, the deficit is 39% with a 60kW wind turbine and 512kWh storage and it is zero with 2785kWh storage. These results prove the point that the proposed wind turbine configuration of 2x60kWs with 2785kWh storage is capable of providing the required autonomy from the grid for meeting essential electrical demand that includes the community pumping station also.

10.4 LIMITATIONS

The results of the analysis would be as good as the input assumptions and values. Hence it is worthwhile to focus the attention on the limitations to the current evaluation.

- The entire analysis is based on the available climate profiles, which actually do not represent Carron Valley climate, and hence the results may be different if actual climate conditions are incorporated.
- The wind speed time series used from the existing climate profiles may be again different from actual wind speeds occurring at Carron Valley, which may influence the power captured by the wind turbine. It is strongly advised to measure the actual wind speeds at identified locations for a period of one year to arrive at an optimum design.
- The demand data is compiled from questionnaires, which may not reflect the actual consumption patterns. Also the response to questionnaires is lukewarm (only 5 responses out of 21 residents). The data from 5 residents is extrapolated to cover 21 residents and the total figures are reduced based on the average energy consumption. Again it is suggested to keep a seasonal track of consumption to obtain more realistic demand profiles.
- The modelling done in ESP-r to obtain heating loads is again based on certain assumptions in the absence of complete building data and occupancy details. However actual conditions might vary with regards to number of occupants in each dwelling, the casual gains etc. It is suggested to obtain more real data to run simulations to obtain more realistic heating loads.
- The pump ratings for the water pumping station are not known in spite of all efforts. Hence the rating of water pump in each house is assumed on the higher side to accommodate for the common pumping station.

- The wind turbine ratings are taken from the available manufacturers suggested by a local wind energy consultant. There may be other sources for similarly rated turbines, which is not looked into.

10.6 LIMITATIONS OF MERIT

- Profiles for alternative storage options such as flywheel are not available which may have to be built from software stage itself.
- The excess and deficit energy statements obtained during the matching stage is observed to be double that of actual excess and deficit. Hence for each case, the values obtained have been halved to get actual excess and deficit.
- The battery profiles available in the database are for small storage requirements for PV applications and larger profiles are needed for wind system storage.

10.7 SUGGESTIONS FOR FURTHER DEVELOPMENT

While acknowledging the versatility of the tool, the author makes some suggestion for further development of this tool.

- Incorporating additional information as suggested in limitations.
- More flexibility may be needed. One way of looking at this is to incorporate features of demand side management. For example, in the present case studies, in matching section, assigned storage tries to cover wherever there is a short fall of supply to meet the required demand and produces match ratings. In actual case, during such periods there can be other options such as demand side management achieved by switching off non-essentials loads and storage needs to cover only the essential loads and this can lead to a reduced sizing of storage and cost reductions. In other words, flexibility is needed so as to be able to specify that storage is required for only peak loads or 25% or 50% of actual demand during shortage periods.

10.8 REFERENCES

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2. J.A. Clarke, J.L.M. Hensen, C.M. Johnstone and I. McDonald - On The Use Of Simulation In The Design Of Embedded Energy Systems. Proc. 6th International IBPSA Conference Building Simulation '99 in Kyoto, Vol. I, pp. 113-119, International Building Performance Simulation Association, 1999
3. Born F J, Clarke J A, Johnstone C M and Smith N A V 2001 ' Merit - An Evaluation Tool for 100% Renewable Energy Provision ' Proc. Renewable Energies for Islands, Chania, Crete
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11 FINANCIAL ANALYSIS

11.1 PROJECT EVALUATION

From different available technical alternatives, the idea is to find a financially viable option, which is capable of bringing about the envisaged benefits. It is necessary to look at both financial and economic costs and benefits of the project before a final investment decision is made. While financial project investment assessments look at the project on purely monetary terms, the economic appraisals look beyond this and include intangible benefits converted to monetary terms such as general benefits to the community that the project will bring about. For example, the benefits of wind energy can be evaluated based on the savings on fuel and capacity (internal value) and by analysing the external costs (environmental, general economic and government subsidies) of conventional electricity production. Environmental costs replicate the costs of damage to flora, fauna, mankind, materials and climate change.

The economics of a wind turbine project are generally site specific. For example developing a wind energy project in remote and inaccessible area would cost higher than that located in an easily approachable site. Similarly locations with higher average wind speeds produce cheaper power than those located in less windy areas. The cost of wind power also depends upon the capital structures terms and conditions for loan repayment, type of technology adopted. Many small wind power producers are typically receiving 1.8p/kWh to 2.5p/kWh *(source: BWEA)*

The various stages involved in project evaluation are

- Project Costing
- Financial Assessment
- Economic Assessment

11.2 DETAILED PROJECT COSTING

The project costs chiefly comprise of fixed costs and variable costs each in turn containing a set of cost components.

Fixed Costs *(GC Bakosl)*

1. **Feasibility Study** (1-10% of total project cost)

Site Investigation
Wind Resource Assessment and Analysis
Environmental Assessment
Preliminary Design
Detailed Cost Estimation
Report Preparation
Project Management
Travel and Accommodation

2. **Development** (1-10% of total project cost)

Permitting, surveying and financing
Legal and Accounting
Project Management
Travel and Accommodation

3. **Engineering (1-10% of total** project cost)

WES Design
Mechanical Design
Electrical Design
Civil Design

4. **Wind Energy Equipment** (40-80% of total wind energy project cost)

Wind Turbine
Accessories
Storage Equipment
Electrical Equipment
Spares
Transportation

5. **Balance of Plant**

Civil Construction including Foundations and Buildings
Mechanical Erection
Site Supervision
Temporary Approaches and Roads
Operation and Maintenance Facilities

6. **Miscellaneous**

Contingencies
Personnel Training etc.

Variable Annual Costs

1. Operation and Maintenance Costs
2. Taxes and Insurance
3. Major Overhauls and Subsystem Replacement
4. Miscellaneous

11.3 FINANCIAL INDICES

The investment decision-making process is supported by a range of financial parameters, which are known as financial indices. Usually the following indicators are most extensively referred in business circles *(AD Karlis et al).*

- Economic or Calculation Life
- Discount Rate
- Net Present Value (NPV)
- Benefit-Cost Ratio (B/C)
- Pay Back Period
- Return on Investment (ROI)
- Generation Cost or Life Cycle Cost of Energy
- Specific Capital Cost

Economic Life represents the normal operating life of a project, which is normally taken as 15-25 years. Renewal of main parts of the equipment or capital for repair is needed after that period.

Discount rate is the compound rate at which future money is discounted annually to calculate present value.

NPV is the summation of all present values of future income and expenditure discounted at prevailing rates. Positive NPV values are an indicator of a potentially feasible project.

Benefit-Cost Ratio is the present value of all benefits divided by the present value of all costs.

Payback Period, which is expressed in years **,** is the capital cost of the project divided by the annual average return. In other words, it represents the length of time that it takes for an investment project to recoup its own initial cost out of the cash receipts it generates. This is especially important to private owners or small firms that are not cash rich.

Return on Investment is the annual return divided by the capital cost expressed in percent. If the estimated ROI is greater than or equal to the required or targeted ROI, then the project is considered acceptable. If it is less, the project is typically rejected.

In order to forecast and to help a reasonable analysis for a particular project investment, more information about the amount of cash generated and the timing involved is required. Having said this, no method of analysis gives a precise answer or avoids the risks involved. The timing assumed in the analysis may not be correct, the forecast cash flows may be inaccurate, the opportunity cost of capital may vary as interest rates and tax regimes change during the life of the project and non-financial aspects (cost-benefit analysis etc) all need to be considered. A most important point is to remember that the cost of analysis and the timing to complete it must be kept in check and should not exceed the benefit obtained from it.

Generally, the NPV method is an acceptable practice in the financial appraisal of a project. When comparing the cash returns over time from different project investment options at a given discount rate, the higher the NPV, the better the investment option. The alternative measure of financial acceptability of the project is to use discounted cash flow techniques to assess the project's internal rate of return (IRR). This is the discount rate that exactly reduces the NPV to zero. It is considered that the higher the IRR the better return on investment. However, it should be noted that cash flows far into the future in the long term have little present day value.

11.4 SENSITIVITY ANALYSIS

The end results of the financial analysis can only be as good as the input data and original assumptions. Items such as interest rates cost of materials, exchange rates and inflation can all change during the life of the project and may have an effect on the viability of the project. For more sophisticated analysis, the sensitivity of the results to such changes is considered. Using spreadsheets, the cash flows are entered in a table and the NPV or IRR are calculated. Next step is to allow variations in parameters, compute the results and assess the effect of such changes. The results can also be represented in graphical form.

11.5 ECONOMIC ASSESSMENT

The economics of wind energy schemes is generally a three-stage process. Firstly the scheme has to be shown as the least cost option. Various technically viable schemes are therefore considered and cost evaluated. Secondly, an estimation of the financial and economic benefits as revenues plus cost savings is made. Thirdly, a comparison between the discounted benefits and cost is computed using discounted cash flow techniques.

11.6 COST BENEFIT ANALYSIS

Cost benefit analysis considers intangible benefits also such as resource saving, saving on environmental costs and reliable supply, which may or may not be attached with a monetary value.

11.7 FINANCING

Financing of community renewables is different from that of utility owned large wind farms. To encourage such initiatives, the UK Government has instituted several financial schemes including grants. Also there are other agencies that offer some form of grants. However grants alone may not be sufficient to finance a project. There are instances of community members themselves supporting in form of equity. And some banks offer loans with easy terms and conditions. In a nutshell, the financial structure of a community wind project may be a combination of debt/loan, equity, grants and other instruments. Sometimes the debt component can be as high as 80%. Some of the possible sources of finance have been listed here.

- **Scottish Community Renewables Initiative (SCRI)- House Hold Grants**:

  In Scotland, Scottish Executive has initiated a Trust called Energy Saving Trust, which is the household component of SCRI with an aim to encourage households and communities to adopt small renewable technologies suitable for communities. The Energy Saving Trust along with Highland and Island Enterprise are managing the community component of SCRI.

  Under household scheme funding is set as 30% of installed cost limited to a maximum of £4000 for a total capital cost of £13300. Any additional capital expenditure is to be entirely borne by the resident. This also covers micro wind turbines besides a range of other renewable energy technologies.

- **Scottish Community Renewables Initiative (SCRI)- Community Renewables Installations**

Amongst the broader objectives of SCRI is to act as one stop shop for communities to develop renewable energy projects. The assistance ranges form project management, technical guidance to financial support. The financial assistance is offered under two heads upon meeting certain criterion.

Technical assistance funding

A grant subject to a maximum of £10000 is offered to communities for feasibility studies, development of a proposal and for training and skills development.

Capital grants

Capital grants to a maximum of £100000 will be provided to encourage small renewables. An SCRI representative however clarifies that owing to the present demand levels, it is highly unlikely to sanction beyond £60000.

- **European Regional Development Fund**

  Most funding granted by the EU is not paid by the European Commission direct but through the national and regional authorities of the Member States. That holds for assistance under the common agricultural policy and most grants awarded under structural policy financial instruments (European Regional Development Fund, European Social Fund, European Agricultural Guidance and Guarantee Fund and the Financial Instrument for Fisheries Guidance), which account for the bulk of EU aid in money terms.

  The Commission gives grants direct to recipients (public or private bodies - universities, firms, interest groups, NGOs - and private individuals in certain cases) for the implementation of other common policies in areas such as research and development, education, training, the environment, consumer protection and information. It also awards direct grants for the development of renewables inline with European Policy for renewables.

- **Scottish Power Green Energy Trust**:

  This has been established with an aim to support the development of new renewable sources in the UK. It not only offers grants for new renewables but also helps in educational projects, which increases the awareness of renewables amongst people to further its cause.

- **Triodos Bank**

  Established in UK in 1995, this bank extensively supports ethical issues and provides debt financing. Their areas include charities, social businesses, environmental and community projects. Some of the projects financed by the bank are Ecotech Wind Park Limited, operating a wind farm at Norfolk, a 5-turbine community owned windfarm developed by Harlock Hill Limited at Cumbria, a wind turbine installed by Lynch Knoll Windpark at Stroud. Loans have been given to buy a piece of land where the turbine is proposed to build or to finance the cost of the equipment including wind turbine or simply to provide the working capital. However, the terms and conditions for extending a loan could not be gathered. More information may be found at the web address www.triodos.co.uk.

- **Miscellaneous Sources of Finance**

  Community Contributions: The members of the community themselves contribute to an equity base in terms of number of shares from each member which can raise substantial amount. For instance the Community wind turbine commissioned by the Bro-Dyfi Community Renewables Company at CAT centre has managed to raise over £30000 towards equity participation by 59 residents out of a total investment of £81000. An interest of 8% is promised if left for 15 years.

  Donations/Lotteries

  Private donations or donations by a Trust can become handy. For example, the Isle of Muck community project could garner £20000 from such contributions.

  The UK National Lotteries Board runs an initiative known as Community Fund. Under this program they give lottery money to charities and voluntary and community groups. For instance, an amount of £95000 was contributed by the lottery board for the Isle of Muck wind project.

Equity Participation by Consultant/Contractor

There have been instances in the past that the consultant/project developer can become an equity partner. One way of operating this is , the costs incurred by the contractor would be converted into equity shares in the venture.

11.8 CASH FLOW ANALYSIS- CARRON VALLEY

A simple financial analysis involving cash flows and calculation of NPV for the proposed Carron Valley project is presented here.

11.8.1 Assumptions

- Two cases considered –a 60kW wind turbine and a 120kW-wind turbine respectively.
- Estimated project life 20years
- Overall capital cost is assumed to be at the rate of £1000/kW of capacity, which may not be the correct method to calculate the capital required. The calculated value includes all capital expenditure including cost of basic wind turbine, storage, grid connection and controls and all other related costs.
- 40% of the capital investment is treated as grants subject to a maximum £50000.
- Interest on loan is taken as 8% for a repayment period of 10 years. Interest is compounded each year on diminishing balance.
- Annual operation maintenance expenses including tax is taken as 3% of total capital
- At a 30% capacity factor, annual energy output of the wind turbine

$$\boxed{0.3 * \text{Rating} * 24 * 365 \text{ kWh}}$$

- Annual electricity generation is assumed constant every year.
- Cost of Electricity sold is 4.5p/kWh
- Discount factor is assumed to be 8% for NPV computation Formula for Present Value

Present value = Future value/$(1+i)^n$, where
n= number of years and i= discount factor

- Effects of inflation, depreciation and scrap value are neglected.
- As effect of inflation is neglected, no price variation is assumed for electricity sold (Real values are considered in stead of nominal values).
- Working capital investment and project risk factors also have been neglected.
- No incentive schemes taken into account.

With these assumptions, spreadsheets are prepared and NPV and simple payback are calculated for both cases. The results are presented and analysed. It is to be remembered all results are sensitive to any variation in assumptions more so in the case of variations in interest and repayment of loan component. Carrying out a sensitivity analysis is omitted from the current scope.

11.8.2 Procedure:

- Initial investment excluding grants is taken as negative cash flow for 0th year.
- Revenue generated from the sale of electricity is treated as positive cash flow
- Expenses in form of operation and maintenance costs and cost of insurance are taken as negative cash flow.
- Interest on loan component also taken as negative cash flow
- The difference of positive and negative cash flow gives the net cash flow for each year under consideration. The present value of the net cash flow is calculated using the present value factor.
- The sum of all present values for each year gives the *NPV.*
- The year at which the arithmetic sum of net cash flows equal to the initial investment gives the *payback* period.

11.8.3 Sample Case: 60kW Wind turbine

Total Capital Investment = 1000*60 = £60000
Grants = 40% = 0.4* 60000= 24000
Loans= 60000-24000= £36000
Loans considered as –ve cash flow for 0th year

Annual Electricity Generation = 0.3*60*24*365 = 157680kWh
Revenue from sale of electricity = 4.5 * 157680/100= £7096

Annual costs = 0.03 *60000= £1800
Interest on Loan component = 8% to be repaid in 10 years
Principal repayment each year= 36000/10= £3600
Interest calculated on diminishing balance each year by formula in Excel spreadsheet.
Total annual expenses = Annual costs + interest.

Net Cash Flow =(Revenue- Expenses) for each year
Present Value = Net Cash Flow * Net Cash Flow for each year

NPV = Sum of all present values for each year + 0th year cash flow

Calculation Table (Note: All values in British Pounds)

Year Number	Revenue (+ve cash flow) A	Expenses (-ve cash flow) B	Net Cash flow (A-B)	Cum net cash flow	PV Factor C	Present value (A-B)*C	Cumulative
0		-36000	-36000		1.000	-36000	-36000
1	7095.6	5400	1695.6	1695.6	0.926	1570	-34430
2	7095.6	4392	2703.6	4399.2	0.857	2318	-32112
3	7095.6	4104	2991.6	7390.8	0.794	2375	-29737
4	7095.6	3816	3279.6	10670.4	0.735	2411	-27327
5	7095.6	3528	3567.6	14238	0.681	2428	-24899
6	7095.6	3240	3855.6	18093.6	0.630	2430	-22469
7	7095.6	2952	4143.6	22237.2	0.583	2418	-20051
8	7095.6	2664	4431.6	26668.8	0.540	2394	-17657
9	7095.6	2376	4719.6	31388.4	0.500	2361	-15296
10	7095.6	2088	5007.6	36396	0.463	2319	-12976
11	7095.6	1800	5295.6	41691.6	0.429	2271	-10705
12	7095.6	1800	5295.6	46987.2	0.397	2103	-8602
13	7095.6	1800	5295.6	52282.8	0.368	1947	-6655
14	7095.6	1800	5295.6	57578.4	0.340	1803	-4852
15	7095.6	1800	5295.6	62874	0.315	1669	-3183
16	7095.6	1800	5295.6	68169.6	0.292	1546	-1637
17	7095.6	1800	5295.6	73465.2	0.270	1431	-206
18	7095.6	1800	5295.6	78760.8	0.250	1325	1119
19	7095.6	1800	5295.6	84056.4	0.232	1227	2346
20	7095.6	1800	5295.6	89352	0.215	1136	3483

Table 11.1: Cash Flows leading to NPV

11.8.4 Results

- Hence NPV = £3483 (Figure 11.1)
- Cumulative of Simple net cash flow gives a sum of £36396 at the end of 10th year against an investment of £36000(excluding grants), which means in 10 years time the investment, is recovered. Therefore simple payback period is 10 years(Figure).
- If £60000 (including grants) is considered as investment, the capital is recovered between 14 th and 15 th year, which means the simple pay back period is 14.5 years (Figure 11.2)

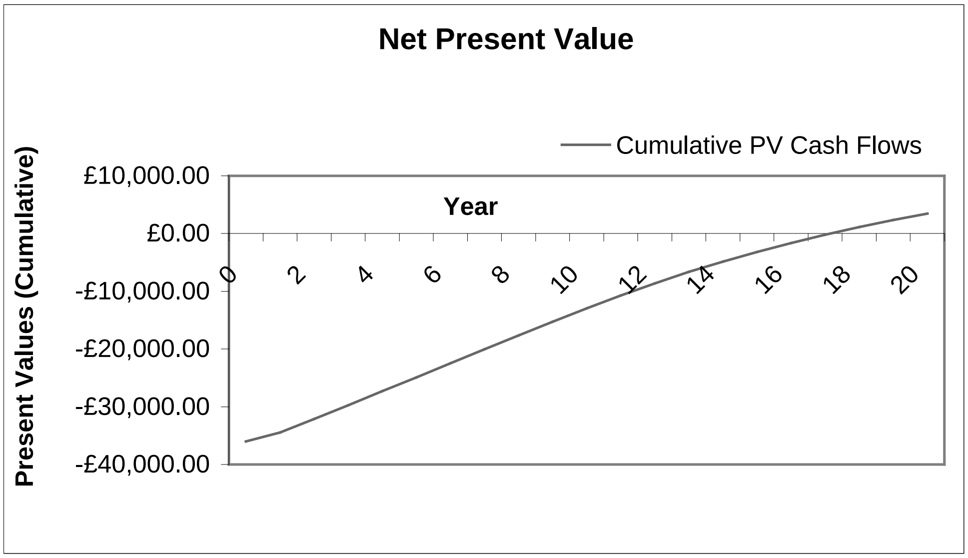

Figure 11.1: Net Present Value for 60kW wind turbine

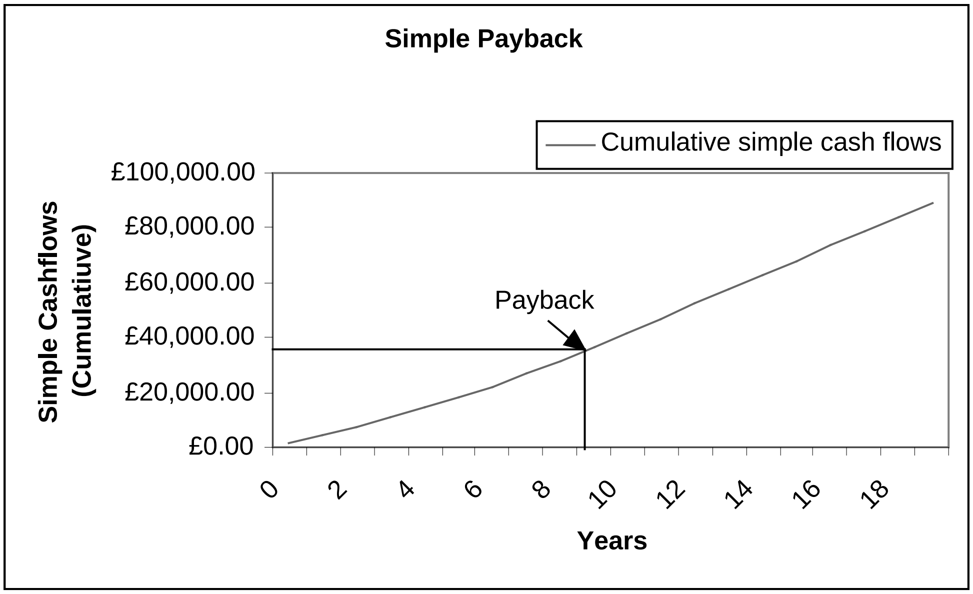

Figure 11.2: Simple Payback for a 60kW wind turbine

- Cash flow statement prepared for 2x60kW scheme, yielded similar results and NPV, which is just double that of the previous one as the total investment including grants taken as double that of sample case.
- However, for 2x 60kW configuration, if grants were to be kept same as in the sample case (£24,000), NPV becomes -£25375 and the simple pay back falls at the end of 13th year if grants are not considered as investment. If grants are also included in the investment the simple payback falls between 15th and 16th year. This indicates that NPV is very much dependent on the capital structure including grant component and interest and repayment of loan component. Detailed spreadsheets are given in the annexure.

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12 SUMMARY AND CONCLUSIONS

12.1 INTRODUCTION

The central aim of the dissertation is to look into the feasibility of a community wind turbine that can provide reasonable autonomy from the grid during periods of crisis when there are blackouts in the community. This dissertation also aimed to get a grasp of other aspects of a community wind power of particular interest to Carron Valley. This includes the planning aspects, storage aspects, grid requirements and policies and to provide a brief picture of sources of finance and the cash flows the project is capable of generating.

12.2 SELECTION OF METHODOLOGY

While sideline objectives such as planning issues called for a thorough study and analysis of available literature and consultations with relevant people in the field, the central aim needed a solid methodology. For devising a methodology, the key lies in pronouncing quantifiable objectives. In the present studies, the objectives naturally deal with demand, supply and storage. During site visit, most of the residents the author interacted with have expressed desire to switch over to space heating using electricity if available through renewables from the existing practice of firing coal, oil or wood in their Rayburns to produce hot water for services and space heating. So the first task is reduced to generating numbers that give an indication of the demand both existing electrical and future heating. Getting these numbers from available resources such as the records of the local grid operator or distributor or -in the absence of both - from the resident himself, if he has maintained any records. But that was not the case to be. The attempts to get a sort of load data from grid operator (Scottish Power) yielded no results as it was informed that no such records would normally be maintained. Even the residents have no such practices. Then what are the alternatives? How to find the electrical loads and heating loads? Possibly a questionnaire can throw some light by breaking down the total household consumption into individual appliances and their patterns. So it is decided to go for a questionnaire for getting electrical loads.

Next question is how to get heating loads. No data, whatsoever, is available in this case. After a thorough background studies, it appeared that ESP-r has the proven capability and required potential to generate numbers for heating loads. But how? Necessary background information is needed to build a model and run simulations. Hence the building dimensions and relevant data have been gathered from Carron Valley to make a building model in ESP-r. Next climate profiles are needed, as heating loads are dependent on local climate. But no climate time series is available for Carron Valley, so again decided to deviate, i.e. to go for existing profiles – Glasgow, Eskdalemuir. Although ESP-r simulations have been done under both profiles, only Eskadalemuir results have been used in subsequent Merit analysis as it represents much meaner climate. Now demand sets are ready and it is only left to manipulations to help create scenarios.

Now that demand data is available, next step is about choosing a method how these demands can be met by wind turbine and storage. Again a background research reduced the options to RETscreen and Merit and the latter appeared to have an advantage over RETscreen in assessing time series matching. Still in its infancy, its practical utility has been proven in a few case studies. Hence Merit is chosen as a decision support tool. Thus the combination of questionnaires, ESP-r and Merit provided the backbone for the entire analysis.

12.3 SUMMARY OF RESULTS

12.3.1 Electricity load profile by questionnaires

The data obtained by questionnaires was only for 5 houses (Annexure A) and hence a multiplication factor is used to convert it into representative data of entire community. The difference between summer and winter months is mainly contributed by small additional lighting in winter as cooking in most residents is carried out using Rayburns. There are 2- day peaks observed, one in the morning and the other is the evening peak. Morning peak is due to lighting, washing machines, tumble driers switched on by most residents, and evening peak is due to lighting, television, PC, and electric cooker in few houses.

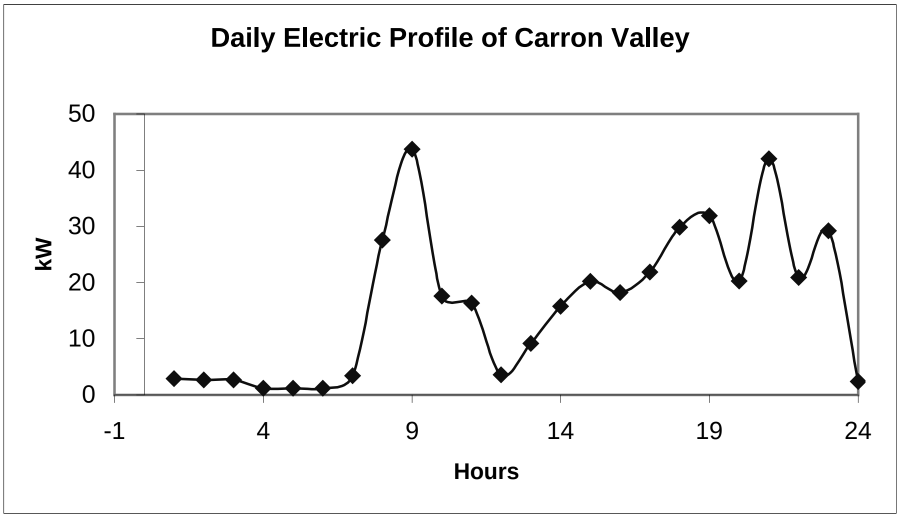

Figure12.1: Daily Electric Load Profile of all houses

12.3.2 Heating Profiles by ESP-r

The simulation exercise in ESP-r has resulted in the following annual heating profile per house with a peak rating of 3.5kW in winter. This exercise has not incorporated the conversion efficiencies. The profile depicts heat required at consumption end. So necessary conversion efficiencies need to be considered based on the technology used for heating for more accurate profiles at supply end.

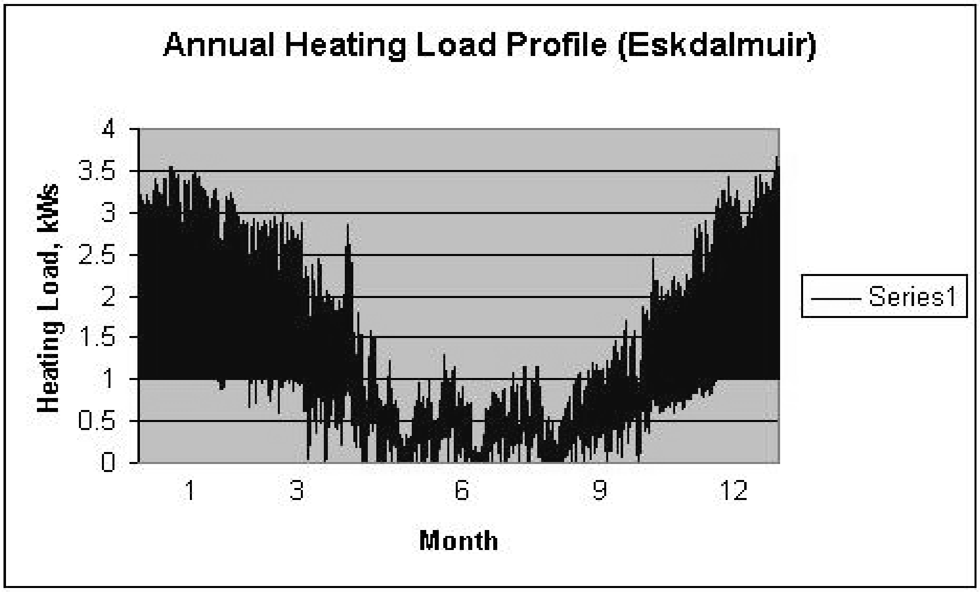

Figure12.2: Annual Heating Profile for One House in Carron Valley

12.3.3 Matching

Once the demand data was compiled, demand scenarios have been formulated. Supply profiles have been built up in Merit for suitably rated wind turbines and battery storage sets. By trial and error the demand profiles under each scenario has been weighed against supply profiles to get an optimum match. The criterion for evaluating an optimum match is based on percentage shortfall in supply combined with the match ratings obtained in Merit. Lower the shortfall of supply, higher the autonomy from grid power which is the requirement of the community during black outs. The results reveal what demand scenarios can be satisfied with wind-battery configuration. The summary of optimum matching results without considering back up in form of diesel engine or grid connection has been tabulated below.

Scenario	Annual Demand, kWh	Supply Capacity	Match Rating	% Excess	% Deficit	Period
Electrical+ Heating	366899	100kW wind+ 2785kWh battery	6/10	26	26	Year
	23424	100kW wind + 8361kWh battery	4/10	0	69	2 week winter
Emergency Electrical+ Heating	255302	100kW wind+ 2785kWh battery	5/10	59	32	Year
	18433	100kW wind+ 2785kWh battery	4/10	0	70	2 week winter
Electrical Only	150001	30kW wind+ 2785kWh battery	7/10	14	18	Year
	7113	100kW wind+ 2785kWh battery	7/10	0.2	22	2 week winter
Emergency Electrical Only	48402	60kW wind + 2785kWh battery	3/10	234	2	Year
	2121	60kW wind + 2785kWh battery	8/10	8	0	2 week winter

Table 12.1: Table of results summary

12.3.4 Technical Discussions and Conclusions

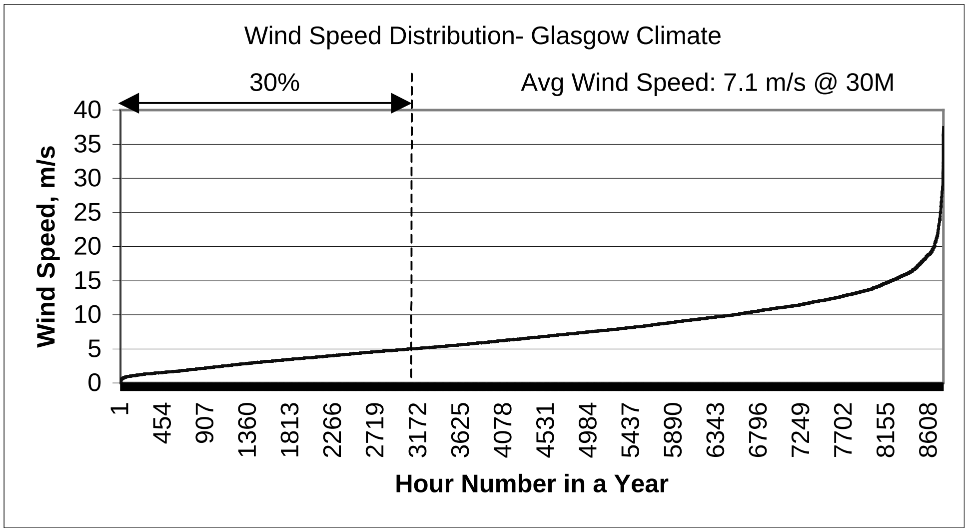

Figure 12.3 Wind speed distribution

The entire analysis in Merit is based on the above wind speed-time series. This is obtained from the existing climate profile for Glasgow in Merit and correcting it to the height of 30M, which is the standard hub height for Vergnet 15/60 wind turbines. The corrected wind speed- time series is rearranged in ascending order to obtain the above trend. Though Weibull distribution gives more accurate expected distribution, the above trend provides an insight into the wind speed characteristics. From the trend, it can be noticed that almost for 30% of the hours, the speed falls below 5m/s, which means that a Vergnet wind turbine with a cut-in speed of 5m/s, can not produce any power for 30% of the time for this model. On the other hand, an LMW 10kW machine with a 3m/s is capable of producing power for 80% of the time though the quantity depends on the cube of the wind speeds.

Hence the large percentage of shortfalls for the first two scenarios in the above result sets, are mainly due to the low wind regimes and the storage specified cannot completely nullify these shortfalls to provide complete autonomy from the grid to meet total heating and electricity requirements. As the demand is gradually reduced only to include essential electric loads, the percentage shortfall reduces to just 2% on an annual basis and it is zero during the possible blackout periods in December.

Hence, the following **conclusions** can be arrived form the modelling

- A 60kW wind turbine with a combination of battery storage (2785kWh) can possibly provide autonomy from the grid only to serve essential electric loads under the assumed climate profiles.
- A 100kW of wind power (possibly 2x60kW) with battery storage of 2785kWh, can meet the combined heating and electric requirements of the village, leaving an excess and deficit of 26% each for maximum annual demand scenario. Existing grid connection can possibly provide energy during short falls and the excess energy can be used for battery charging applications on a commercial basis.
- However, if complete autonomy from grid is sought for all load conditions, a suitably rated back up diesel generator only can provide the solution. Additional battery storage can save the number of starts and stops for the diesel generator in during momentary fluctuations.
- The decision to choose between a large enough battery storage (2785kWh) and an equivalent diesel generator shall be carefully made based on economics of initial costs and running costs, reliability and longevity.

12.4 GENERAL CONCLUSIONS

Planning: The planning procedures described in Chapter 4, though common to all wind systems, are more rigorous for large wind farms and generally lenient towards small community wind systems and thus easier and faster to obtain planning permission. However, the past cases indicate that a general acceptance by all residents of the community is a common pre requisite.
It is necessary that a separate set of planning guidelines need to be formulated to encourage community initiatives for small wind power, as currently no separate guidelines are available.

Siting : Although the location spotted in figure 3.12 looks idle, actual siting of the wind turbine has to be determined after taking in view all micro-siting criterion and actual wind speed measurement at least for one year using standard masts and anemometer with recorders

Storage Technologies : The literature survey indicates the importance of storage for renewables and the attributes and characteristics of each storage technology. There is a vast scope in near future for all these technologies for integration with renewables.

One technology that is quite close to playing a role for wind energy is flywheel storage. The currently available schemes are generally wind-diesel-flywheel in which it is traditional flywheels offering storage, the duration of which is from few seconds to few minutes. However the advent of Composite flywheels with magnetic bearings under vacuum conditions looks set to revolutionise storage practices for renewables. Hydrogen fuel cells appear to be another important technology with huge potential for renewable applications.

Grid Connection: This is a key issue and vastly determines the economics as well as security of supply. The costs depend on the required level of local grid up-gradation, type of scheme (Stand alone and or grid connected) and length of cable etc. The dual scheme of switching between grid and wind turbine based on power flows would provide the most reliable and flexible solution. However the absence of net metering concept, higher installation costs, technical complexity and safety issues make this option the least attractive. It can be concluded from the literature survey that lack of net metering provisions unlike in the United States proves detrimental to the flexibility and economic viability of small wind power.

The local grid in Carron Valley needs up gradation from the existing single phase to 3-phase level with an additional 3 phase transformer capable of accepting the required kVA , if wind turbine were to be installed. However, in the current scenario the chances of upgrading the local grid look quite remote in the absence of which it is not worthwhile to go ahead with the wind project.

Environmental Benefits: The use of a 60kW wind turbine would produce 160597kWh of electricity annually with corrected Glasgow climate. This energy will effectively replace 60T of CO_2 emissions into the atmosphere (With the current mix of energy in UK, 1kWh of grid power accounts for 0.43kg of CO_2), *(Source: http://www.defra.gov.uk/environment/envrp/gas/05.htm).* If two 60kW turbines were deployed, obviously the environmental savings would be double the estimated.

If the entire power were to be produced by diesel alone, assuming, still a 60kW wind turbine would prevent the release of 40Tons of CO_2 emissions into the atmosphere. Besides the benefit of fuel saving accounts for 15000litres of saving of diesel fuel per annum.

Local Employment: A community wind farm has the potential to trigger a whole range of community development, which can create employment opportunities in the community.

Economic Benefits: As there is a possibility of getting grants under various schemes, the capital burden is vastly reduced. The positive future cash flows can be reinvested within the community for common benefits, which would be a basis for all new economic activity. For example, there is no public transport facility for Carron Valley, which can be provided as an offshoot of wind project development. The excess power garnered in days of high wind can be diverted to charge the battery-operated vehicles to provide reliable public transport. In addition there are intangible benefits in the form of saving on CO_2 emissions, saving on primary fuel (already discussed) and a feel good factor for committing to sustainable technologies (renewables).

Project Financing

Literature survey and few examples of past projects in the UK indicate that there is growing support to community renewable and wind in particular from various sources such as Energy Saving Trust and Scottish Power Green Energy Trust. These institutions offer grants for community wind power. Also other sources of finance include equity participation by the community and/or project contractor, loans from charity banks such as Triodos Bank, proceeds of National Lotteries, European Regional Development Fund and donations.

Cash flow analysis: The cash flow analysis tells that community wind power projects are capable of producing positive cash flows assuming they yield a fixed price for the power generated. The possibility of the same is construed if the entire power is sold to grid/ private customer or entirely used by the community themselves. By selling to the grid, they stand a chance of decent tariff plans. They also save a fortune even if they use the said power for the own business, which otherwise will have to be sourced from the grid. If they want to use it partly and sell the remnant to the grid, they don't do justice to the investment, as the rate offered by the grid operator is meagre. Grant component of the investment, interest and repayment term of the loan component, depreciation costs, taxes and insurance are other major factors influencing NPV of a wind energy project. The figure below shows the trend of NPV for a 60kW wind turbine for a design life of 20 years and the proceedings of selling the power @4.5p/kWh with an investment @ £1000/kW. It is worthwhile to note that £24000 comes in form of grant and the remnant as loan @8% interest for 10 years. The discount factor for Present Value is assumed to be 8%. The resulting NPV is £3483 with a simple pay back of 10 years.

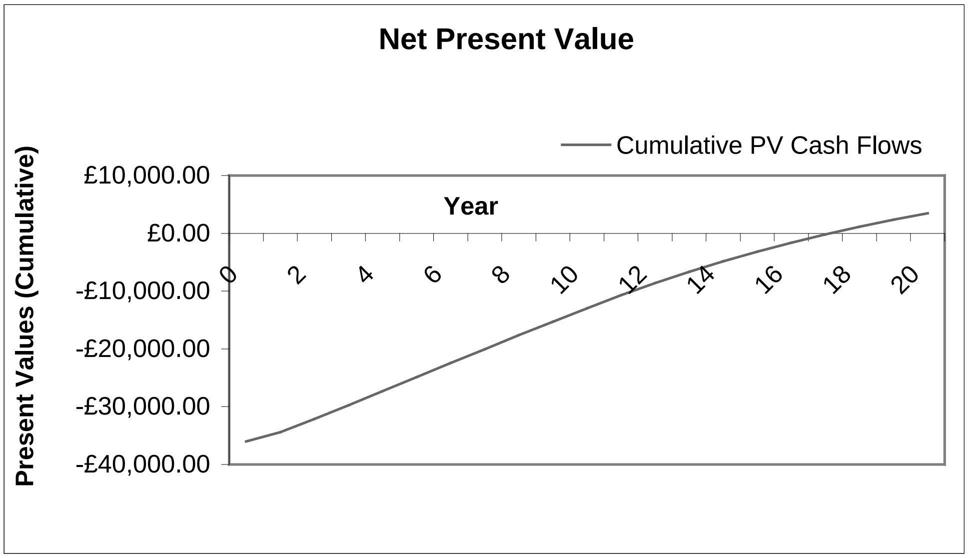

Figure 12.4 NPV for a 60kW wind turbine scheme

12.5 SUMMARY OF CONCLUSIONS

- It is impossible to get complete autonomy from the grid extending over a few days with a wind- battery scheme alone to serve the total electric and heating loads of the community.
- A 60kW wind turbine with a combination of battery storage (2785kWh) can possibly provide autonomy from the grid only to serve essential electric loads under the assumed climate profiles.
- A 100kW of wind power (possibly 2x60kW) with battery storage of 2785kWh, can meet the combined heating and electric requirements of the village, leaving an excess and deficit of 26% each for maximum annual demand scenario. Existing grid connection can possibly provide energy during short falls and the excess energy can be used for battery charging applications on a commercial basis.
- If complete autonomy from grid is sought for all load conditions, a suitably rated (possibly 120kW peak loads) back up diesel generator only can provide the solution. Additional battery storage can save the number of starts and stops for the diesel generator in during momentary fluctuations.
- The decision to choose between a large enough battery storage (2785kWh) and an equivalent diesel generator shall be carefully made based on economics of initial costs and running costs, reliability and longevity.
- The existing local grid at Carron Valley is a single-phase, 11kV overhead line with an installed transmission capacity of 100kVA. For the proposed wind project, grid up gradation to 11kV, 3-phase and to accommodate an additional 100kVA (for a 60kW wind turbine) is necessary to provide operating flexibility to the wind project. As the chances of grid up gradation appear quite remote, it would not be a worthwhile proposition to go ahead with the wind project.
- Obtaining planning permission for community wind projects is relatively easy provided there are no major objections to the proposed project with in the community. A response received form the Stirling Council

for a planning enquiry is quite positive and encouraging (Enclosed in the Annexure)

- Various sources of funding are available which include grants from Energy Saving Trust, Scottish Power Green Energy Trust and European Regional Development Fund; soft loans form charity institutions like Troidos Bank. Funds can also be raised through equity participation from the community members and construction contractor, national lotteries and donations.
- It is shown that the future cash flows and Net Present Value for the project very much depend upon the percentage of grants in the capital structure and the loan repayment conditions (interest and period of repayment). For the case studies a simple pay back period obtained is 10 years.
- The benefits that can be accrued from the project include both tangible and intangible. Apart form raising positive cash flows, the project can generate local employment, a whole range of financial activity by reinvestment of positive cash flows, provide environmental benefits by saving 60tons of CO_2 emissions for a 60kW wind turbine.

12.5 FUTURE WORK

The future work involves two aspects - one about the theoretical front and the second about the practical front.

Though the current objectives of the dissertation have been fulfilled, on the practical side, a lot of work still remains to make the project a reality. The first step in that direction is to gather correct information pertaining to the area for example wind speeds (by actually recording for a year) and more realistic demand profiles. When these inputs become available, the modelling work can be redone to produce more accurate results. Once the technical alternatives have been arrived at, a detailed economic analysis needs to be done keeping the market conditions in mind to arrive at an economically viable solution.

On the theoretical front, this dissertation has not focussed on demand side management involving energy efficiency measures to reduce the demand, actual configuration of the wind energy system involving wind turbine, storage and the grid, modelling of flywheel storage to study its effects on demand - supply matching and power control methods –all of which can be considered for future studies.

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22 http://www.dti.gov.uk/energy/inform/energy_indicators/ind11.pdf

Domestic energy trends

23 http://www.est.co.uk/bestpractice/uploads/publications/pdfs/gpg345.pdf
Domestic electric heating

25 http://www.defra.gov.uk/environment/energy/research/domestic/pdf/domestic_energy.pdf
Domestic energy fact file

24 http://www.nationalgrid.com/uk/activities/mn_demand.html
Summer and winter demands 2002

25 http://trading.innogy.com/resources/InnForm_Sept_2002.pdf

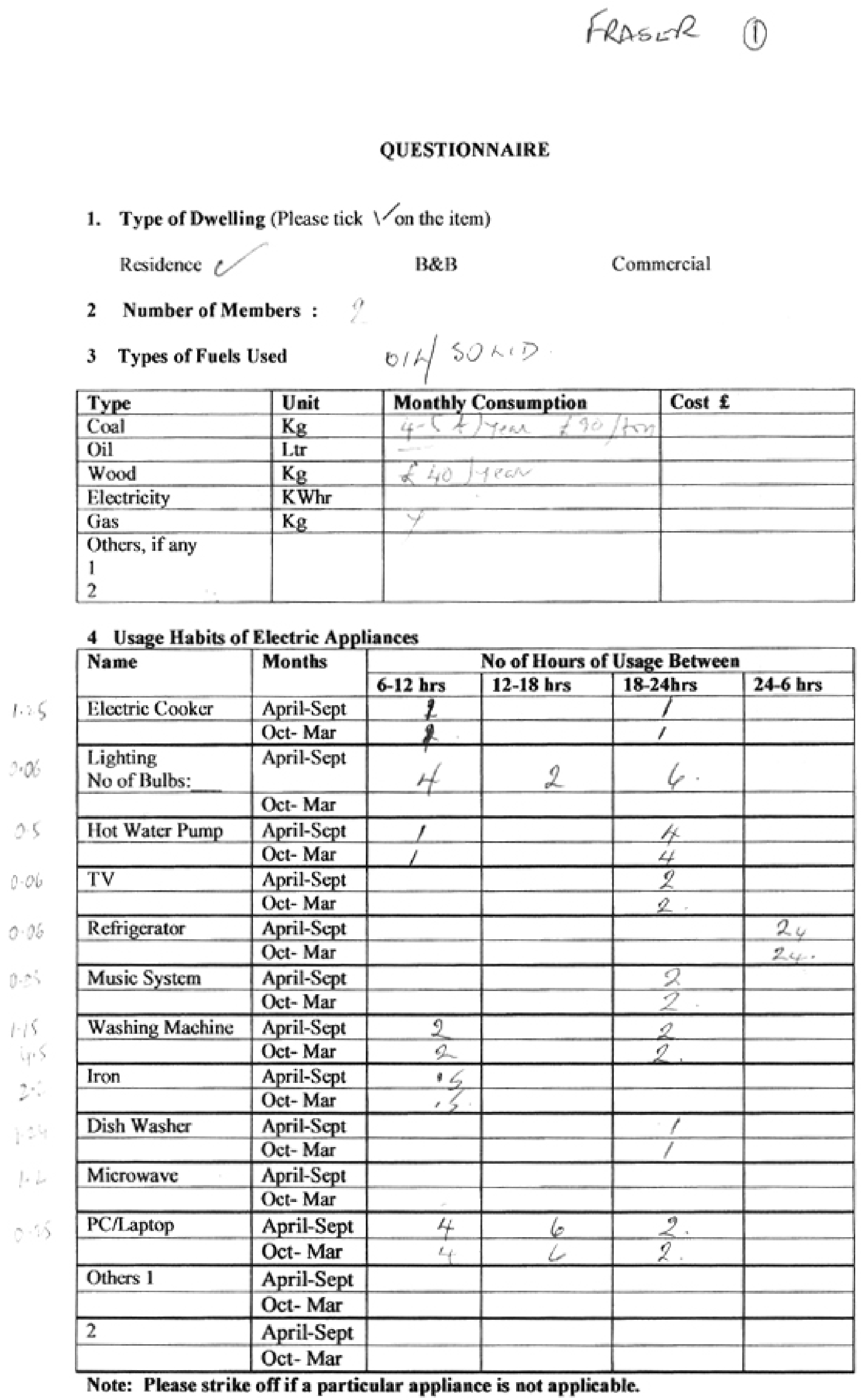
Some forward curves

26 http://www.dti.gov.uk/energy/inform/energy_trends/

Energy production and consumption in the UK

APPENDICES

A Response to Questionnaires



FRASER ①

QUESTIONNAIRE

1. **Type of Dwelling** (Please tick √ on the item)

Residence [✓] B&B Commercial

2 **Number of Members** : 2

3 **Types of Fuels Used** Oil / SOLID.

Type	**Unit**	**Monthly Consumption**	**Cost £**
Coal	Kg	4-5 (t) year £90/ton	
Oil	Ltr	—	
Wood	Kg	£40 / year	
Electricity	KWhr		
Gas	Kg	✓	
Others, if any 1 2			

4 **Usage Habits of Electric Appliances**

	Name	**Months**	**No of Hours of Usage Between**			
			6-12 hrs	**12-18 hrs**	**18-24hrs**	**24-6 hrs**
1·25	Electric Cooker	April-Sept	1		1	
		Oct- Mar	1.		1	
0·06	Lighting No of Bulbs:___	April-Sept	4	2	6.	
		Oct- Mar				
0·5	Hot Water Pump	April-Sept	1		4	
		Oct- Mar	1		4	
0·06	TV	April-Sept			2	
		Oct- Mar			2.	
0·06	Refrigerator	April-Sept				24
		Oct- Mar				24.
0·05	Music System	April-Sept			2	
		Oct- Mar			2.	
1·15	Washing Machine	April-Sept	2		2	
4·5		Oct- Mar	2		2.	
2·[illegible]	Iron	April-Sept	·5			
		Oct- Mar	·5.			
1·[illegible]	Dish Washer	April-Sept			1	
		Oct- Mar			1	
1·2	Microwave	April-Sept				
		Oct- Mar				
0·35	PC/Laptop	April-Sept	4	6	2.	
		Oct- Mar	4	6	2.	
	Others 1	April-Sept				
		Oct- Mar				
	2	April-Sept				
		Oct- Mar				

Note: Please strike off if a particular appliance is not applicable.

5 **Type of electricity back-up arrangement you have**

Type : Diesel Generator Battery/UPS Others: NONE

Rating :

6 **If reliable electricity is available would you like to switch over to electric water heating** [✓ Yes]/No

7 **If reliable electricity is available would you like to switch over to electric cooker** [✓ Yes]/No

8 **If reliable electricity is available would you like to add any additional electric appliances** [✓ Yes]/No

if yes, please specify: ____________________

9 **Are you willing for a community wind turbine** [✓ Yes]/No

10 **What role you wish to assume in this task** (Please tick)

Planner Developer [✓ Operator] Maintenance Commercial Laisoning

None DOMESTIC.

Jimmy ②

QUESTIONNAIRE

1. **Type of Dwelling** (Please tick √ on the item)

Residence B&B [✓] Commercial

2 **Number of Members :**

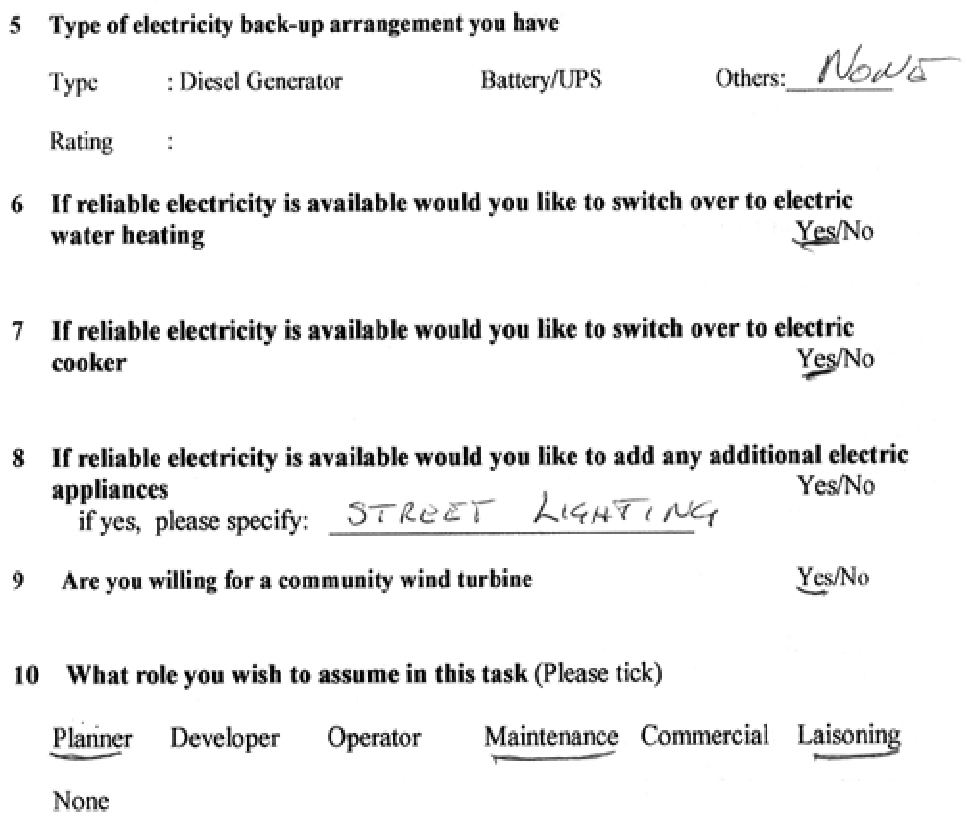
3 **Types of Fuels Used**

Type	**Unit**	**Monthly Consumption**	**Cost £**
Coal	Kg		
Oil	Ltr	350 LITRES	£100
Wood	Kg	100 KG	£50
Electricity	KWhr	1500 UNITS	£1560 ANNUAL
Gas	Kg	N/A	
Others, if any 1 2			

4 **Usage Habits of Electric Appliances**

Name	**Months**	**No of Hours of Usage Between**			
		6-12 hrs	**12-18 hrs**	**18-24hrs**	**24-6 hrs**
Electric Cooker	April-Sept	½ HR	4 HRS	2 HRS	0
	Oct- Mar	3 HRS	6 HRS	4 HRS	0
Lighting No of Bulbs:___	April-Sept	10	30	35	10
	Oct- Mar				
Hot Water Pump	April-Sept	2 HRS	4	5	
	Oct- Mar	4 HRS	3	5	
TV	April-Sept	2 HRS	4	3	
	Oct- Mar	5 HRS	5 HRS	5	
Refrigerator	April-Sept	6	6	6	24
	Oct- Mar	6	6	6	24
Music System	April-Sept	3	1	1	
	Oct- Mar				
Washing Machine	April-Sept	4	4	1	
	Oct- Mar	2	2	2	
Iron	April-Sept	1	1	1	
	Oct- Mar	1	1	1	
Dish Washer	April-Sept	0	0	0	
	Oct- Mar	0	0	0	
Microwave	April-Sept	1	1	1	
	Oct- Mar	1	1	1	
PC/Laptop	April-Sept	1	1	1	
	Oct- Mar	1	1	1	
Others 1	April-Sept				
	Oct- Mar				
2	April-Sept				
	Oct- Mar				

Note: Please strike off if a particular appliance is not applicable.



5 Type of electricity back-up arrangement you have

Type : Diesel Generator Battery/UPS Others: NONE

Rating :

6 If reliable electricity is available would you like to switch over to electric water heating [✓ Yes]/No

7 If reliable electricity is available would you like to switch over to electric cooker [✓ Yes]/No

8 If reliable electricity is available would you like to add any additional electric appliances Yes/No

if yes, please specify: STREET LIGHTING

9 Are you willing for a community wind turbine [✓ Yes]/No

10 What role you wish to assume in this task (Please tick)

[✓ Planner] Developer Operator [✓ Maintenance] Commercial [✓ Laisoning]

None

Dougie ③

QUESTIONNAIRE

1. **Type of Dwelling** (Please tick ✓ on the item)

Residence [✓] B&B Commercial

2 **Number of Members :** 3

3 **Types of Fuels Used** Coal ELECTRICITY

Type	**Unit**	**Monthly Consumption**	**Cost £**
Coal	Kg	1 TON	£ 90
Oil	Ltr		
Wood	Kg	½ TON	
Electricity	KWhr		£ 85
Gas	Kg		
Others, if any 1 2			

4 **Usage Habits of Electric Appliances**

Name	**Months**	**No of Hours of Usage Between**			
		6-12 hrs	**12-18 hrs**	**18-24hrs**	**24-6 hrs**
Electric Cooker	April-Sept			✓	
	Oct- Mar			✓	
Lighting No of Bulbs: 31	April-Sept				
	Oct- Mar				
Hot Water Pump	April-Sept		✓		
	Oct- Mar				✓
TV	April-Sept		✓		
	Oct- Mar		✓		
Refrigerator	April-Sept				✓
	Oct- Mar				✓
Music System	April-Sept	✓			
	Oct- Mar	✓			
Washing Machine	April-Sept			✓	
	Oct- Mar			✓	
Iron	April-Sept	✓			
	Oct- Mar	✓			
Dish Washer	April-Sept				
	Oct- Mar				
Microwave	April-Sept	✓			
	Oct- Mar	✓			
PC/Laptop	April-Sept	✓			
	Oct- Mar	✓			
Others 1	April-Sept				
	Oct- Mar				
2	April-Sept				
	Oct- Mar				

Note: Please strike off if a particular appliance is not applicable.

5 **Type of electricity back-up arrangement you have**

Type : Diesel Generator Battery/UPS Others: ✓

Rating :

6 **If reliable electricity is available would you like to switch over to electric water heating** [✓ Yes]/No

7 **If reliable electricity is available would you like to switch over to electric cooker** [✓ Yes]/No

8 **If reliable electricity is available would you like to add any additional electric appliances** [✓ Yes]/No

if yes, please specify: Heating

9 **Are you willing for a community wind turbine** [✓ Yes]/No

10 **What role you wish to assume in this task** (Please tick)

Planner [✓ Developer] Operator Maintenance Commercial Laisoning

None

DAVID ⑥

QUESTIONNAIRE

1. **Type of Dwelling** (Please tick ✓ on the item)

Residence ✓ B&B Commercial

2 **Number of Members :** 2

3 **Types of Fuels Used**

Type	**Unit**	**Monthly Consumption**	**Cost £**
Coal	Kg		–
Oil	Ltr	301	£61-00
Wood	Kg		–
Electricity	KWhr	39	£20-00
Gas	Kg		–
Others, if any 1 2			

4 **Usage Habits of Electric Appliances**

Name	**Months**	**No of Hours of Usage Between**			
		6-12 hrs	**12-18 hrs**	**18-24hrs**	**24-6 hrs**
Electric Cooker	April-Sept	–	–	1 - 2hrs	–
	Oct- Mar	–	–	1 - 2hrs	–
Lighting No of Bulbs: 15	April-Sept	½hr	–	2hrs.	
	Oct- Mar	1hr	2hrs	6hrs.	–
Hot Water Pump	April-Sept	1hr	–	2hrs	–
	Oct- Mar	2hrs	–	5hrs	2hrs
TV	April-Sept	2hrs	1hr	5hrs	1hr
	Oct- Mar	2hrs	1hr	5hrs	1hr
Refrigerator	April-Sept	On	all the	time	
	Oct- Mar	On	all the	time	
Music System	April-Sept	–	1hr	–	–
	Oct- Mar	–	1hr	–	–
Washing Machine	April-Sept	1hr	–	1hr	–
	Oct- Mar	1hr	–	1hr	–
Iron	April-Sept	–	2hr	–	–
	Oct- Mar	–	2hr	–	–
~~Dish Washer~~	April-Sept	N/A	N/A	N/A	N/A
	Oct- Mar				
Microwave	April-Sept	/	½hr	/	/
	Oct- Mar	/	½hr		
PC/Laptop	April-Sept	/	/	2hrs	/
	Oct- Mar			2hrs	
Others 1 Freezer	April-Sept	On	all the	time.	
	Oct- Mar				
2 Video	April-Sept	/	/	1hr	/
	Oct- Mar			1hr	

Note: Please strike off if a particular appliance is not applicable.

5 **Type of electricity back-up arrangement you have**

Type : Diesel Generator Battery/UPS Others:_________

Rating :

6 **If reliable electricity is available would you like to switch over to electric water heating** [✓ Yes]/No

7 **If reliable electricity is available would you like to switch over to electric cooker** [✓ Yes]/No

8 **If reliable electricity is available would you like to add any additional electric appliances** Yes/[✓ No]

if yes, please specify: ______________________________

9 **Are you willing for a community wind turbine** [✓ Yes]/No

10 **What role you wish to assume in this task** (Please tick)

Planner Developer [✓ Operator] Maintenance Commercial Laisoning

None

Mick ⑤

QUESTIONNAIRE

1. **Type of Dwelling** (Please tick √ on the item)

Residence ✓ B&B Commercial

2 **Number of Members :** 4

3 **Types of Fuels Used**

Type	**Unit**	**Monthly Consumption**	**Cost £**
Coal	Kg	250	£25
Oil	Ltr		
Wood	Kg		
Electricity	KWhr		
Gas	Kg		
Others, if any 1 2			

4 **Usage Habits of Electric Appliances**

Name	**Months**	**No of Hours of Usage Between**			
		6-12 hrs	**12-18 hrs**	**18-24hrs**	**24-6 hrs**
Electric Cooker	April-Sept	2	3	1	\
	Oct- Mar	2	3	1	\
Lighting No of Bulbs:___	April-Sept	6	5	7	
	Oct- Mar	6	5	7	
Hot Water Pump	April-Sept	3	3	3	3
	Oct- Mar	6	6	6	6
TV	April-Sept	2	4	4	\
	Oct- Mar	2	4	4	\
Refrigerator	April-Sept	6	6	6	6
	Oct- Mar	6	6	6	6
Music System	April-Sept	3		2	
	Oct- Mar	3		2	
Washing Machine	April-Sept		4		
	Oct- Mar		4		
Iron	April-Sept			3	
	Oct- Mar			5	
Dish Washer	April-Sept			2	
	Oct- Mar			2	
Microwave	April-Sept				
	Oct- Mar				
PC/Laptop	April-Sept			2	
	Oct- Mar			2	
Others 1	April-Sept				
	Oct- Mar				
2	April-Sept				
	Oct- Mar				

Note: Please strike off if a particular appliance is not applicable.

5 **Type of electricity back-up arrangement you have**

Type : ~~Diesel Generator~~ ~~Battery/UPS~~ ~~Others:~~________

Rating :

6 **If reliable electricity is available would you like to switch over to electric water heating** [✓ Yes]/No

7 **If reliable electricity is available would you like to switch over to electric cooker** [✓ Yes]/No

8 **If reliable electricity is available would you like to add any additional electric appliances** [✓ Yes]/No

if yes, please specify: POSSIBLE HEATING

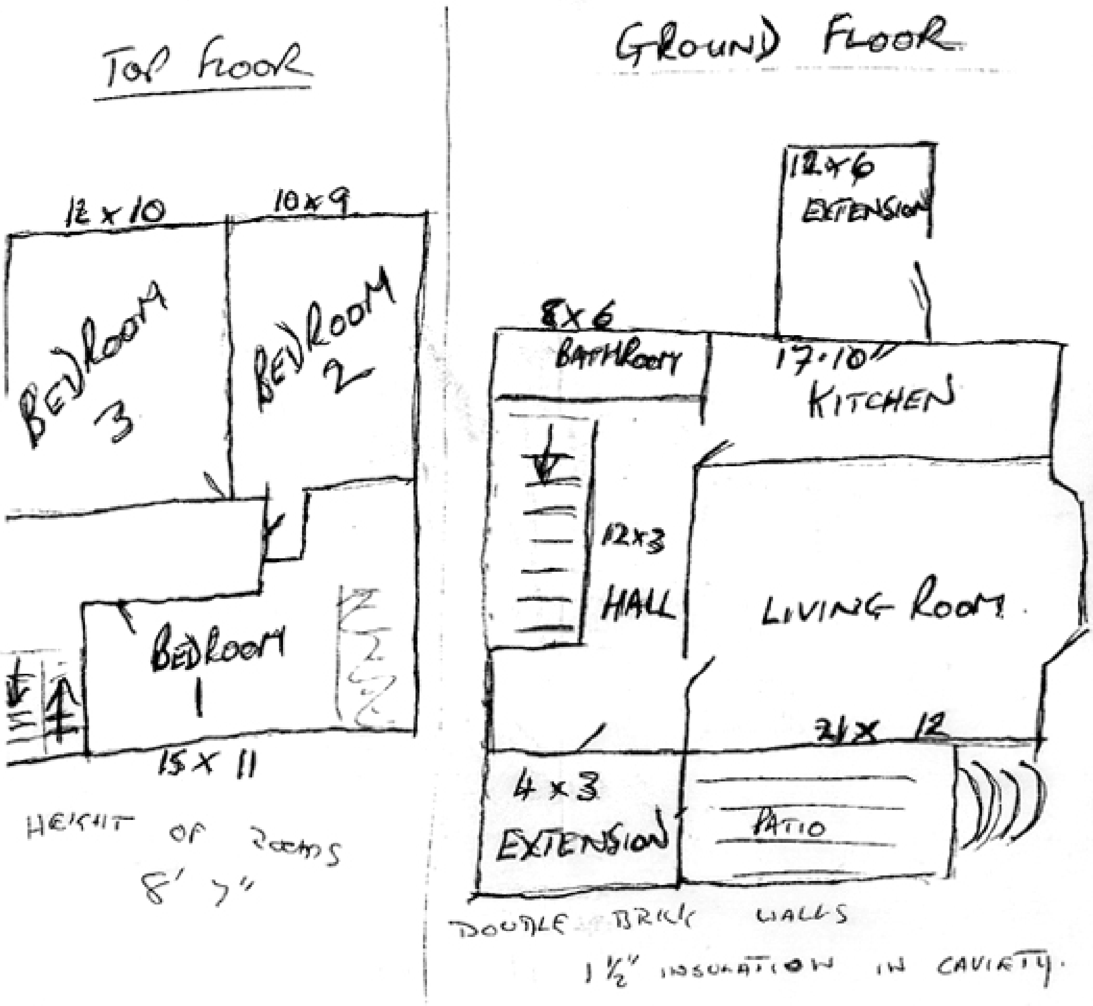
9 **Are you willing for a community wind turbine** [✓ Yes]/No

10 **What role you wish to assume in this task** (Please tick)

[✓ Planner] Developer [✓ Operator] [✓ Maintenance] Commercial Laisoning

None

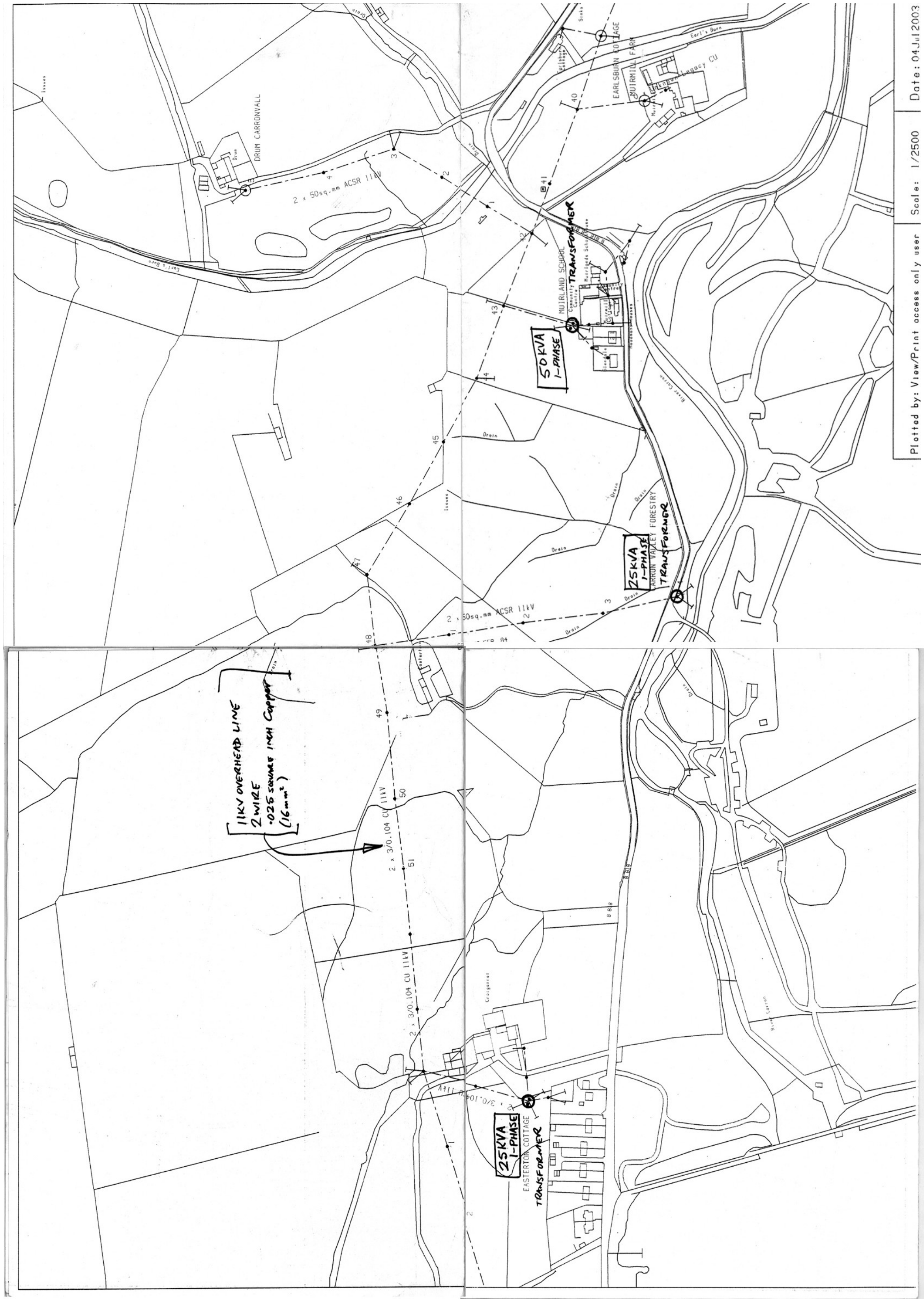
B Sketch of the House Plan provided by a resident of Carron Valley



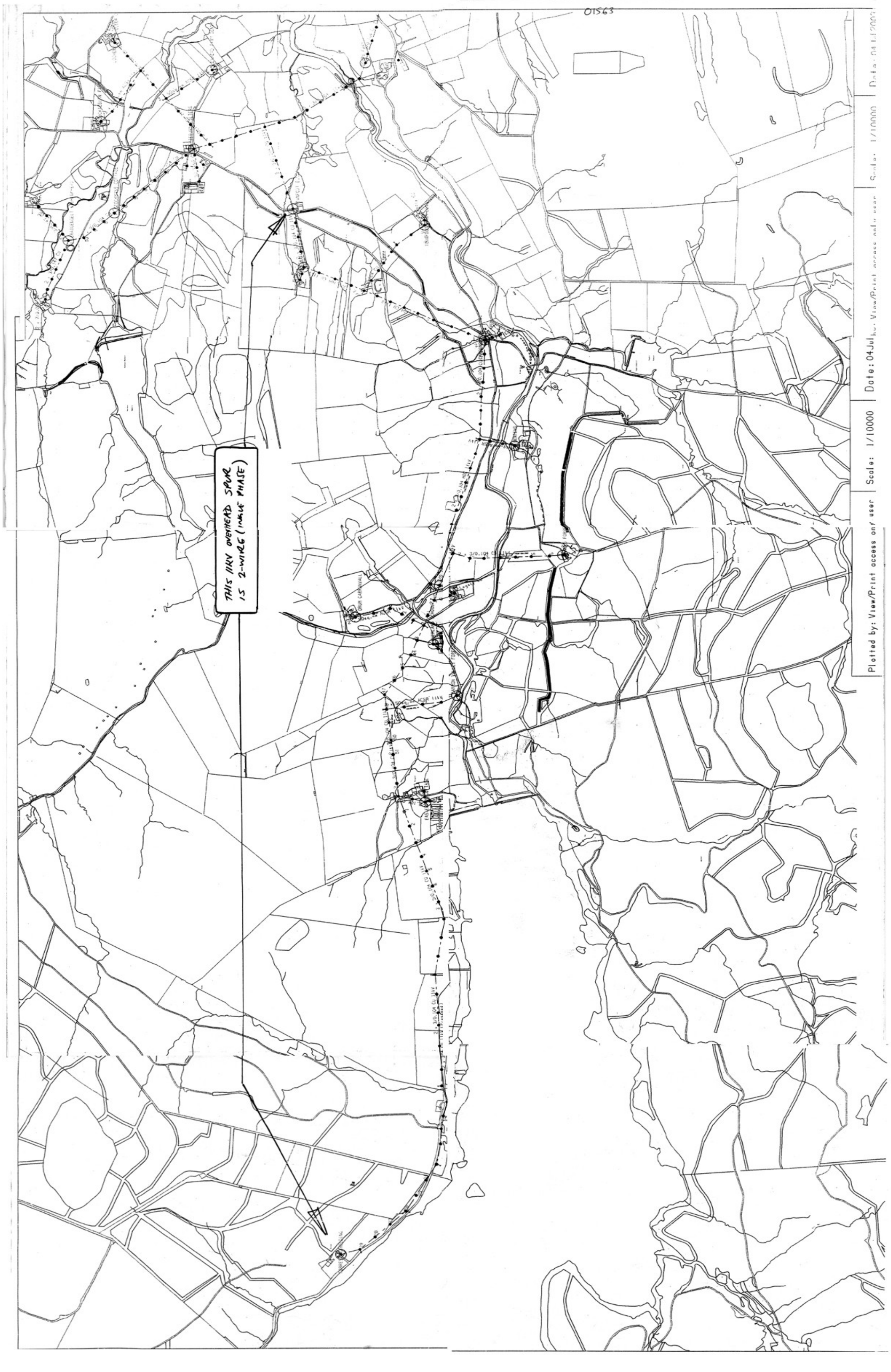
Bill McDonald 14 Carron Valley Denny FK6 5JL.

C. Carron Valley Local Grid

Arrangement of Local Transformers



Single phase, 11kV distribution line, Carron Valley



D Zone Control Summary for ESP-r Simulations

```
Welcome to the ESP-r System, Version 10.2

 (ESP-r Project Manager Version 4.39a
 of October 2002, Copyright 2001 Energy
 Systems Research Unit, University of
 Strathclyde, Glasgow, Scotland.)

 Loading supplied model description.
 Site location:    56.0N    4.0E of local meridian.
 Ground reflectivity 0.20.
 Site exposure isolated rural.


 Overall description: project control
 Zones control: no descrip : 3 functions.

 The sensor for function  1 senses the temperature of the current
zone.
 The actuator for function  1 is air point of the current zone
 There have been  1-day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 18.0 100.0 0.0
   2 10.00 db temp   > flux      free floating
   3 16.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 18.0 100.0 0.0

 The sensor for function  2 senses the temperature of the current
zone.
 The actuator for function  2 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      free floating
   2 10.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 18.0 100.0 0.0
   3 16.00 db temp   > flux      free floating

 The sensor for function  3 senses the temperature of the current
zone.
 The actuator for function  3 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 18.0 100.0 0.0
   2  7.00 db temp   > flux      free floating
   3 19.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 18.0 100.0 0.0
```

```
 Zone to contol loop linkages:
 zone ( 1) hall         << control  1
 zone ( 2) living       << control  2
 zone ( 3) kitchen      << control  0
 zone ( 4) bed_one      << control  3
 zone ( 5) bed_Three    << control  3
 zone ( 6) bed_two      << control  3
 zone ( 7) top          << control  0
 Welcome to the ESP-r System, Version 10.2

 (ESP-r Project Manager Version 4.39a
 of October 2002, Copyright 2001 Energy
 Systems Research Unit, University of
 Strathclyde, Glasgow, Scotland.)

 Loading supplied model description.
 Site location:    56.0N    4.0E of local meridian.
 Ground reflectivity 0.20.
 Site exposure isolated rural.


 Overall description: project control
 Zones control: no descrip : 3 functions.

 The sensor for function  1 senses the temperature of the current
zone.
 The actuator for function  1 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0
   2 10.00 db temp   > flux      free floating
   3 16.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0

 The sensor for function  2 senses the temperature of the current
zone.
 The actuator for function  2 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      free floating
   2 10.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0
   3 16.00 db temp   > flux      free floating

 The sensor for function  3 senses the temperature of the current
zone.
 The actuator for function  3 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0
```

```
   2  7.00 db temp   > flux      free floating
   3 19.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0

 Zone to contol loop linkages:
 zone ( 1) hall         << control  1
 zone ( 2) living       << control  2
 zone ( 3) kitchen      << control  0
 zone ( 4) bed_one      << control  3
 zone ( 5) bed_Three    << control  3
 zone ( 6) bed_two      << control  3
 zone ( 7) top          << control  0
 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0

 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  2  2  2
Day Gain Type     Period Sensible  Latent     Radiant    Convec
    No.  labl     Hours  Magn.(W)  Magn. (W)  Frac       Frac
Wkd  1 OccuptW    9 - 16     20.0     20.0       0.50       0.50
Wkd  2 LightsW   17 - 24     50.0     50.0       0.50       0.50
Sat  1 OccuptW    9 - 16     20.0     20.0       0.50       0.50
Sat  2 LightsW   17 - 24     50.0     50.0       0.50       0.50
Sun  1 OccuptW    9 - 16     20.0     20.0       0.50       0.50
Sun  2 LightsW   17 - 24     50.0     50.0       0.50       0.50
 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0

 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  0  0  0
 Description: nil_operations
 Control: no control of air flow

 Number of Weekday Sat Sun air change periods =  0  0  0

 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  5  5  5
Day Gain Type     Period Sensible  Latent     Radiant    Convec
    No.  labl     Hours  Magn.(W)  Magn. (W)  Frac       Frac
Wkd  1 OccuptW    7 -  8     20.0     20.0       0.50       0.50
Wkd  2 OccuptW    8 - 11     10.0     10.0       0.50       0.50
Wkd  3 OccuptW   11 - 18     30.0     30.0       0.50       0.50
Wkd  4 LightsW   18 - 22    100.0    100.0       0.50       0.50
Wkd  5 OccuptW   18 - 23     50.0     50.0       0.50       0.50
Sat  1 OccuptW    7 -  8     20.0     20.0       0.50       0.50
Sat  2 OccuptW    8 - 11     10.0     10.0       0.50       0.50
Sat  3 OccuptW   11 - 18     30.0     30.0       0.50       0.50
Sat  4 LightsW   18 - 22    100.0    100.0       0.50       0.50
Sat  5 OccuptW   18 - 23     50.0     50.0       0.50       0.50
Sun  1 OccuptW    7 -  8     20.0     20.0       0.50       0.50
Sun  2 OccuptW    8 - 11     10.0     10.0       0.50       0.50
Sun  3 OccuptW   11 - 18     30.0     30.0       0.50       0.50
Sun  4 LightsW   18 - 22    100.0    100.0       0.50       0.50
Sun  5 OccuptW   18 - 23     50.0     50.0       0.50       0.50
 Description: nil_operations
 Control: no control of air flow
```

```
 Number of Weekday Sat Sun air change periods =  0  0  0

 Description : nil_operations
 Number of Weekday Sat Sun casual gains=  3  3  3
Day Gain Type     Period Sensible  Latent     Radiant    Convec
    No.  labl     Hours  Magn.(W)  Magn. (W)  Frac       Frac
Wkd  1 OccuptW    7 - 10     20.0     20.0       0.50       0.50
Wkd  2 LightsW   17 - 24     50.0     50.0       0.50       0.50
Wkd  3 OccuptW   16 - 20     50.0     50.0       0.50       0.50
Sat  1 OccuptW    7 - 10     20.0     20.0       0.50       0.50
Sat  2 LightsW   17 - 24     50.0     50.0       0.50       0.50
Sat  3 OccuptW   16 - 20     50.0     50.0       0.50       0.50
Sun  1 OccuptW    7 - 10     20.0     20.0       0.50       0.50
Sun  2 LightsW   17 - 24     50.0     50.0       0.50       0.50
Sun  3 OccuptW   16 - 20     50.0     50.0       0.50       0.50

 Overall description: project control
 Zones control: no descrip : 3 functions.

 The sensor for function  1 senses the temperature of the current
zone.
 The actuator for function  1 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0
   2 10.00 db temp   > flux      free floating
   3 16.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0

 The sensor for function  2 senses the temperature of the current
zone.
 The actuator for function  2 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      free floating
   2 10.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0
   3 16.00 db temp   > flux      free floating

 The sensor for function  3 senses the temperature of the current
zone.
 The actuator for function  3 is air point of the current zone
 There have been  1 day types defined.

 Day type  1 is valid Sat  1 Jan to Sun 31 Dec, 2000 with  3
periods.
 Per|Start|Sensing  |Actuating  | Control law       | Data
   1  0.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0
   2  7.00 db temp   > flux      free floating
   3 19.00 db temp   > flux      basic control       1000.0 0.0
1000.0 0.0 21.0 100.0 0.0

 Zone to contol loop linkages:
```

```
zone ( 1) hall         << control  1
zone ( 2) living       << control  2
zone ( 3) kitchen      << control  0
zone ( 4) bed_one      << control  3
zone ( 5) bed_Three    << control  3
zone ( 6) bed_two      << control  3
zone ( 7) top          << control  0
```

E ESP-r Results- Zone wise Heating Loads for a Typical Winter Day

```
Timestep        performance metrics.

Lib: siva.esk78.res:    Results         for siva        Climate : Eskdalemuir

Period:         Sat  1 Jan @ 00h45 to:  Sun     31-Dec          @23h 45
Year:2000 : sim@30                                      "
                        Time    Hall    Living         Kitchen  Bed_one     Bed_three
Bed_two  Top

|       kW     |kW     |kW     |kW     |       kW     |kW      |       kW
00h15   1       0               0               0.73    0.8             0.57    0
00h45   1       0               0               0.71    0.79            0.55    0
01h15   1       0               0               0.69    0.78            0.53    0
01h45   1       0               0               0.68    0.77            0.52    0
02h15   1       0               0               0.68    0.76            0.52    0
02h45   1       0               0               0.67    0.75            0.51    0
03h15   1       0               0               0.67    0.74            0.5     0
03h45   1       0               0               0.66    0.73            0.5     0
04h15   1       0               0               0.66    0.72            0.49    0
04h45   1       0               0               0.66    0.71            0.49    0
05h15   1       0               0               0.65    0.7             0.48    0
05h45   1       0               0               0.65    0.7             0.48    0
06h15   1       0               0               0.65    0.69            0.47    0
06h45   1       0               0               0.22    0.25            0.08    0
07h15   1       0               0               0       0               0       0
07h45   1       0               0               0       0               0       0
08h15   1       0               0               0       0               0       0
08h45   1       0               0               0       0               0       0
09h15   1       0               0               0       0               0       0
09h45   0.5     0.5             0               0       0               0       0
10h15   0       1               0               0       0               0       0
10h45   0       1               0               0       0               0       0
11h15   0       1               0               0       0               0       0
11h45   0       1               0               0       0               0       0
12h15   0       1               0               0       0               0       0
12h45   0       1               0               0       0               0       0
13h15   0       1               0               0       0               0       0
13h45   0       1               0               0       0               0       0
14h15   0       1               0               0       0               0       0
14h45   0       1               0               0       0               0       0
15h15   0       1               0               0       0               0       0
15h45   0.5     0.5             0               0       0               0       0
16h15   1       0               0               0       0               0       0
16h45   1       0               0               0       0               0       0
17h15   1       0               0               0       0               0       0
17h45   1       0               0               0       0               0       0
```

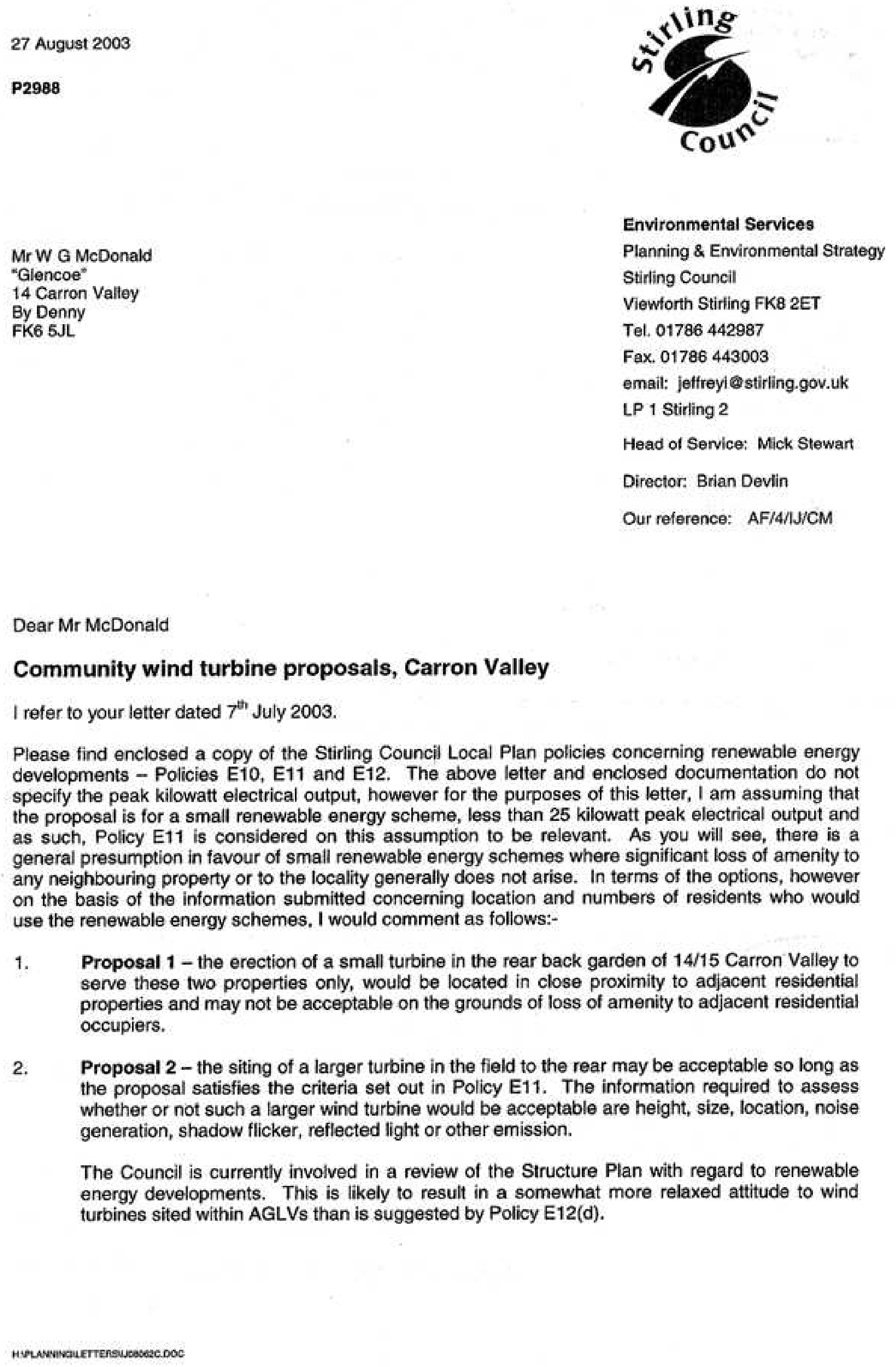
18h15	1	0	0	0	0	0	0
18h45	1	0	0	0.5	0.5	0.33	0
19h15	1	0	0	0.76	0.81	0.54	0
19h45	1	0	0	0.76	0.82	0.64	0
20h15	1	0	0	0.78	0.77	0.57	0
20h45	1	0	0	0.78	0.77	0.54	0
21h15	1	0	0	0.79	0.77	0.51	0
21h45	1	0	0	0.77	0.74	0.49	0
22h15	1	0	0	0.75	0.72	0.48	0
22h45	1	0	0	0.75	0.72	0.48	0
23h15	1	0	0	0.75	0.72	0.48	0
23h45	1	0	0	0.75	0.72	0.48	0
00h15	1	0	0	0.74	0.72	0.48	0
00h45	1	0	0	0.73	0.71	0.47	0
01h15	1	0	0	0.73	0.7	0.47	0
01h45	1	0	0	0.72	0.7	0.46	0
02h15	1	0	0	0.71	0.69	0.45	0
02h45	1	0	0	0.71	0.69	0.45	0
03h15	1	0	0	0.7	0.68	0.44	0
03h45	1	0	0	0.69	0.67	0.43	0
04h15	1	0	0	0.69	0.67	0.43	0
04h45	1	0	0	0.68	0.67	0.42	0
05h15	1	0	0	0.68	0.66	0.42	0
05h45	1	0	0	0.68	0.66	0.41	0
06h15	1	0	0	0.67	0.65	0.41	0
06h45	1	0	0	0.24	0.22	0.07	0
07h15	1	0	0	0	0	0	0
07h45	1	0	0	0	0	0	0
08h15	1	0	0	0	0	0	0
08h45	1	0	0	0	0	0	0
09h15	1	0	0	0	0	0	0
09h45	0.5	0.5	0	0	0	0	0
10h15	0	1	0	0	0	0	0
10h45	0	1	0	0	0	0	0
11h15	0	1	0	0	0	0	0
11h45	0	1	0	0	0	0	0
12h15	0	1	0	0	0	0	0
12h45	0	1	0	0	0	0	0
13h15	0	1	0	0	0	0	0
13h45	0	1	0	0	0	0	0
14h15	0	1	0	0	0	0	0
14h45	0	1	0	0	0	0	0
15h15	0	1	0	0	0	0	0
15h45	0.5	0.5	0	0	0	0	0
16h15	1	0	0	0	0	0	0
16h45	1	0	0	0	0	0	0
17h15	1	0	0	0	0	0	0
17h45	1	0	0	0	0	0	0
18h15	1	0	0	0	0	0	0
18h45	1	0	0	0.5	0.48	0.31	0

F ESP-r Results- Zone wise Heating Loads for a Typical Summer Day

```
Timestep            performance metrics.

Lib: siva.esk78.res:          Results             for siva            Climate : Eskdalemuir

Period:             Sat  1 Jan @ 00h45 to:                  Sun       31-Dec              @23h 45
Year:2000 : sim@30                                                              "
                             Time      Hall      Living            Kitchen     Bed_one           Bed_three
Bed_two  Top

|         kW       |kW       |kW         |kW       |         kW       |kW        |          kW
00h15     0.38      0                   0                   0.07      0.03                0         0
00h45     0.39      0                   0                   0.07      0.04                0         0
01h15     0.4       0                   0                   0.07      0.05                0         0
01h45     0.4       0                   0                   0.08      0.05                0         0
02h15     0.41      0                   0                   0.08      0.06                0.01      0
02h45     0.42      0                   0                   0.08      0.07                0.01      0
03h15     0.42      0                   0                   0.09      0.07                0.01      0
03h45     0.43      0                   0                   0.09      0.08                0.01      0
04h15     0.43      0                   0                   0.09      0.08                0.01      0
04h45     0.43      0                   0                   0.09      0.09                0.01      0
05h15     0.44      0                   0                   0.09      0.09                0.01      0
05h45     0.43      0                   0                   0.09      0.09                0.01      0
06h15     0.43      0                   0                   0.09      0.09                0.01      0
06h45     0.43      0                   0                   0.04      0.05                0.01      0
07h15     0.42      0                   0                   0         0                   0         0
07h45     0.42      0                   0                   0         0                   0         0
08h15     0.41      0                   0                   0         0                   0         0
08h45     0.39      0                   0                   0         0                   0         0
09h15     0.37      0                   0                   0         0                   0         0
09h45     0.1       0.5                 0                   0         0                   0         0
10h15     0         0.73                0                   0         0                   0         0
10h45     0         0.73                0                   0         0                   0         0
11h15     0         0.74                0                   0         0                   0         0
11h45     0         0.74                0                   0         0                   0         0
12h15     0         0.73                0                   0         0                   0         0
12h45     0         0.69                0                   0         0                   0         0
13h15     0         0.66                0                   0         0                   0         0
13h45     0         0.64                0                   0         0                   0         0
14h15     0         0.63                0                   0         0                   0         0
14h45     0         0.62                0                   0         0                   0         0
15h15     0         0.61                0                   0         0                   0         0
15h45     0.12      0.18                0                   0         0                   0         0
16h15     0.18      0                   0                   0         0                   0         0
16h45     0.24      0                   0                   0         0                   0         0
17h15     0.24      0                   0                   0         0                   0         0
17h45     0.24      0                   0                   0         0                   0         0
18h15     0.24      0                   0                   0         0                   0         0
```

18h45	0.22	0	0	0	0	0	0
19h15	0.21	0	0	0	0	0	0
19h45	0.22	0	0	0	0	0	0
20h15	0.24	0	0	0	0	0	0
20h45	0.27	0	0	0	0	0	0
21h15	0.29	0	0	0	0	0	0
21h45	0.3	0	0	0	0	0	0
22h15	0.31	0	0	0	0	0	0
22h45	0.32	0	0	0.02	0	0	0
23h15	0.33	0	0	0.04	0	0	0
23h45	0.34	0	0	0.05	0	0	0
00h15	0.36	0	0	0.06	0	0	0
00h45	0.37	0	0	0.06	0	0	0
01h15	0.37	0	0	0.07	0.01	0	0
01h45	0.38	0	0	0.07	0.01	0	0
02h15	0.38	0	0	0.07	0.02	0	0
02h45	0.39	0	0	0.08	0.03	0	0
03h15	0.4	0	0	0.08	0.04	0	0
03h45	0.4	0	0	0.09	0.05	0	0
04h15	0.41	0	0	0.09	0.06	0	0
04h45	0.41	0	0	0.09	0.06	0	0
05h15	0.41	0	0	0.09	0.07	0	0
05h45	0.41	0	0	0.08	0.07	0	0
06h15	0.41	0	0	0.07	0.07	0	0
06h45	0.4	0	0	0.03	0.04	0	0
07h15	0.39	0	0	0	0	0	0
07h45	0.37	0	0	0	0	0	0
08h15	0.36	0	0	0	0	0	0
08h45	0.34	0	0	0	0	0	0
09h15	0.32	0	0	0	0	0	0
09h45	0.1	0.36	0	0	0	0	0
10h15	0	0.5	0	0	0	0	0
10h45	0	0.64	0	0	0	0	0
11h15	0	0.57	0	0	0	0	0
11h45	0	0.52	0	0	0	0	0
12h15	0	0.48	0	0	0	0	0
12h45	0	0.46	0	0	0	0	0
13h15	0	0.44	0	0	0	0	0
13h45	0	0.43	0	0	0	0	0
14h15	0	0.42	0	0	0	0	0
14h45	0	0.42	0	0	0	0	0
15h15	0	0.42	0	0	0	0	0
15h45	0	0.01	0	0	0	0	0
16h15	0	0	0	0	0	0	0
16h45	0	0	0	0	0	0	0
17h15	0	0	0	0	0	0	0
17h45	0	0	0	0	0	0	0
18h15	0	0	0	0	0	0	0
18h45	0	0	0	0	0	0	0
19h15	0	0	0	0	0	0	0

G Response Letter from Stirling Council



27 August 2003

P2988

Mr W G McDonald
"Glencoe"
14 Carron Valley
By Denny
FK6 5JL

Environmental Services
Planning & Environmental Strategy
Stirling Council
Viewforth Stirling FK8 2ET
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LP 1 Stirling 2
Head of Service: Mick Stewart
Director: Brian Devlin

Our reference: AF/4/IJ/CM

Dear Mr McDonald

Community wind turbine proposals, Carron Valley

I refer to your letter dated 7th July 2003.

Please find enclosed a copy of the Stirling Council Local Plan policies concerning renewable energy developments – Policies E10, E11 and E12. The above letter and enclosed documentation do not specify the peak kilowatt electrical output, however for the purposes of this letter, I am assuming that the proposal is for a small renewable energy scheme, less than 25 kilowatt peak electrical output and as such, Policy E11 is considered on this assumption to be relevant. As you will see, there is a general presumption in favour of small renewable energy schemes where significant loss of amenity to any neighbouring property or to the locality generally does not arise. In terms of the options, however on the basis of the information submitted concerning location and numbers of residents who would use the renewable energy schemes, I would comment as follows:-

1. **Proposal 1** – the erection of a small turbine in the rear back garden of 14/15 Carron Valley to serve these two properties only, would be located in close proximity to adjacent residential properties and may not be acceptable on the grounds of loss of amenity to adjacent residential occupiers.

2. **Proposal 2** – the siting of a larger turbine in the field to the rear may be acceptable so long as the proposal satisfies the criteria set out in Policy E11. The information required to assess whether or not such a larger wind turbine would be acceptable are height, size, location, noise generation, shadow flicker, reflected light or other emission.

   The Council is currently involved in a review of the Structure Plan with regard to renewable energy developments. This is likely to result in a somewhat more relaxed attitude to wind turbines sited within AGLVs than is suggested by Policy E12(d).

I note from my visit to the above property and conversation with Mr Mooney, 15 Carron Valley that the neighbours at 11, 12, 13, 16 and 17 have expressed an interest in a small renewable energy scheme but the other neighbours at Carron Valley have not yet been approached.

From my site inspection, I noted that the site is not visible from the public road on approach from the east, as the view is blocked by the trees adjacent to Craigannet Farm. In terms of approaching the site from the west, along the public road, owing to the undulating road alignment, rising ground to the north of the road and vegetation along the roadside, the site is only visible at intermittent sections. The site is highly visible from adjacent housing and from the public road in between Nos 13 and 14 Carron Valley and public road to the west of 16/17 Carron Valley. The site is visible from the dam at the Carron Valley reservoir and there is a rising field/hillside to the north of the housing at Carron Valley. A single turbine proposal for all the housing at Carron Valley, located in the field, may reach the hilltop/skyline when viewed from the dam. Information on the layout of a wind turbine and whether it breaches the skyline is therefore necessary.

I hope the above information is of assistance.

Please note that the above is an officer view only and does not bind the Council to any particular decision.

Yours sincerely

Iain Jeffrey

Iain Jeffrey
Planning Officer

F. Miscellaneous

Following attachments have been incorporated in the CD-ROM as appendices

- ESP-r input and result files
- Profiles created in Merit
- Spreadsheets for Cash Flow Analysis
