Wind And Hydro Power System For The Tweed Valley Ecovillage

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"Energy Systems and the Environment"

By

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Declaration of Author's Right

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Summary

This thesis presents a background review of three of the most well known renewable sources of energy; the Solar, the Wind and the Hydro Energy that can been used to provide power for the Tweed Valley Ecovillage in Scotland.

The Ecovillage is consisted of fifteen houses, one community house and a visitor/education centre. Due to the fact that the cost of oil, gas and electricity increases, the engineers were urged in finding alternative sources of energy. Another reason, which urged them to do, so was to reduce the impacts of the environment. The systems, which can be, used for each one of these sources for example solar collectors and photovoltaic panels, schemes of hydropower systems and different kinds of wind turbines are presented more analytically. The research of this thesis is concentrated at the micro-hydro power system, which is going to be used as a back up system. Attention has been given to both the wind turbine which is going to produce power for the Ecovillage and to the pump in order to pump the water back to the upper reservoir.

The layout of the micro-hydro power system in this project consists of an upper reservoir, a lower reservoir, a Pelton turbine, a generator, a pump and pipes. Calculations of the power that the water turbine can produce and the power that the pump will need in order to drive the water up to the upper reservoir have been made according to the volume of the reservoirs, slope and the head of the site as well as the pipe diameter. Also calculations have been done for the estimation of the power that the wind turbine can produce according to the wind data of Bishopton, Glasgow 2001, in order to see whether this power is enough to cover the Ecovillage's needs. For all these calculations a number of spreadsheets has been developed which are included in the CD-Rom. All the graphs, tables and figures, which are included in the main body of this thesis, present the results more clearly.

It is intended that this thesis can be read and understood by anyone. However, it must be considered that this research includes technical descriptions, diagrams and spreadsheets – the full meaning of which may appear unclear.

Contents

Table of Figures

Chapter 1: Introduction

1.1 General

For many years now people have been dreaming living in totally sustainable communities. Thirty years ago this dream was remaining a dream. However, nowadays this dream becomes real. These sustainable communities have been given the name *ecovillage* (ecological village). What is an ecovillage?

Eco-villages are citizen initiatives to model sustainable, low-impact, human settlements. They are applicable to both rural and urban settings and accessible to all.

Eco-villagers utilise renewable energy technology, ecological building techniques, and human-scale design to reduce exploitation of natural resources, facilitate community self-reliance, and improve quality of life. They are about the creation of new settlements as well as retrofitting existing villages and urban areas.

An eco-village is designed in harmony with its bioregion instead of the landscape being unduly engineered to fit construction plans. By thinking in terms of bioregions, sustainable settlements are planned considering water availability, the ability to grow food, and accessibility.

The topic of this research is to create a feasibility of a 100% renewable energy community at Tweed Valley, Scotland. The Ecovillage aims to be completely autonomous in terms of energy (wind turbines, micro-hydro plant, solar collectors, photovoltaic panels), water and sewage. A description of the proposed ecovillage is made below.

1.2 Where the eco-village is situated

The Tweed Valley Village is going to be situated at the Thornylee forest on South East Scotland, about 40 miles south of Edinburgh. It is only 6 miles away from a village called Innerleithen. The site is situated just of the main Peebles to Galashiels road (A72).

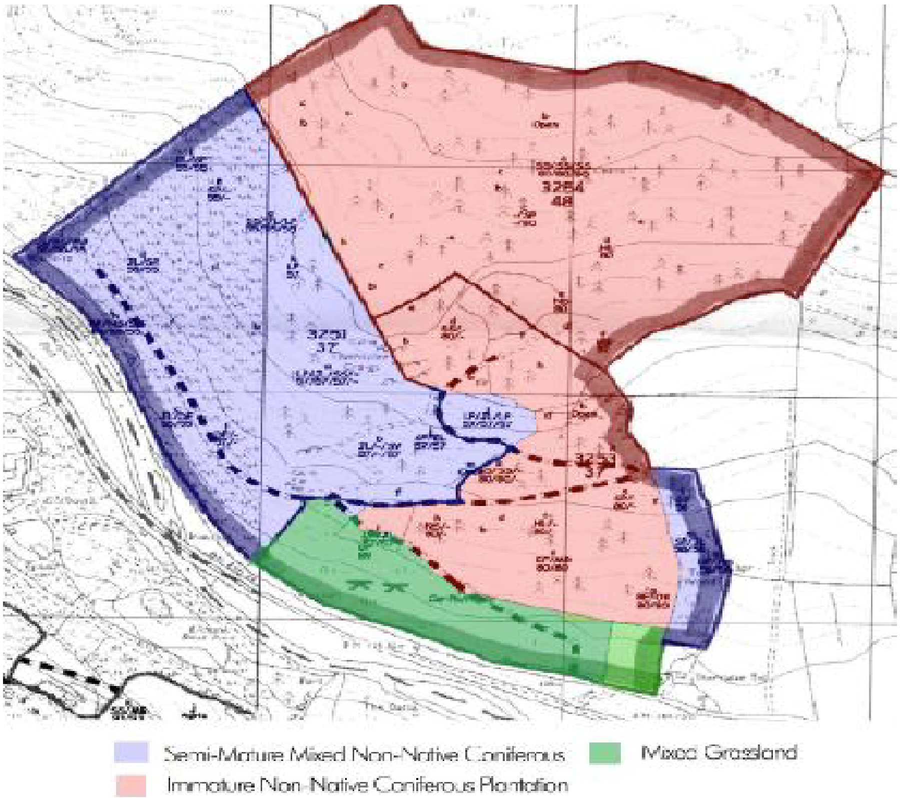

Figure 1.1: Thornylee Forest

The advantages of the Thornylee as a site for Eco-village are:

- ✓ <u>South Facing Slope</u>: which maximises the potential for solar energy collection of all the types (passive, photovoltaic, water heating, heating space etc.) It is also important for the organic garden that is planed to situated on the southeast side of the site, which will enable the residents to provide their own food.

- ✓ <u>Low Environmental Impacts</u>: the Thornylee is a sheltered, unobtrusive site. The houses will be designed to integrate into the surroundings landscape with a very low visual impact sign environmentally responsible materials. These materials will be sourced, where possible, from local merchants, stimulating the local economy and reducing transport emissions.

- ✓ <u>Rural Location</u>: the construction of an ecovillage on the Thornylee site would be positive enhancement on the countryside amenities, landscape and nature conservation through the creation of the new possibilities for leisure, relaxation, and tourism. This is a stated aim of the Ecovillage development.

- ✓ Regeneration of Degraded Land: vast areas around Thornylee are dominated by plantation monoculture that supports few other species, and prevents biodiversity. In a recent report of resentment where noted amongst older residents of Walkerburn and Innerleithen about the loss of their hills and small native woodlands to spruce forests. A change of a land us at Thornylee from uneconomical forestry to residential and recreational/educational use will promote local involvement and increase its biodiversity through the planting of native species.
- ✓ Space: it is very important to have a site where the space is not restricted. Thornylee Forest covers a large area, (approx. 300 acres or 1.2km^2) which will provide ample space for living, working, the positioning of energy systems, and the provision of waste management through Wetland (Reed Bed System) construction.

1.3 A Description of the Ecovillage

The village will have 15 households, a community house (Co-house), a visitor/education centre, parking and the organic garden. The site is big enough to have in all these buildings.

For the construction and maintenance of the village it is going to be used natural non-toxic materials, source locally where possible. The house will incorporate passive solar design features and increased wood use (Biomass) from sustainable, managed forests – such as Thornylee – for space and water heating which will negate the need for fossil fuels energy sources. The building will have approximately two and a half times the insulation values of a standard Scottish Building Regulation homes by using super-insulation techniques. That will have as result much lover energy requirement for space heating and to reduce the use of renewable resources.

In order to fit the houses into the land in a correct place into the surroundings the inhabitants will plant shelterbelts to reduce energy loss by cooling winds, use trees and landscape feature to reduce noise and visibility from the road.

The Thornylee site has the unrivalled potential for an inspiring vegetable and fruit garden within an existing walled paddock. This will supply the eco-village, and potentially local shops and restaurant, with healthy, local produce, as well as becoming an educational resource for the ever-expanding interest in natural methods of food production. It could also accommodate Willow farming to support the booming basket and sculptural markets.

In Scotland, on average, around 2000 litres of water per day fall on the roof of a house with a total roofing area of $100m^2$. Multiplied by the number of homes proposed, this amount of water will adequately provide the most water requirements for the eco-village. Any shortfall will be taken up by a Surface Water Catchment Pond, which will have the added bonus of creating a rich wildlife habitat.

1.4 Aims

This project is all about the production of energy for the ecovillage. This project aims to:

a) study three of the possible renewable sources of energy which can be used in the Tweed Valley Ecovillage such as:
    - Solar energy
    - Wind energy
    - Hydro energy

b) micro-hydro power:
    - The type of turbine, which is going to be installed.
    - Volume of the water reservoirs.
    - The power that is going to be produced and if it is enough to cover the needs of the ecovillage when the other renewable sources of energy are out of use.

c) wind turbine:
    - The type of the wind turbine that is going to be installed.
    - The power that is going to be produces and if it is enough to cover the ecovillage needs.

1.5 Outline

Chapter two presents the sources of renewable energy that can be used at the Tweed Valley Ecovillage; that of solar energy systems, of different kinds of solar collectors and of photovoltaic technology as well as ways for using the daylight. In the same chapter there is information about the wind power and the different kinds of the wind turbines, which are used nowadays, as well as a description of how a wind turbine is operated. Finally there is information about the hydropower and the different kinds of hydropower schemes.

Chapter three presents in more detail the location of the micro-hydro power system and all the components such as upper and lower reservoirs, pipes, and pumps. Also a description of a solar heating system is presented, as well as the location of the solar collectors and finally provides a system layout. Finally some wind data are presented as well as the location of the wind turbines.

At Chapter four details of the hydropower are presented such as estimations of the turbine size and pump size. Furthermore, the flow rate of the water in the pipe is calculated to get the appropriate power for the coverage of the village's needs. In addition, calculations of the time that the upper reservoir needs to empty and become full again are presented.

According to the wind data of the year 2001 a calculation of the power that the wind turbine can produce for covering the needs of the village and also to pump the water up from the lower to the upper reservoir is presented.

Chapter five presents the conclusions drawn and a future recommendation.

Chapter 2: Background Research

2.1 Introduction

In this chapter we are going to go discuss about solar, hydro and wind energy. As well as the basic systems that all those sources can be use in order to produce energy.

2.2 Solar Energy

Radiation is emitted from the sun with an energy distribution fairly similar to that of a “black body”, or a perfect radiator, at a temperature of 6000 K Radiation travels with a velocity of 3 x10^8 m/s taking approximately 8 minutes to reach the earth’s atmosphere. The value of the solar radiation received outside the earth’s atmosphere, at the earth’s mean distance from the sun, by a unit surface perpendicular to the solar beam is 1.353KW/m^2. [1]

The earth follows an elliptical path around the sun, taking about a year for each cycle. The earth’s axis is titled at a constant angle of 23^0 27’ relative to the plane of rotation at all times. The apparent daily motion of the sun across the sky viewed from any particular location on earth varies cyclically throughout the year and is defined by the angle of declination. This is the angle formed at solar noon between a vector parallel to the sun’s rays which would pass through the centre of the earth and the protection of this vector upon the earth’s equatorial plane. The spectral distribution of direct solar radiation is altered as it passes through the atmosphere by absorption and scattering. The amount of energy absorbed depends on the length of path the solar beam traverses.

Every hour the sunlight that reaches the earth is greater than the amount used by every person on the planet in an entire year. The sunlight is produced when four hydrogen atoms fuse to make one helium atom. The loss of atomic matter (photons) is flung into the space and hits the earth providing light and heat.

The sun is the most inexhaustible, renewable source of energy, known to man as *Solar Energy*, which provides light, heat and energy to all living things on Earth. Solar Energy can be absorbed, reflected, transmitted, insulated and measured. Also the sunlight can be collected and stored and has many commercial uses: agriculture; heating houses and other buildings; heating hot water; distilling water; heating swimming pools; power for satellites in space; power for space shuttles; supplying electricity; power for solar cars; power for outdoor boards; power for boats; power for generators in emergencies; power for toys; power for calculators; watches and miscellaneous small appliances; power for parking meters; power for security systems; power for lighting, indoor and outdoor.

Actually, we are living at a time when there is a greater awareness of the energy problems facing the world than at any other period in history. It is now widely accepted that the growth in energy consumption which has been experienced for many years cannot continue indefinitely as there is a limit to our reserves of fossil fuel. Solar energy is by far the most attractive alternative energy source for the future, as apart its non-polluting qualities, the amount of energy which is available for conversion is several orders of magnitude greater than all present world requirements.

2.2.1 Solar Thermal Energy

Most systems for low-temperature solar heating depend on the use of glassing, in particular its ability to transmit visible light but to block infrared radiation. High-temperature solar collection is more likely to employ mirrors. In practice, solar systems of both types can take a wide range of forms. [2]

Active solar heating. This always involves discrete solar collector, usually mounted on the roof of a building, to gather solar radiation. Mostly, collectors are quite simple and the heat produced will be at low temperature and used for domestic hot water.

Solar thermal engines. These are an extension of active solar heating, usually using more complex collectors to produce temperatures high enough to drive steam turbines to generate electric power.

Passive solar heating. This term has come to have two different meanings:

a) In the ‘narrow’ sense, it means the absorption of solar energy directly into a building to reduce the energy required for heating the habitable spaces. Passive solar heating systems mostly use air to circulate the collected energy, usually without pumps or fans. Indeed the collector is often an integral part of the building.

b) In the 'broad' sense, it means the whole process of integrated low-energy building design, effectively to reduce the heat demand to the point where small passive solar gains make a significant contribution in winter. A large solar contribution to a large heat load may look impressive, but what really counts is to minimise the total fossil fuel consumption and thus achieve the minimum cost.

Daylighting. This means making the best use of natural daylight, through both careful building design and the use of controls to switch off artificial lighting when there is sufficient natural light available.

2.2.2 Active Solar Systems

Active solar systems consist of collectors that collect solar radiation and electric fans or pumps to distribute heat from the collectors. A liquid or air is used as the heat transfer fluid. Most systems also incorporate storage systems to provide heat when the sun is not shining. If you want to heat your home with solar energy, you will need to decide whether you want an active or a passive system. Although passive systems are popular because of their simplicity, they are sometimes impractical to install (retrofit) in an existing home, particularly if much of the site is shaded. Active systems are often more practical for such applications.

Choosing the proper solar energy system depends on varying conditions such as the site, design, and heating needs of the house.
In general, the optimum collector orientation is true south. True south is the highest apparent point in the sky that the sun reaches during the day. A collector receives the most solar radiation between 9:00 am and 3:00 pm. Trees, buildings, hills, or other obstructions that shade collectors reduce their ability to collect solar radiation.

You can position collectors in different locations. Collectors usually receive the most sunlight when placed in rows on the roof. If the roof does not receive enough sunlight, you may want to mount the collectors on a supporting structure on the ground, or in rows on the south wall of the house, where there is enough sunlight for the collectors to perform satisfactorily. Collectors mounted on the ground or on an exterior wall perform almost as well as those mounted on most roofs.

Solar collectors are usually roof mounted on houses and once installed are difficult to reach for maintenance and repairs. They must be firmly attached to the roof in a leak-proof manner and then must withstand everything that nature can throw at them – frost, wind, acid rain, sea spray and hailstones. They also have to be proof against internal corrosion and very large temperature swings. A double-glazed collector is potentially capable of producing boiling water in high summer if the heat is not carried away fast enough. It is quite an art to make something that can survive up to 20 or more years of this treatment.

In order for the collector to collect enough solar energy to supply the winter demand, the collector would have to be very large. This would mean that over much of the summer its potential output would not be used because the demand would not be there, and the capital expenditure would effectively be wasted. Also if the house had been better insulated, it would not have required so much space heating energy, and what it did consume could have been better met by passive solar means.

2.2.3 Solar Collectors

There are two basic types of solar collectors: the *concentrating solar collector* and the *flat-plate solar collector*. The *concentrating solar collector* uses a curved surface, usually a parabolic shape, to concentrate the sun's rays at the centre (focal) point. At that focal point, a black pipe filled with liquid is heated, usually water. The advantage of concentrating collector is its ability to generate high-grade temperatures of 94^{o}C to 150^{o}C or more. Concentrators should be pointed directly at the sun. To do this, these systems use tracking mechanisms to move the collectors during the day to keep them focused on the sun. Single-axis trackers move from east to west; dual-axis trackers move from east to west and from north to south (to follow the sun throughout the year). In addition to these mechanical trackers, there are passive trackers that use *freon* to supply the movement. While not widely used, they do provide a low-maintenance alternative to mechanical systems. The main disadvantages are: (a) the manufacturing cost. The collector and the mechanism are very expensive, whereas the mechanism needs frequent maintenance, (b) it must follow the direction of the sun in order to work properly if the collector is a parabola or a truncated cone type, with the result being that their performance is poor on hazy or cloudy days. [3]

The *flat-plate solar collector* is made up of an enclosed box or panel in which an absorber plate is located. The panel is covered with either plastic or glass. The main advantages of the flat-plate collector are: it can be placed in a fixed position that faces the sun for most of the day (e.g. on the roof of the house), and second it is inexpensive to build. The box or panel can be manufactured of any material that can withstand weathering and temperature. Either metal or painted wood, have been used successfully as the frame of a flat-plate collector. The absorber can be constructed of any material that can accept paint and will not degenerate with temperature. The maximum temperature reached is approximately 149^{o}C or 300^{o}F under stagnant condition (when no air or no water is passing through the collector). The cover is made either from plastic or high-grade glass (low in iron content).

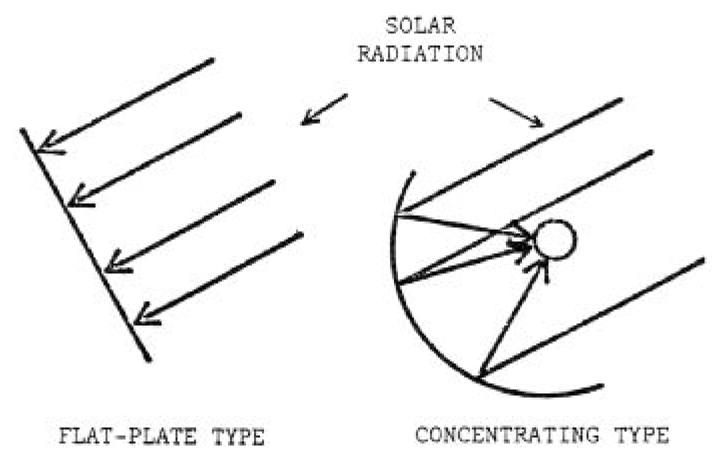

Figure 2.1: Flat-Plate Type and Concentrating Type Collectors

Figure 2.2: The Luz Solar Electric plant, near Barstow, California

2.2.3.1 The Flat Plate Collector

The majority of flat plate collectors have fine main components:

a) A transparent cover which may be one or more sheets of glass of radiation-transmitting plastic film or sheet.

b) Tubes, fins, passages or channels integral with the collector absorber plate or connected to it, which carry the water, air or other fluid.

c) The absorber plate, normally metallic and with a black surface, although a wide variety of other materials can be used, particularly with air heaters.

d) Insulation, which should provided at the back and sides to minimise the heat losses.

e) The casing or container which encloses the other components and protects them from the weather.

2.2.3.2 Principles of Flat-Plate Collector

Sunlight is made of short-wave radiation. This radiation can be converted to heat. If the glass is of good grade in the collector - that is low iron level - only 12% of the radiation is reflected and the rest 88% absorbed from the collector. The absorber is usually made of insulation material covered with a film of aluminium and painted with a high-temperature matt-black paint, which can absorb approximately 95% of the sunlight and then emit this radiation as long-wave radiation. The difference between the high-temperature matt-black paint and a typical black paint is that the second will convert approximately 15% of the radiation directly to heat and emit about 85%. However, the long-wave radiation that is emitted strikes the glass and bounces back. The glass reflects all of the radiation and it strikes the absorber and reflected internally until it is all converted to heat.

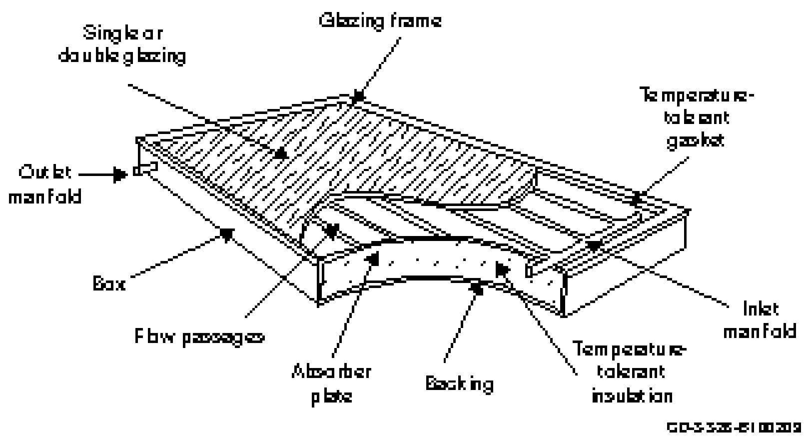

Figure 2.3: Flat plate collector

2.2.3.3 Liquid Collectors

In a liquid collector, solar energy heats a liquid, as it flows through tubes in or adjacent to the absorber plate. For this type of collector, the flow tubes are attached to the absorber plate so the heat absorbed by the absorber plate is readily conducted to the liquid.

The flow tubes can be routed in parallel, using inlet and outlet headers, or in a serpentine pattern. A serpentine pattern eliminates the possibility of header leaks and ensures uniform flow. A serpentine pattern is not appropriate, however, for systems that must drain for freeze protection because the curved flow passages will not drain completely.

The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house to be used for bathing, laundry, etc. This design is known as an "open-loop" (or "direct") system. In areas where freezing temperatures are common, however, liquid collectors must either drain the water when the temperature drops or use an antifreeze type of heat-transfer fluid.

In systems with heat-transfer fluids, the transfer fluid absorbs heat from the collector and then passes through a heat exchanger. The heat exchanger, which generally is in the water storage tank inside the house, transfers heat to the water. Such designs are called "closed-loop" (or "indirect") systems.

Glazed liquid collectors are used for heating household water and sometimes for space heating. Unglazed liquid collectors are commonly used to heat water for swimming pools. Because these collectors need not withstand high temperatures, they can use less expensive materials such as plastic or rubber. They also do not require freeze proofing because swimming pools are generally used only in warm weather.

We can store the heat for liquid systems by using tanks of water. The tanks are usually steel, concrete, fibreglass reinforced plastic (FRP) or wood. New construction often uses steel tanks because it is easier to attach pipes and fittings. Before choosing a storage tank, you should consider several factors. First, you should decide where to place the tank, for example, in the basement or outside. Next, you should choose the size, shape, and material of the tank.

2.2.3.4 Air Collectors

In the air system we are using air for collecting solar energy. Air collectors are simple, flat-plate collectors used primarily for space heating. The absorber plates in air collectors can be metal sheets or non-metallic materials. The air flows past the absorber by natural convection or when forced by a fan. Because air conducts heat much less readily than liquid does, less heat is transferred between the air and the absorber than in a liquid collector.

In some solar air-heating systems, fins or corrugations on the absorber are used to increase air turbulence and improve heat transfer. The disadvantage of this strategy is that it can also increase the amount of power needed for fans and, thus, increase the costs of operating the system. In colder climates, the air is routed between the absorber plate and the back insulation to reduce heat loss through the glazing. However, if the air is not heated in more than 17^{o}C or 30^{o}F above the outdoor temperature, the air can flow on both sides of the absorber plate without sacrificing efficiency.

Air systems have the advantage of eliminating the freezing and boiling problems associated with liquid systems. Although leaks are harder to detect and plug in an air system, they are also less troublesome than leaks in a liquid system. Air systems can often use less-expensive materials, such as plastic glazing, because their operating temperatures are usually lower than those of liquid collectors.

To store heat, an air system delivers hot air from the collectors to the storage bin. The air first enters a plenum, which is an empty mixing space at the top of the bin. It passes down through the bin where the rocks absorb most of the heat. The air then returns to the collectors from a lower plenum for reheating. When the system uses rock bins to heat the home, it draws house air from the lower plenum up through the rocks. Warm air is then drawn from the top of the bin and distributed to the house. Thus, the rock bin serves as storage and as a heat exchanger. When storing heat, the top of the bin is usually about 60°C or 140°F and the bottom of the bin is about 21.1°C or 70°F. If the air in the bin is too cool, a back-up system heats the air leaving the top of the bin to the desired temperature before distributing it.

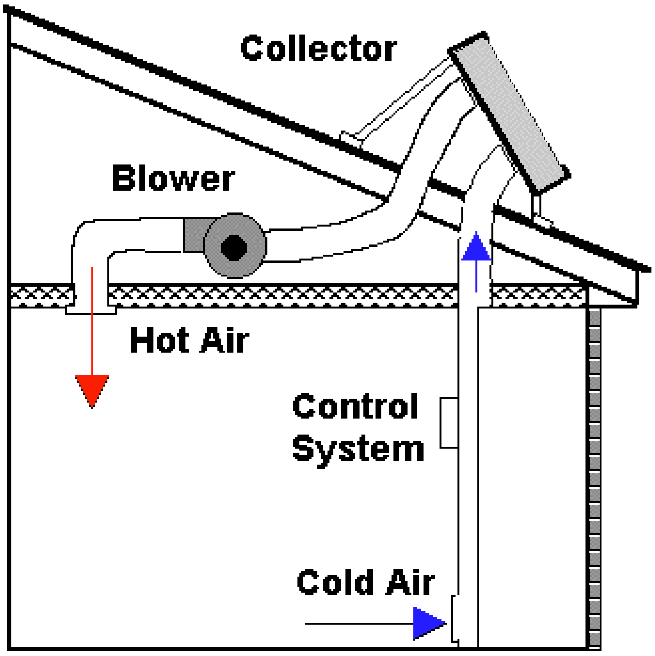

Figure 2.4: Air type collector

2.2.4 Photovoltaic Power

The direct conversion of solar energy into electrical energy has been studied since the end of the 19th century.

The major advantages of the photovoltaic power are:

- Short lead-time to design, install, and start up a new plant.
- Highly modular, hence, the plant economy is not a strong function of size.
- Static structure, no moving parts, hence, no noise.
- High power capacity per unit of weight.
- Long life with little maintenance because of no moving parts.
- Highly mobile and portable because of light weight.

The photovoltaic (PV) power technology uses semiconductor cells, generally several square centimetres in size. From the solid-state physics point of view, the cell is basically a large area p-n diode with the junction positioned close to the top surface. The cell converts the sunlight into direct current electricity. Numerous cells are assembled in a module to generate required power.

Because much of the current PV technology uses crystalline semiconductor material similar to integrated circuit chips, the production costs have been high.

There are suitable for a wide range of power applications from less than a watt to several thousand megawatts. Silicon is widely used in the production of solar cells and is fortunately a very common material.

The doping of a very pure semiconductor with small traces of impurities can modify its electrical properties, producing two basic types: p-type, having fixed negative and free positive charges, and n-type, having fixed positive and free negatives charges. If these two types are placed together and the surface is exposed to sunlight, electrons will diffuse through the p-n junction in opposite directions giving rise to an electric current. [4]

The earliest solar cells were made of silicon and one type of modern silicon cell is made by doping a slice cut from a single crystal of highly purified silicon with phosphorous, arsenic or antimony and diffusing boron into the upper surface, forming a ‘p-on-n’ cell. A thin glass or quartz cover protects the front of the cell. The commercial production process is complex, involving temperature control within $\pm 0.1^0$C at 1420^0C during one stage, the ‘pulling’ of a crystal from the melt.

2.2.4.1 PV Cell Technologies

In making comparisons between alternative power technologies, the most important measure is the energy cost per kWh delivered. In PV power, this cost primarily depends on two parameters, the photovoltaic energy conversion efficiency, and the capital cost per watt capacity. Together, these two parameters indicate the economic competitiveness of the PV electricity.

The conversion efficiency of the photovoltaic cell is defined as follows:

$$\eta = \frac{electrical\ power\ output}{solar\ power\ impinging\ the\ cell}$$

The continuing development efforts to produce more efficient low cost cells have resulted in various types of pv technologies available on the market today, in terms of the conversion efficiency and the module cost. The major types are:

- The *single crystal silicon*, which is widely available cell material, and has been the workhorse of the industry. In the most common method of producing this material, the silicon raw material is first melted and purified in a crucible. A seed crystal is then placed in the liquid silicon and drawn at a slow constant rate. This results in a solid, single-crystal cylindrical ingot. The manufacturing process is slow and energy intensive, resulting in high raw material cost presently at £15 to £20 per half kilogram. The ingot is sliced using a diamond saw into 200 to 400 _m thick wafers. The wafers are further cut into rectangular cells to maximize the number of cells that can be mounted together on a rectangular panel. Unfortunately, almost half of the expensive silicon ingot is wasted in slicing ingot and forming square cells. The material waste can be minimized by making the full size round cells from round ingots. Using such cells would be economical where the panel space is not at a premium. Another way to minimize the waste is to grow crystals on ribbons. Some U.S. companies have set up plants to draw pv ribbons, which are then cut by laser to reduce waste.
- The *polycrystalline and semicrystalline* is relatively a fast and low cost process to manufacture thick crystalline cells. Instead of drawing single crystals using seeds, the molten silicon is cast into ingots. In the process, it forms multiple crystals. The conversion efficieny is lower, but the cost is much lower, giving a net reduction in cost per watt of power.
- The *thin films* are new types of photovoltaics entering the market. Copper Indium Diselenide, Cadmium Telluride, and Gallium Arsenide are all thin film materials, typically a few _m or less in thickness, directly deposited on glass, stainless steel, ceramic or other compatible substrate materials. This technology uses much less material per

square area of the cell, hence, is less expensive per watt of power generated.

- For the *amorphous silicon* vapour is deposited on a couple of _m thick amorphous (glassy) films on stainless steel rolls, typically 610 meters long and 0.33 meters wide. Compared to crystalline silicon, this technology uses only one percent of the material. Its efficiency is about one-half of the crystalline silicon at present, but the cost per watt generated is projected to be significantly lower. On this premise, two large plants to manufacture amorphous silicon panels started in the U.S.A. in 1996.
- Another technology is that is being explored in the laboratories is the *spheral*. The raw material is low-grade silicon crystalline beads, presently costing about £1.50 per kilogram. The beads are applied on typically 0.10 meters squares of thin perforated aluminium foil. In the process, the impurities are pushed to the surface, from where they are etched away. Since each sphere works independently, an individual sphere failure has negligible impact on the average performance of the bulk surface. According to a Southern California Edison Company's estimate, 9.3 square meters of spheral panels can generate 2,000 kWh per year in an average southern California climate.
- In an attempt to improve the conversion efficiency, we can use the *concentrated cells* where the sunlight is concentrated into ten or hundreds of times the normal sun intensity by focusing on a small area using low cost lenses. The primary advantage is that such cells require a small fraction of area compared to the standard cells, thus significantly reducing the pv material requirement. However, the total module area remains the same to collect the required sun power. Besides increasing the power and reducing the size or number of cells, such cells have the additional advantage that the cell efficiency increases under concentrated light up to a point. Another advantage is that they can use small area cells. It is easier to produce high efficiency cells of small area than to produce large area cells with comparable

efficiency. On the other hand, a major disadvantage of the concentrator cells is that they require focusing optics adding into the cost.

2.2.4.2 'Autonomous' Roof-Top PV Systems For UK Homes

The electricity demand of a typical UK household is currently around 4000kWh a year – say 11kWh per day on average. In order to supply this necessary electrical demand, our roof-top PV system would probably have to have PV panels of at least 10^2m in area and about 1kW in capacity. The roofs of most UK houses could accommodate a PV array of this size, and surveys have suggested that about half of UK roofs are oriented in a direction sufficiently close to due south to enable them to be used for solar collection purposes. But a roof-top domestic PV system like this would still be much too expensive to complete with convectional sources in all but the most remote of UK locations. Another major shortcoming is that in a country like the UK its output would be at its maximum in the summer, when demand is at its lowest, and at its minimum in winter, when demand is at its peak. This might suggest the need for an extremely large battery, to store solar-generated electricity from summer, when it is available, until winter, when it is needed. But the size and cost of such battery would currently be prohibitive in most cases.

At considerable extra cost, the PV array might be made much larger than is necessary for summer use, in order to provide a more adequate level of power in winter. Or a second, backup energy system, such as a wind generator, could be installed to provide power when the output of the PV array is inadequate.

Whether or not it would be economic to install an 'autonomous' PV power system depends, clearly, on how the cost per kWh of PV electricity from it compares with that of power from other renewable sources.

2.2.5 Passive Solar Heating

All glazed buildings are already to some extent passively solar heated: effectively they are live-in solar collectors. In a typical UK house, to keep the inside warmer than the outside air temperature, it is necessary to inject heat. The greater the temperature difference between the inside and the outside, the more heat needs to be supplied. In summer it may not be necessary to supply any heat at all, but in mid-winter large amounts will be needed. The total amount of heat that needs to be supplied over the year can be called *gross heating demand*. [5]

This will have to be supplied from three sources:

a) 'free heat gains', which are those energy contributions to the space heating load of the building from the normal activities that take place in it: the body heat of people, and heat from cooking, washing, lighting and appliances. Taken individually, these are quite small. In total, they make a significant contribution to the total heating need. In a typical UK house, this can amount to 15kWh per day;
b) passive solar gains, mainly through the windows;
c) fossil fuel energy, from the normal heating system.

There are some basic general rules for optimising the use of passive solar heating in buildings.

a) They should be well insulated to keep down the overall heat losses.
b) They should have a responsive, efficient heating system.
c) They should face south. The glazing should be concentrated in the south side, as should the main living rooms, with little-used rooms such as bathrooms on the north.
d) They should avoid overshading by other buildings in order to benefit from the essential mid-winter sun.
e) They should be 'thermally massive' to avoid overheating in summer.

2.2.5.1 Avoiding Overshading

One useful tool to avoid overshading is the sunpath diagram (see figure 2.5). For a given latitude, the diagram shows the apparent path of the sun through the sky as seen from the ground. In practice, the contours of surrounding trees and buildings can be plotted on it (see figure 2.6).

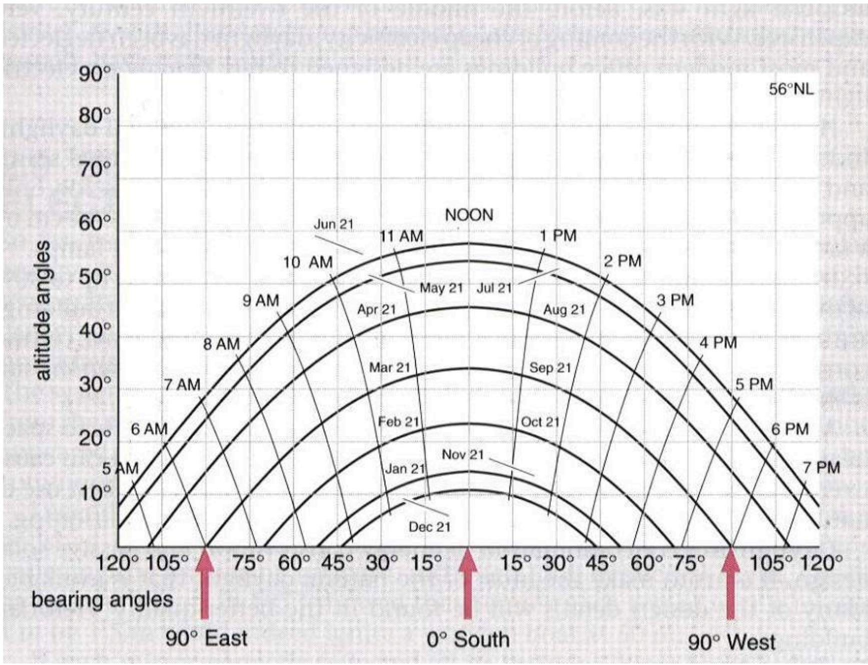

Figure 2.5: Sunpath diagram; latitude of 56^0 N, Glasgow & Edinburgh

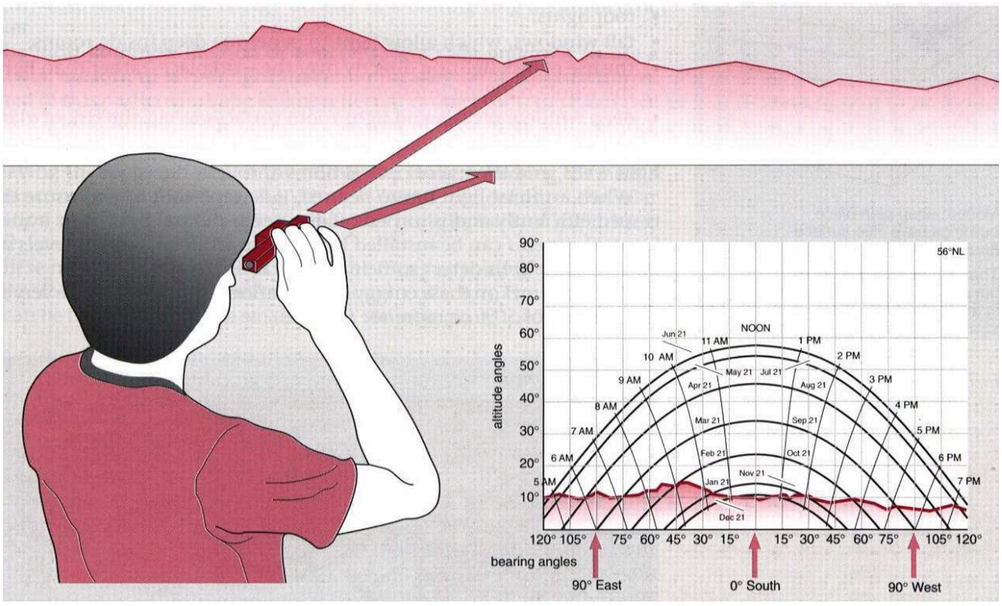

Figure 2.6: The skyline on a sunpath diagram

2.2.5.2 Daylighting

Daylight is a commodity that we all take for granted. Replacing it with artificial light was, before the middle of the twentieth century, very expensive. With the coming of cheap electricity, daylight has been neglected and most modern office buildings are designed to rely heavily on electric light.

Houses are traditionally well designed to make use of natural daylight. Indeed, most of those that were not have long ago been designated slums and duly demolished. In the UK, domestic lighting accounts for only approximately 2% of the delivered energy use, and even this could be cut by a factor of three or more by substituting low-energy fluorescent lamps.

In some commercial offices, however, lighting can account for up to 30% of the delivered energy use. Modern factory units and hypermarket buildings are built with barely any windows.

Although in winter the heat from lights can usefully contribute to space heating energy, in summer it can cause overheating, especially in well-insulated buildings. Making the best use of natural light saves both on energy and on the need for air conditioning.

Daylighting is a combination of energy conservation and passive solar design. It aims to make the most of the natural daylight that is available.

Traditional techniques include:

- Shallow-plan design, allowing daylight to penetrate all rooms and corridors
- Light wells in the centre of the buildings
- Roof lights
- Tall windows, which allow light to penetrate deep inside rooms
- The use of task lighting directly over the workplace, rather than lighting the whole building interior
- Deep window reveals and light room surfaces to cut the risk of glare.

More modern variants are the use of mirrors to direct light into light wells, and the use of optical fibres and light ducts. When artificial light is used, it is important to make sure that it is used efficiently and is turned off as soon as natural lighting is available. Control systems can be installed that reduce artificial lighting levels when photoelectric cells detect sufficient natural light. Payback times on these energy conservation techniques can be very short and savings of 50% or more are feasible.

2.3 Wind Energy

Wind energy offers the potential to generate substantial amounts of electricity without the pollution problems of most conventional forms of electricity generation. Wind energy has been used for thousands of years for milling grain, pumping water, and offer mechanical power applications. Today, there are over one million windmills in operation around the world; these are used principally for pumping water. Whilst the wind will continue to be used for this purpose, it is the use of wind energy as a pollution-free means of generating electricity on a potentially significant scale that is attracting most current interest in the subject.

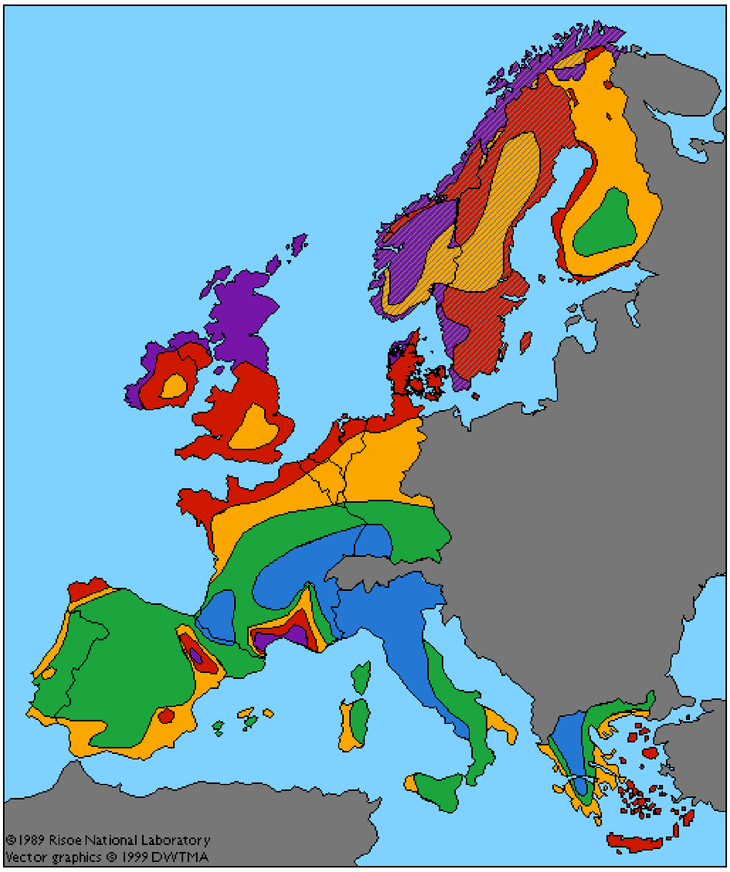

Figure 2.7: Wind resources at 50 m above ground level

Colour	Sheltered terrain		Open plain		At a sea coast		Open sea		Hills & ridges	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2
Purple	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
Red	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
Orange	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
Green	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
Blue	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400
Purple (hatched)			>7.5							
Red (hatched)			5.5-7.5							
Orange (hatched)			<5.5							

A common way of sitting wind turbines is to place them on hills or ridges overlooking the surrounding landscape. In particular, it is always an advantage to have as wide a view as possible in the prevailing wind direction in the area. On hills, one may also experience that wind speeds are higher than in the surrounding area. Once again, this is due to the fact that the wind becomes compressed on the windy side of the hill, and once the air reaches the ridge it can expand again as it soars down into the low pressure area on the lee side of the hill (see figure 2.8).

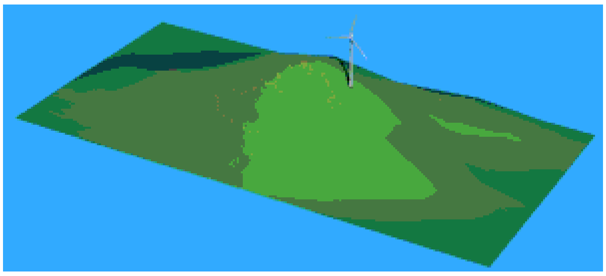

Figure 2.8

You may notice that the wind in the figure 2.9 starts bending some time before it reaches the hill, because the high pressure area actually extends quite some distance out in front of the hill. Also, you may notice that the wind becomes very irregular, once it passes through the wind turbine rotor.

As before, if the hill is steep or has an uneven surface, one may get significant amounts of turbulence, which may negate the advantage of higher wind speeds.

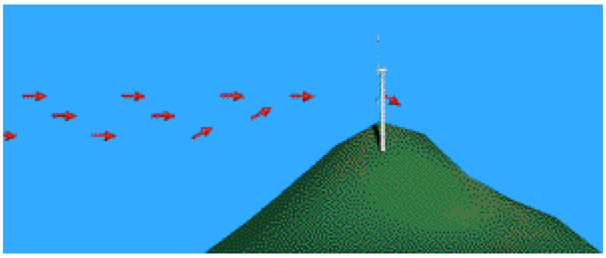

Figure 2.9

The United Kingdom is the windiest country in Europe and has relatively high average wind speeds. So it is an appropriate place to use the wind in this way. By 2010 wind energy might be supplying 6% of UK electricity. The figure 2.10 shows the annual wind speed in m/sec at 25m above ground level in United Kingdom.

Figure 2.10 Annual wind speed in the UK
(m/s 25 metres above ground level)

[6]

2.3.1 How Wind Turbines Work

These three-bladed wind turbines, that figure 2.11 shows, are operated "upwind," with the blades facing into the wind. The other common wind turbine type is the two-bladed, downwind turbine.

So how do wind turbines make electricity? Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. Utility-scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

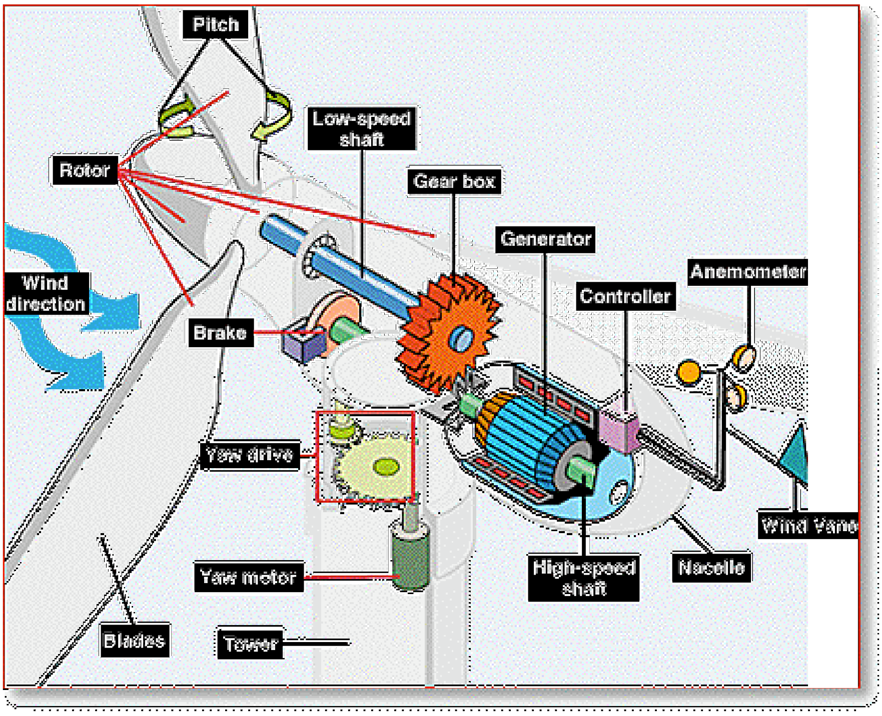

Figure: 2.11: Wind turbine

[7]

- ✓ **Anemometer**: Measures the wind speed and transmits wind speed data to the controller.
- ✓ **Blades**: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to generate lift and rotate.
- ✓ **Brake**: A disc brake which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.
- ✓ **Controller**: The controller starts up the machine at wind speeds of about 3.5 to 7.2 meters per sec (m/s) and shuts off the machine at about 30 m/s.
- ✓ **Gear box**: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

- ✓ **Generator**: Usually an off-the-shelf induction generator that produces 50-cycle AC electricity in UK.
- ✓ **High-speed shaft**: Drives the generator.
- ✓ **Low-speed shaft**: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.
- ✓ **Nacelle**: The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.
- ✓ **Pitch**: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.
- ✓ **Rotor**: The blades and the hub together are called the rotor.
- ✓ **Tower**: Towers are made from tubular steel (shown here) or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.
- ✓ **Wind direction**: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.
- ✓ **Wind vane**: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
- ✓ **Yaw drive**: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.
- ✓ **Yaw motor**: Powers the yaw drive.

2.3.2 Types of wind turbines

2.3.2.1 Horizontal Axis

Horizontal axis wind turbines (HAWTs) generally have either two or three blades or else a large number of blades, as well as there are turbines with only one blade. Wind turbines with large number of blades called high sodility devices because they appear to be virtually a solid disc covered by solid blades and are used for water pumping on farms. The wind turbines that use only few blades are called low solidity devices. The modern low solidity wind turbines (HAWTs) are the most common nowadays. They have a clean, streamlined appearance, due to wind turbine designers' improved understanding of aerodynamics, derived largely from developments in aircraft wing and propeller design. Their rotors generally have two or three wing – like blades. They are almost universally employed to generate electricity.

2.3.2.2 Vertical Axis

Vertical Axis wind turbines (VAWTs) have an axis of rotation that is vertical. They can harness winds from any direction without the need to reposition the rotor when the wind direction changes.

The modern VAWT has been created from ideas of the engineer Georges Darrieus in 1925. The Darrieus machine is characterised by its C-shaped rotor blades which make it look like an egg beater as figure 2.12 shows.

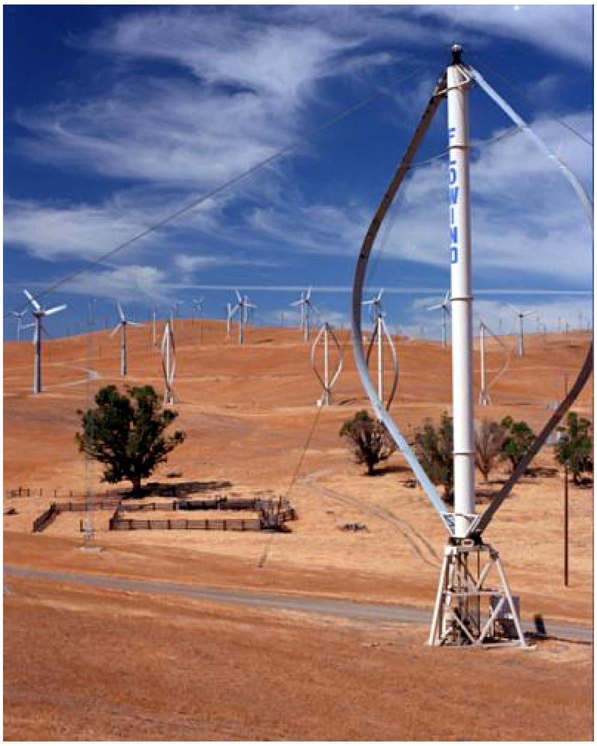

Figure 2.12: VAWTs Wind Turbine

The basic theoretical advantages of a vertical axis machine are:

1) You place the generator, gearbox etc. on the ground, and you may not need a tower for the machine.
2) You do not need a yaw mechanism to turn the rotor against the wind

The basic disadvantages are:

1) Wind speeds are very low close to ground level, so although you may save a tower, your wind speeds will be very low on the lower part of your rotor
2) The overall efficiency of vertical axis machines is not impressive.
3) The machine is not self-starting (e.g. a Darrieus machine will need a "push" before it starts. This is only a minor inconvenience for a grid-connected turbine, however, since you may use the generator as a motor drawing current from the grid to start the machine).
4) The machine may need guy wires to hold it up, but guy wires are impractical in heavily farmed areas.

5) Replacing the main bearing for the rotor necessitates removing the rotor on both a horizontal and a vertical axis machine. In the case of the latter, it means tearing the whole machine down.
6) The VAWTs wind turbines are still under research and development hence they are not yet out in the market.

2.4 Hydro Energy

The economic situation now favours smaller hydropower projects, and special equipment is being developed. Techniques for making the new low head hydraulic turbines and related equipment practical and economically viable have introduced new facets to hydropower engineering.

Hydropower engineering refers to the technology involved in converting the pressure energy and kinetic energy of water into more easily used electrical energy. The prime mover in the case of hydropower is a water wheel or hydraulic turbine which transforms the energy of the water into mechanical energy.

During the period from 1940 to 1970, small units were actually forced out of production because of the high cost of operation and the ready availability of electrical energy from large steam power plants and large high capacity hydro plants. That situation having changed, small-scale hydropower development is becoming an attractive energy production alternative. [8]

The pumped/storage hydropower technique is an energy storing system, that water pumped from the lower reservoir to a higher one using inexpensive “dump” energy produced during periods of low demand by power plants which cannot economically shut down. The water is then run back down through turbines to produce more valuable power needed during periods of peak demand.

2.4.1 Types of Hydro Power Systems

Two hydroelectric plants with the same power output could be very different: one using a relatively low volume of high-speed water from high mountain reservoir and the other the huge volume flow of a slowly moving river. Sites, and the corresponding hydroelectric installations, can be classified as low-head, medium-head or high-head. The boundaries are a little fuzzy and tend to depend on whether the subject of discussion is the civil engineering work ot the choice of turbine, but high-head usually implies an effective head of appreciably more than 100 meters, and low-head less than perhaps 10 meters.

2.4.1.1 Impoundment

An impoundment facility, typically in a large hydropower system, uses a dam to store river water in a reservoir. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.

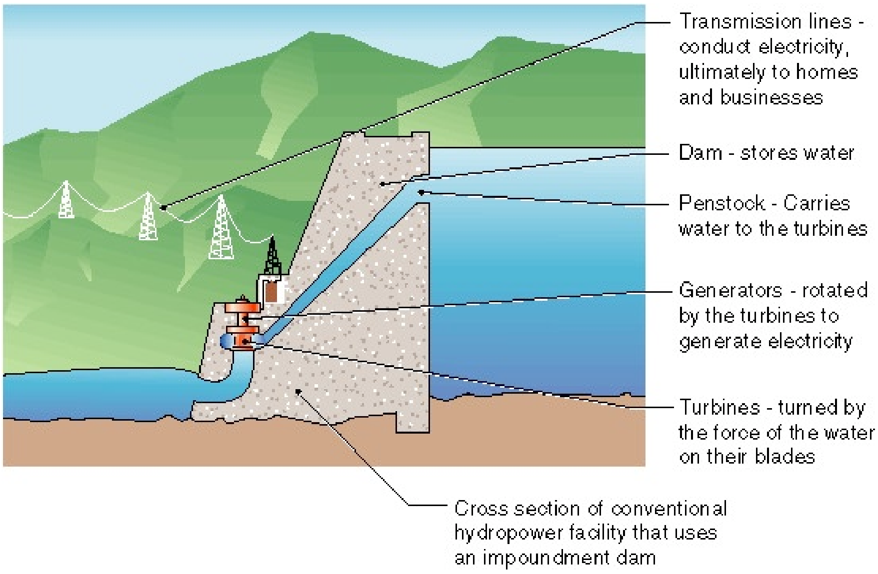

Figure 2.13: Dam

2.4.1.2 Run-of-river type

A dam with a short penstock (supply pipe) directs the water to the turbines, using the natural flow of the river with very little alteration to the terrain stream channel at the site and little impoundment of the water.

Figure 2.14: Run-of-River

2.4.1.3 Diversion and canal type

The water is diverted from the natural channel into a canal or a long penstock, thus changing the flow of the water in the stream for a considerable distance.

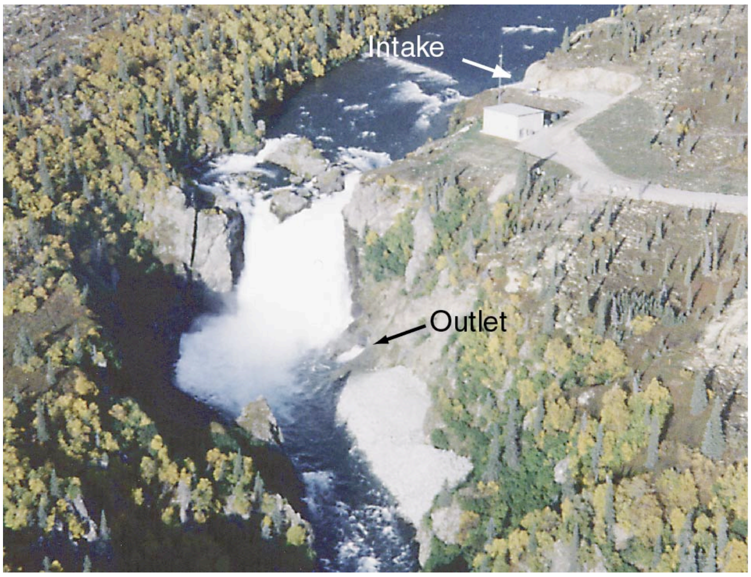

Figure 2.16: Diversion & Canal

2.4.1.4 Pumped Storage type

When the demand for electricity is low, a pumped storage facility stores energy by pumping water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir to generate electricity.

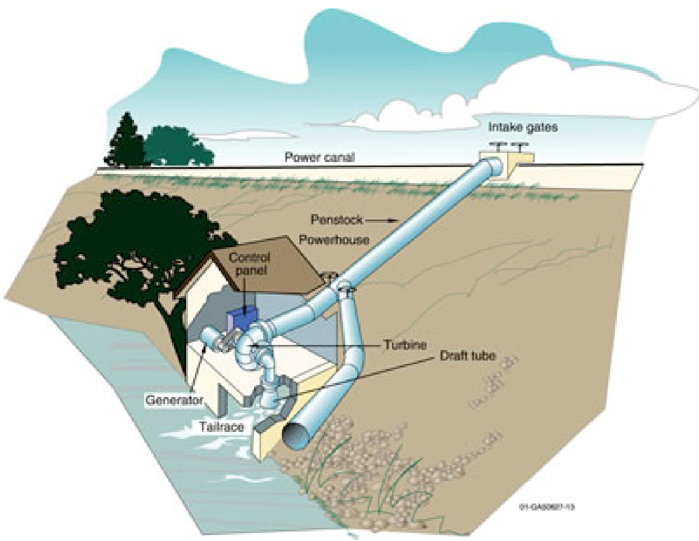

Figure 2.17: Pumped Storage

[9]

Chapter 3: Location Characteristics

3.1 Introduction

In this chapter we are going to go into more details about the location of the micro-hydro power plant and all the components such as upper and lower reservoirs, pipes, pumps. We also going to describe the solar heating system, the location of the solar collectors and finally provide a system layout.

3.2 Micro-Hydro Power System

3.2.1 The Upper and Lower Reservoirs

On the left hand side of the hill, where the ecovillage will be situated, and approximately 110m high above the river level situated a natural reservoir which already collects water from the rainfall (see picture 1). By digging we can increase the volume of the reservoir and the volume of the water that it is going to be collected. We have to build a small dam at the left hand side (as figure 3.1 shows where the blue line appears) and the right hand side (as figure 3.3 shows where the blue line appears) in order to avoid water waste and flooding.

Figure 3.1: Upper Reservoir

To build the dams we can use the stones that are already present there and by adding some more we can increase the height of it (see picture 2). It is better to use stones for the construction of the dams than concrete because:

a) Stones are physical material, you can find them everywhere and it is friendly to the environment while concrete has environmental impacts.

b) Stones are cheap while concrete is not.

Figure 3.2: Stones

The figure 3.3 shows more clearly the water in the reservoir at the moment.

Figure 3.3: Upper Reservoir

We can manage to have a reservoir of dimension 30m wide, 50m long and 3.0m deep (see figure 3.4). That means that the volume of the water that the reservoir can collect is given by the equation below:

$$V = W \times L \times D \times [m \times m \times m] = 30 \times 50 \times 3 [m^3] \Rightarrow V = 4500 m^3$$

Figure 3.4: Upper Reservoir

The water will flow down to the lower reservoir from the left hand side of the reservoir as shown at figure 3.1 above. Pipes will transfer the water to the lower reservoir which will be situated close to the river level. At figure 3.5 below we can see the slope of the hill were the water will flow down to the lower reservoir.

Figure 3.5: Slope of the Hill

The volume of the lower reservoir should be the same as the upper reservoir because the microhydro power plant is going to be used as a back up system when the energy that will be provided to the ecovillage from the wind turbines or any other renewable sources it is not enough to cover the needs of the villagers. At the begging we thought to use the river as the lower reservoir but that it could not be achieved because the river is protected from the ecologists and it will affect the ecosystem of the river. So, we have to build a new reservoir close to the river level in order to use it as a lower reservoir for the microhydro power plant. Attention should be given to aesthetic of the lower reservoir; a good idea is to dig the area in order to create a space that would look like a small lake or a pool. Also it would be nice to plant some trees around the reservoir in order to avoid any accident. A pipe should be used to connect the lower reservoir with the river in case that the water level increased significantly into the reservoir. By that way we will avoid any flooding that might occur.

3.2.2 Rainfall Data

There is a general misconception that the whole of Scotland experiences high rainfall. In fact, rainfall in Scotland varies widely, with a distribution closely related to the topography, ranging from over 3,000 mm per year in the western Highlands (comparable with rainfall over the mountains of the English Lake District and Snowdonia in Wales) to under 800 mm per year near the east coast (comparable with the Midlands of England).

Typically, measurable rainfall (an amount of 0.2 mm or more) occurs on over 250 days per year over much of the Highlands, decreasing to around 175 days per year on the Angus, Fife and East Lothian coasts. In comparison, the driest part of Britain, along the Thames Estuary in south-east England, averages around 150 days per year with measurable rainfall.

The frequency of thunderstorms in Scotland, around three to nine days per year, is relatively low compared with an average of nine to fifty days over England. The number of thunderstorms can vary widely from year to year, but in general the northern and eastern coasts of Scotland average only three or four days with thunder per year, whilst inland values range from nine in the south to six in the north. Figure3.6 shows a 30 years (1961-1990) average of rainfall in millimetres (mm) for the selection stations

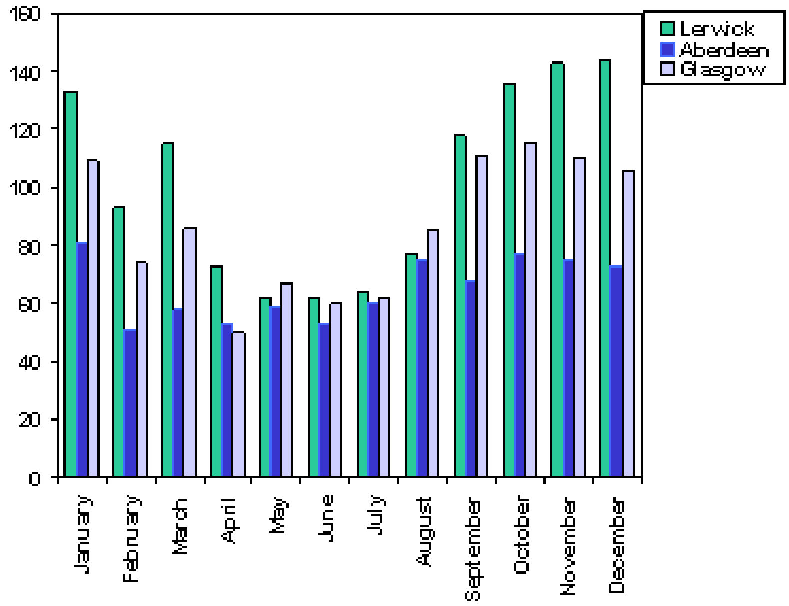

Figure 3.6: 30 years Average Rainfall in mm.

[10]

3.2.3 Types of turbines

As water passes through a hydropower plant its energy is converted into electrical energy by a prime mover known as a hydraulic *turbine* or water wheel. The turbine has vanes, blades or buckets that rotate about an axis by the action of the water. The rotating part of the turbine or water wheel is often referred to as the *runner*. Rotary action of the water turbine in turn drives an electrical generator that produces electrical energy or could drive other rotating machinery.

Hydraulic turbines are machines that develop torque from the dynamic and pressure action of water. They can be grouped into two types. One type is an *impulse turbine*, which utilizes the kinetic energy of a high-velocity jet of water to transform the water energy into mechanical energy. The second type is a *reaction turbine*, which develops power from the combined action of pressure energy and kinetic energy of the water. Reaction turbines can be further divided into several types, of which the principal two are the Francis and the propeller.

3.2.3.1 Impulse Turbines

Impulse turbines are the oldest forms of hydraulic machines - usually called *Pelton wheel* - used for converting hydro-energy to mechanical work. These are also the simplest hydraulic machines in terms of their transparent design, low maintenance and easy control. They are generally used at hydropower plants characterised by high heads and low discharges. Being a low specific speed machine their designs need not be that robust and complicated. The specific speed can, however, be increased by the addition of extra “nozzles” when the need arises. Moreover, since these machines operate under atmospheric pressure, there is also no need of elaborate seal designs. Even the cavitation risk on them is very much limited as compared to other types of turbines. Because of these and other advantages impulse turbines have become the most widely used hydraulic machines for generating micro-hydro power all over the world. [11]

3.2.3.1.1 Pelton Turbine

A Pelton turbine that shows at figure 3.7 consists of a set of specially shaped buckets mounted on a periphery of a circular disc. It is turned by jets of water which are discharged from one or more nozzles and strike the buckets. The buckets (see figures 3.8 and 3.9) are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet. The cutaway on the lower lip allows the following bucket to move further before cutting off the jet propelling the bucket ahead of it and also permits a smoother entrance of the bucket into the jet. The Pelton bucket is designed to deflect the jet through 165 degrees (not 180 degrees) which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet. [12]

Figure 3.7: Pelton Turbine

Figure 3.8: Buckets from Pelton Turbine

[13]

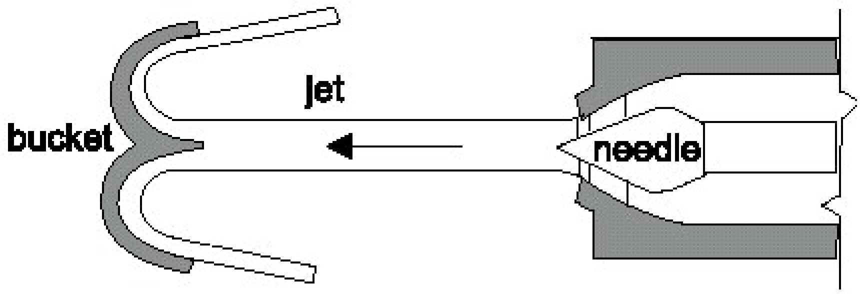

Figure 3.9: Pelton Impulse Turbine (bucket shape)

In large scale hydro installations Pelton turbines are normally only considered for heads above 150 m, but for micro-hydro applications Pelton turbines can be used effectively at heads down to about 20 m. Pelton turbines are not used at lower heads because their rotational speeds become very slow and the runner required is very large and unwieldy. If runner size and low speed do not pose a problem for a particular installation, then a Pelton turbine can be used efficiently with fairly low heads. If a higher running speed and smaller runner are required then there are two further options:

- Increasing the number of jets by having two or more jets enables a smaller runner to be used for a given flow and increases the rotational speed. The required power can still be attained and the part-flow efficiency is especially good because the wheel can be run on a reduced number of jets with each jet in use still receiving the optimum flow.
- Twin runners. Two runners can be placed on the same shaft either side by side or on opposite sides of the generator. This configuration is unusual and would only be used if the number of jets per runner had already been maximised, but it allow the use of smaller diameter and hence faster rotating runners.

3.2.3.1.2 TurgoTurbine

The Turgo turbine (see figure 3.10) is an impulse machine similar to a Pelton turbine but which was designed to have a higher specific speed. In this case the jet is aimed to strike the plane of the runner on one side and exits on the other. Therefore the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a Turgo turbine can have a smaller diameter runner than a Pelton for an equivalent power. With smaller faster spinning runners, it is more likely to be possible to connect Turgo turbines directly to the generator rather than having to go via a costly speed-increasing transmission.

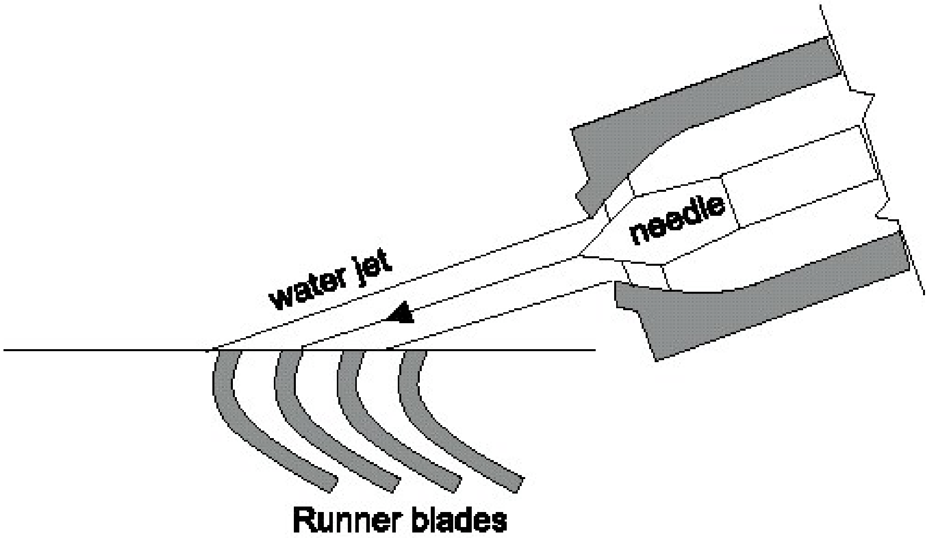

Figure 3.10: Turgo Turbine

Like the Pelton, the Turgo is efficient over a wide range of speeds and shares the general characteristics of impulse turbines listed for the Pelton, including the fact that it can be mounted either horizontally or vertically. A Turgo runner is more difficult to make than a Pelton and the vanes of the runner are more fragile than Pelton buckets.

3.2.3.2 Reaction Turbine

3.2.3.2.1 Francis Turbines

Francis turbines, that figures 3.11 and 3.12 shows, can either be volute-cased or open-flume machines. The spiral casing is tapered to distribute water uniformly around the entire perimeter of the runner and the guide vanes feed the water into the runner at the correct angle. The runner blades are profiled in a complex manner and direct the water so that it exits axially from centre of the runner. In doing so the water imparts most of its pressure energy to the runner before leaving the turbine via a draft tube.

The Francis turbine is generally fitted with adjustable guide vanes. These regulate the water flow as it enters the runner and are usually linked to a governing system which matches flow to turbine loading in the same way as a spear valve or deflector plate in a Pelton turbine. When the flow is reduced the efficiency of the turbine falls away.

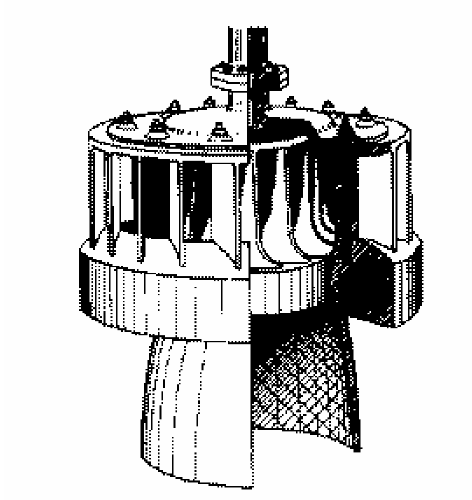

Figure 3.11: Francis Turbine

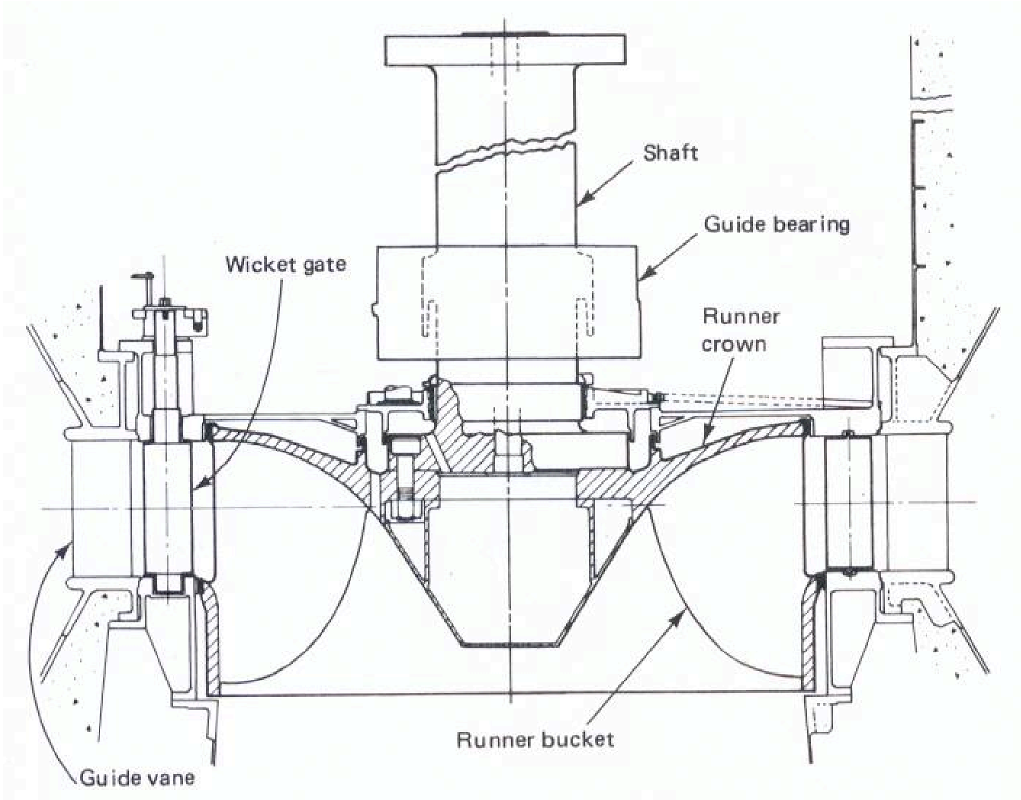

Figure 3.12: Francis Turbine

3.2.3.2.2 Kaplan's Turbine

The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube (see figures 3.13 and 3.14). The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates ("wicket gates") just upstream of the propeller. This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed. The part-flow efficiency of fixed-blade propeller turbines tend to be very poor. Large scale hydro sites make use of more sophisticated versions of the propeller turbines. Varying the pitch of the propeller blades together with wicket gate adjustment enables reasonable efficiency to be maintained under part flow conditions.

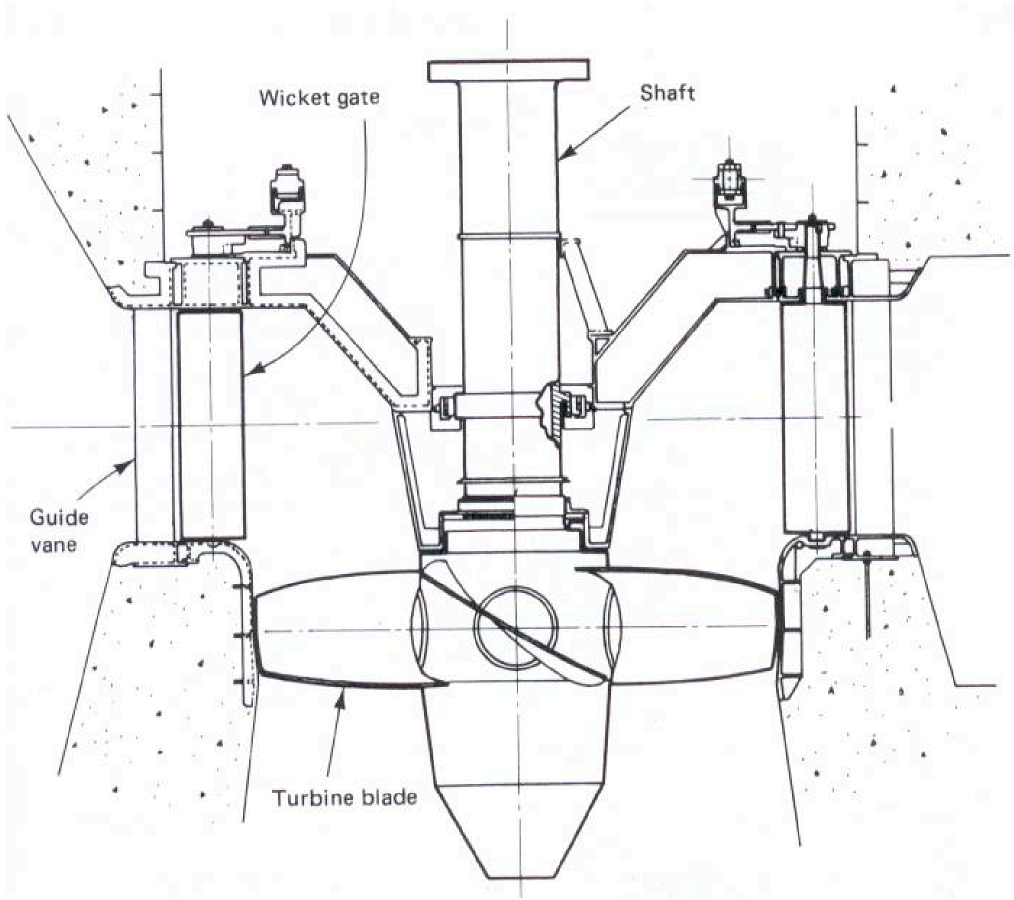

Figure 3.13: Kaplan's Turbine

Figure 3.14: Hydrolink Kaplan's Turbine

[12]

3.2.4 Basic Concepts of Micro-hydro and Mini-hydro systems

Microhydro power usually refers to hydraulic turbine systems having a capacity of less than 100kW. Minipower usually refers to units having a power capacity from 100kW to 1000kW. Units this small have been in use for many years, but recent increases in the value of electrical energy and incentive programs have made the construction and development of microhydro and minihydro power plants much more attractive to developers. Similarly small villages and isolated communities in developing nations are finding it beneficial and economical to use microhydro and minihydro power systems [13]

The principles of operation, types of units, and the mathematical equations used in selection of microhydro and minihydro power systems are essentially the same as for conventional hydropower developments. However, there are unique problems and often the costs of the feasibility studies and the expenses of meeting all regulatory requirements make it difficult to justify microhydro and minihydro power developments on an economic basis.

3.2.5 Specific Speed

The parameter normally used in selecting turbines is the specific speed (Ns), which is related to the output power (P in kW), the effective head (H in meters) and the rate of rotation (n in revolutions per minute) as follows:

$$N_s = n\sqrt{\left(\frac{P}{H^2 \cdot \sqrt{H}}\right)}$$

or

$$N_s = \frac{n\sqrt{P}}{H^{5/4}}$$

where: Ns is the specific speed, units of rpm, kW and m

n is the rotational speed of turbine, rpm

P is the power output at best efficiency, kW

H is the net head, m

The formula above can been written in a more simple form:

$$N_s = 500\left(\frac{r}{R}\right)\left(\frac{v_B}{v_W}\right)$$

where: r/R is the ratio of diameter of the incoming flow or jet of water to the total diameter of the turbine: d/D or r/R

v_B/v_W is the ratio of the blade speed to the water speed

3.2.6 Unit Power

The unit power is the power produced by a runner with a unit diameter operating under a unit head. The corresponding dimensional unit power is

$$P_{ed} = \frac{P}{\rho \cdot D^2 \cdot (gH)^{3/2}}$$

where: P_{ed} is the unit power, dimensional

P is the turbine power output, watts

_ is the mass density of water, kg/m3

g is the acceleration of gravity, m/s^2

3.2.7 Unit Speed

The speed ratio variable times the constant terms is replaced with a single variable n_1, known as the unit speed. Then:

$$n_1 = \frac{nd}{\sqrt{h}}$$

Where: n_1 is the speed in rpm of a theoretical turbine having a unit diameter and operating under a net head of unity.

3.2.8 Unit Discharge

The corresponding dimensionless unit discharge specified by international standards is as follows:

$$Q_{ed} = \frac{Q}{D^2 \sqrt{gH}}$$

where: Q_{ed} is the unit discharge

Q is the design discharge flowing through turbine, m^3/s

3.2.9 Speed

To determine the runner speed, it should be determined in a special way if a synchronous speed must be used to drive the generator. If the turbine is directly connected to the generator, the turbine speed, n, must be a synchronous speed. For turbine speed, n, to be synchronous, the following equation must be fulfilled:

$$n = \frac{120(f)}{N_p}$$

where: n is the rotational speed, rpm

f is the electrical, hertz (Hz)

N_p is the number of generator poles, (multiples of four poles are preferred, but generators are available in multiples of two poles).

3.2.10 Diameter

To estimate the diameter of the turbine, it is necessary to depend on empirical equations or experience curves that have been developed from statistical studies of many already constructed units. It is customary to relate the variable of diameter to the universal number, the specific speed, n_s, N_s, w_s or _.

The work of deSiervo and deLeva (1976) shows the following equation for the Francis runner:

$$D_3 = (26.2 + 0.211N_S)\frac{\sqrt{H}}{n}$$

where: D_3 is the discharge or outlet diameter, m.

For propeller turbines, deSiervo and deLeva (1977) show the following equation for determining design diameter:

$$D_M = (66.76 + 0.136N_S)\frac{\sqrt{H}}{n}$$

where: D_M is the outer diameter of the propeller, m.

For Pelton turbines, deSiervo and Lugaresi (1978) show that the following equations can be used for estimating the turbine diameter:

$$\frac{D_3}{D_2} = 1.028 + 0.137N_{sj}$$

$$N_{sj} = \frac{\left(P/i\right)^{0.5}}{H^{1.25}}$$

$$\frac{D_j}{D_2} = \frac{N_{sj}}{250.74 \square 1.796N_{sj}}$$

where: N_{sj} is the specific speed for impulse runner per jet

i is the number of jets used by impulse turbine

D_2 is the wheel pitch diameter, m

D_2 is the outer wheel diameter, m

D_j is the jet diameter, m

P is the turbine rated capacity, KW

Doland (1954) gives the following equation in order to determine the size of Pelton wheels:

$$d_2 = 830\frac{\sqrt{h}}{n}$$

where: d_1 is the diameter of circle passing through the centres of the buckets (pitch diameter), inches.

3.3 Solar Energy System

3.3.1 Location

Unfortunately, to locate the houses some trees had to be cut down in order to get more space. The houses have to be build at the south face of the hill in order to face the sun so that the surfaces will get the maximum solar radiation. The area where the houses are going to be situated is shown figures 3.15 and 3.16 below.

Figure 3.15: Area of the houses

Figure 3.16: Area of the houses

The collectors should obviously face the noon sun – south on the northern hemisphere and north on the southern hemisphere – on nearly so.

3.3.2 Sunshine Data

Generally, Scotland is more cloudy than England, due mainly to the hilly nature of the terrain and the proximity of low-pressure systems from the Atlantic. Even so, parts of Angus, Fife, the Lothians, Ayrshire, and Dumfries and Galloway average over 1,400 hours of sunshine per year. This compares favourably with the coastal areas of Northern Ireland and the north of England, though not perhaps with the annual totals of over 1,700 hours achieved along the south coast of England. The dullest parts of Scotland are the more mountainous areas, with an annual average of less than 1,100 hours of sunshine over the mountains of the Highland region.

Mean daily sunshine figures reach a maximum in May or June, and are at their lowest in December. Wind and cloud play their part, but the key factor is, of course, the variation in the length of the day through the year. The relatively high latitude of Scotland means that although winter days are very short, this is amply compensated by long summer days with an extended twilight. On the longest day there is no complete darkness in the north of Scotland. Lerwick, in Shetland, has about four hours more daylight (including twilight) at midsummer than London. The graph bellow shows a 30 years (1961-1990) average monthly duration of bright sunshine in hours for the selected stations.

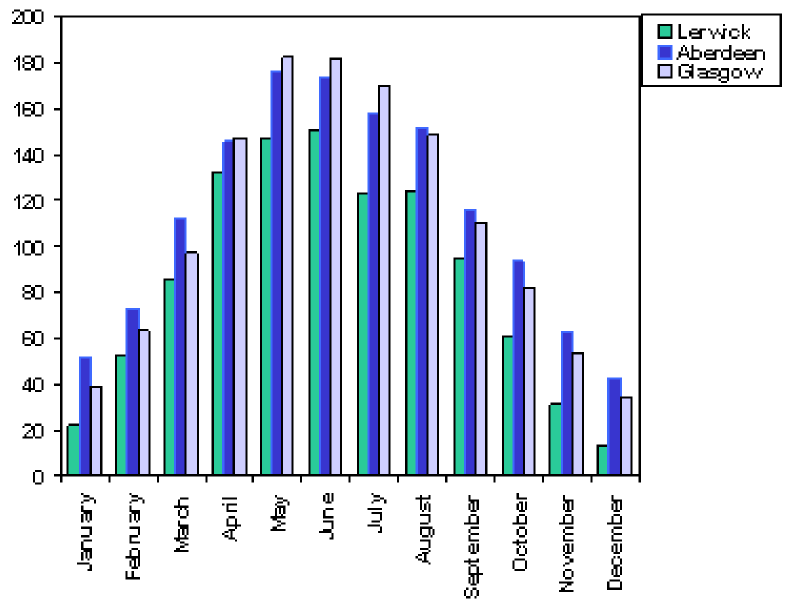

Figure3.17: 30 years Average Monthly of Sunshine in Hours

[15]

3.3.3 Design of a Flat Plate Collector

The first law of thermodynamics can be applied at solar panel, referring to the figure below:

$$Q_{in} = Q_{transferred} + Q_{loss}$$

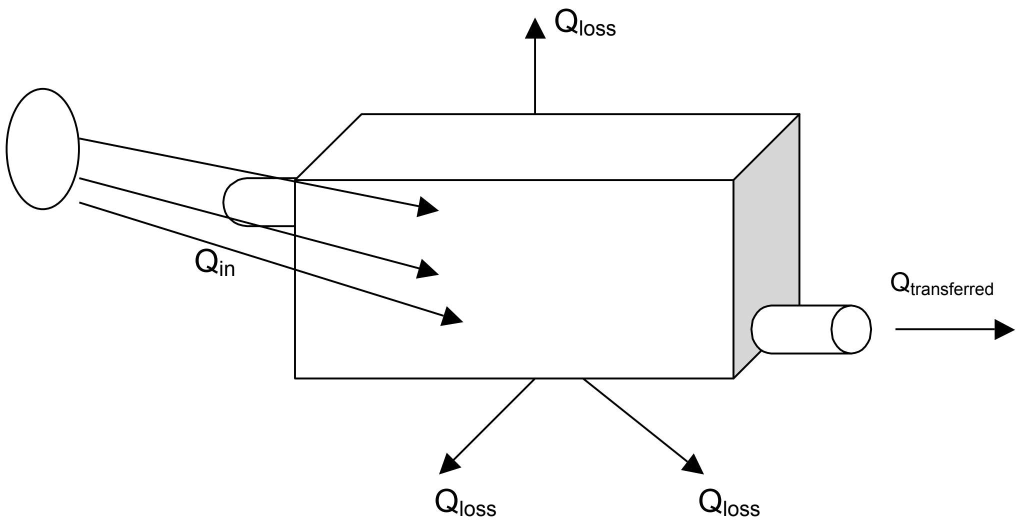

Figure 3.18: Layout of a Solar Panel

The transferred energy ($Q_{transferred}$) is the useful energy, which can be used to heat a building or heat water. Since the energy from the sun (Q_{in}), is constant for any given locality, the energy transferred can be optimised by minimizing the heat loss (Q_{loss}).

3.3.4 Collector Sizing

When using a water system for space heating, a heat exchanger must be used to transfer energy from the water to the recirculating air. Heat exchangers are less that 100% efficient and the collector size must be increased to compensate for this. It is suggested that an increase between 3 and 5% in the collector size is necessary. Since the fluid is returned to the collector from the bottom or cool portion of the storage, the lower this temperature is the higher the efficiency of the collector.

The flow rate in a solar water system appreciably affects the performance characteristics. It is generally agreed that 1.018 litre/min for every square meter of collector should be used, that is, an 88.4m^2 collector would require a flow rate of 88.4x1.018 or 90 litre/min. [16]

Collectors specifically for hot water heating are designed to provide 70 to 80% of heating load. The required collector size can be determined from:

$$S = \frac{P \cdot Q}{F \cdot I_o \cdot E}$$

where: S is the size of the collector in m^2

P is the portion of energy supplied by solar, decimal form

Q is the energy required in kJ/day

F is the portion of clean sky insolation received, decimal form

I_o is the clear sky solar insolation in kJ/m^2-day

E is the average annual collector efficiency, decimal form

3.3.5 System

According to figure 3.19, during the winter the water is heated in the collector which collects the rays from the sun and then water passes from the top of the collector to the tank, the motor pump 1 circulates the water from the tank through the collector and back to the tank. The hot water that flows from the collector goes inside the tank, heats the water in the storage tank and then goes back to the collector. The hot water from the collector also passes through the heat generator on cloudy days in order to become hotter and then goes directly to the central heating to heat the space of the house. Valve 1 is also open in order to permit the cold water to return from the fan coils back to the collector. Pump 2 helps the circulation of the water.

Through the heat controller we can operate the temperature of the room. This controller is connected with the steam vent, the pump 1 and the storage tank. The steam vent is used in case that the water in the collector becomes very hot and works as ventilation for the collector to drop the water temperature in order to avoid any damage. The pump 1 is used for circulation of the water from the collector to the tank and back to the collector but it is also used when the temperature in the storage tank drops under the temperature that we want. When this happens the pump 1 starts to work again in order to flow hot water in the tank.

The valve 3 is an anti-scald valve which supplies cold water in case that the water from the heat generator is too hot to avoid any damage that might occur in the system or in the heating units. The anti-scald valve 3 is connected with the tank and with the valve 2, which again supplies cold water in order to decrease the temperature of the tank of the boiler. The water from the tank passes through the boiler where a heat electronic devise is placed and is working as a back up system. Then the boiler supplies hot water to the house (for example to the shower, hot water for any other use, etc).

In order to protect our collector from freezing when the heat generator is not working, in other words when we switch off the system an electrical resistant can be placed in the collector and when the temperature drops below 5^0C or 40^0F will automatically switch on and start to heat the water in the collector until the water reaches the temperature of 10^0C or 50^0F. An automatic valve can also be used which will start to circulate the water from the collector to the tank when the temperature drops below 5^0C or 40^0F.

During the summer there is no need of heating the space so, by closing the valve 1 and 5 the water is going to be circulated from the collector to the tank and back to the collector. The water inside the tank is going to be heated and then passes to the boiler and from the boiler to the showers or the taps.

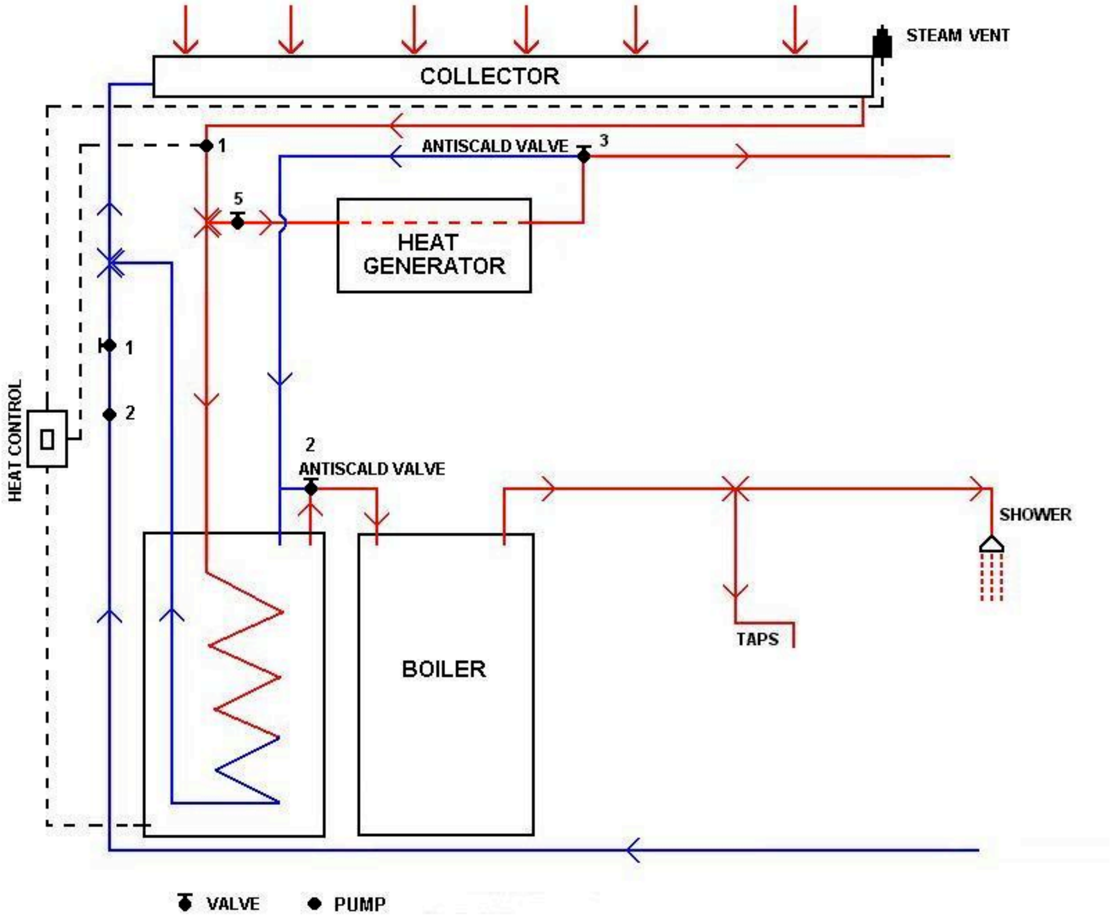

Figure 3.19: Hot Water System Layout

3.4 Wind Turbines

3.4.1 Location

The wind turbines will be installed at the top of the hill of the Tweed Valley Ecovillage in order to get the maximum wind speed and produce the maximum power from the wind. The figures 3.20, 3.21 and 3.22 are shown the area where the wind turbines are going to be situated. This is the highest point of the hill approximately 300m above the sea level.

Figure 3.20: Area for the Wind Turbines

Figure 3.21: Area of the Wind Turbines

Figure 3.22: Area of the Wind Turbines

3.4.2 Wind Data

The most common direction from which the wind blows in Scotland is the south-west, but the wind direction often changes markedly from day to day with the passage of weather systems. There is a close relationship between surface isobars (lines joining points of equal air pressure) and the wind speed and direction over open, level terrain. However, in mountainous areas local topography also has a significant effect, with winds tending to blow along well-defined valleys.

Over land, the roughness of the ground causes a decrease in the mean wind speed compared with that which occurs over the sea, with the size of the decrease depending on the nature of the terrain. In general, wind speed increases with height, with the strongest winds being observed over the summits of hills and mountains.

Since many of the major Atlantic depressions pass close to or over Scotland, the frequency of strong winds and gales is higher than in other parts of the United Kingdom. Over low ground, the windiest areas are the Western Isles, the north-west coast and Orkney and Shetland with over 30 days with gales per year in some places. A day of gale is defined as a day on which the mean wind speed at the standard measuring height of 10 m above ground attains a value of 34 knots (17.5 m/s) or more over any period of 10 minutes during the 24 hours.

The following figure shows at a period of 30 years (1961-1990) the average number of days with gales for selected station points.

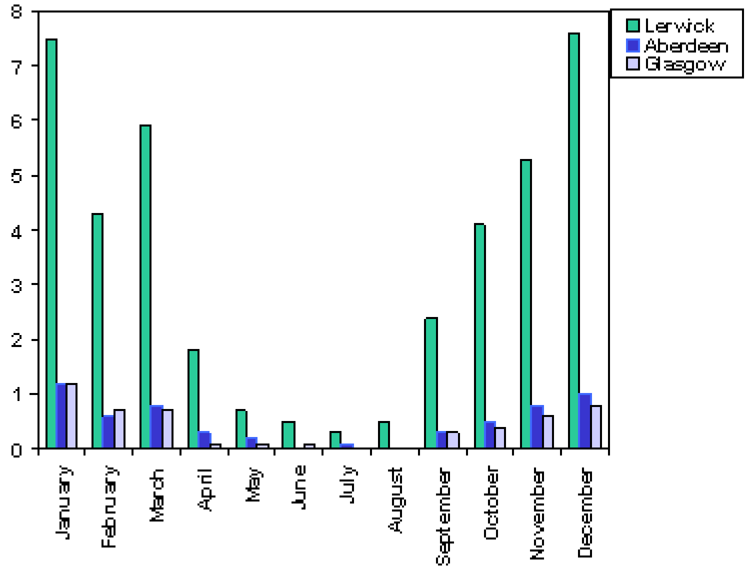

Figure 3.23: 30 years Average number of Days with Gales

[17]

Chapter 4: Analysis

4.1 Introduction

In this chapter details of the hydropower are presented such as estimations of the turbine size and pump size. Furthermore, the flow rate of the water in the pipe is calculated to get the appropriate power for the coverage of the village's needs. In addition, calculations of the time that the upper reservoir needs to empty and become full again are presented.

According to the wind data of the year 2001 a calculation of the power that the wind turbine can produce for covering the needs of the village and also to pump the water up from the lower to the upper reservoir is presented, as well as the changes at the height of the water into the upper reservoir.

4.2 Hydropower Estimation

4.2.1 Water Turbine Size Calculation

The hydro-electric scheme is the most familiar application (see Figure 4.1). The water is taken from the upper (storage) reservoir to drive a hydraulic turbine, which in turn drives a generator to produce electricity and then the water passes to a lower reservoir.

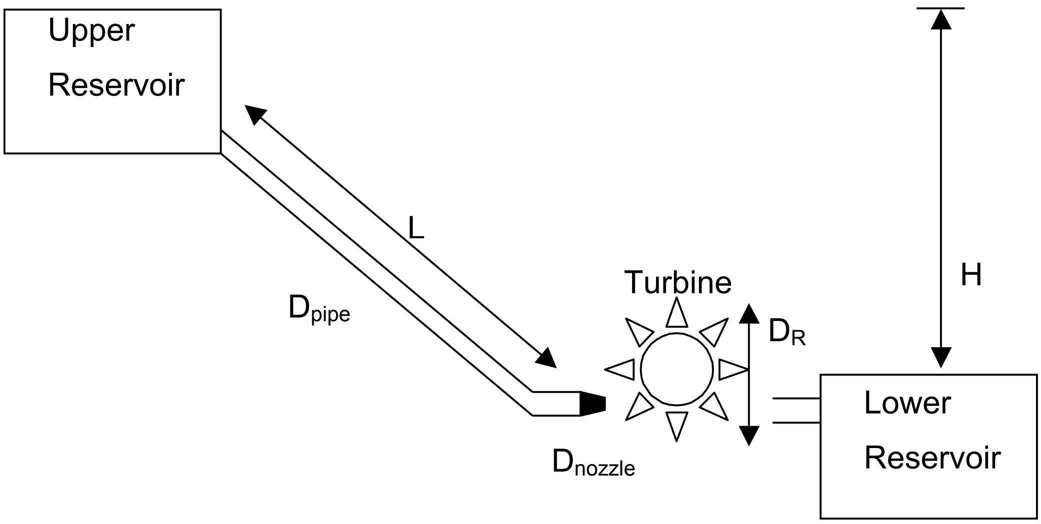

Figure 4.1: Micro-Hydro Power System Layout (Turbine)

According to the above layout, the energy equation is:

$$g \cdot H = W_{out} + \square_{losses}$$

The power extracted by the turbine is given by the formula below:

$$p \cdot g \cdot W_{out} = p \cdot q \cdot \left[g \cdot H \square \square_{losses} \right] = p \cdot A \cdot \overline{V} \left(g \cdot H \square \frac{4 \cdot f \cdot l}{d} \cdot \frac{\overline{V}^2}{2} \right)$$

Where V is the mean velocity of the pipe. It is obvious that power = 0 when the V = 0. Also for large V, _losses _ gH and the power _0

A graph of power against flow rate q, would look like the Figure 4.2 below:

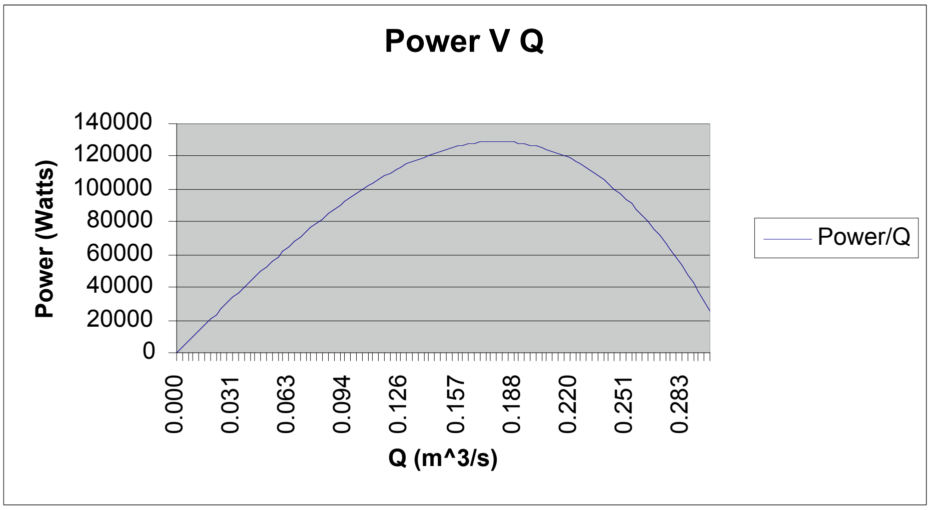

Figure 4.2: Power Graph

For maximum power condition,

$$\frac{d}{dV}(power) = 0 = \square \cdot A \cdot \left(g \cdot H \square \frac{4 \cdot f \cdot l}{d} \cdot \frac{3 \cdot \overline{V}^2}{2} \right)$$

$$\square \; g \cdot H = 3 \cdot \frac{4 \cdot f \cdot l}{d} \cdot \frac{\overline{V}^2}{2} \; \square \; \frac{4 \cdot f \cdot l}{d} \cdot \frac{\overline{V}^2}{2} = \frac{1}{3} g \cdot H$$

The efficiency of the pipe in general is:

$$\eta_{tr} = \frac{g \cdot H - losses}{g \cdot H} = 1 - \frac{losses}{g \cdot H}$$

So _$_{tr}$ will be 1.0 for q = 0, the value of n_{tr} falling as the flow rate increases, to a limit of zero where losses = gH.

In general the power is given from the formula below:

$$Power = p \cdot q \cdot W_{out} = p \cdot q \cdot \left(g \cdot H - \frac{32 \cdot f \cdot l \cdot q^2}{\pi^2 \cdot d^5} \right)$$

If the power required is known, a cubic equation for q is produced which in general will have two solutions. The smaller solution will be accepted because the system will run at the lower flow rate, q.

At the table 4.1 that follows the kW-hrs/year that each building in the village is going to be need for electricity and for heating are presented. At the last column there is the total consumption of kW-hrs/year of the whole village. At this point the street lamps have not been taken in mind.

Buildings	Power Electricity (kW-hrs/year)	Power Heating (kW-hrs/year)	Total (kW-hrs/year)	Number of Buildings	Power (kW-hrs/year)
Houses	4500	3000	7500	15	112500
Co-House	4500	3000	7500	1	7500
Ed. Centre	6000	4000	10000	1	10000
Total Power (kW-hrs/year)					130000

Table 4.1

As we have already discussed above the power output in kW of a turbine is given from the above equation so in order to calculate the flow rate of the water in the pipe we have to transfer the kW-hrs/year in kW:

$$Power\ output = 130000 \frac{kW \cdot hrs}{year} \cdot \frac{3600[\sec]}{3600[\sec] \cdot 24[hours] \cdot 365[days]} = 14.84 kW$$

That is the required power output to be obtained from the generator in order to cover the needs of the eco-village. But the efficiency of the turbine is at 0.8 or 80% and the efficiency of the generator is at 0.8 or 80%. To get the power output that is needed we need to divide the power output by the two efficiencies, that of the turbine and that of the generator (see Table 4.2).

Power output (kW)	Turbine Efficiency	Generator Efficiency	Total Efficiency	Power output (kW)
14.84	0.8	0.8	0.64	23.18

Table 4.2

To calculate the flow rate of the water in the pipe that is going to produce the power output which is required, the formula below is used:

$$Power\ output = p \cdot q \left(g \cdot H - 32 \frac{f \cdot l \cdot q^2}{\pi^2 \cdot d^5} \right)$$

where: p is the density of water 1000 kg/m^3

q is the flow rate of the water in m^3/s

g is the gravity of the 9.81 m/s^2

H is the head of the upper reservoir from the lower reservoir in meters

f is the friction factor 0.005

d is the diameter of the pipe

To calculate the length of the pipe l in meters we have to know the slope of the hill. The slope of the hill is about 30^0 degrees to the horizontal so:

$$\sin 30^0 = \frac{H}{l} \Rightarrow l = \frac{H}{\sin 30^0}$$

$$\Rightarrow l = 2 \cdot H$$

According to the above calculations above the formula becomes:

$$Power\ output = p \cdot q \cdot \left(g \cdot H - 32 \frac{f \cdot 2 \cdot H \cdot q^2}{\pi^2 \cdot d^5} \right)$$

$$24000 = 1000 \cdot q \cdot \left(9.81 \cdot H - 32 \frac{0.005 \cdot 2 \cdot H \cdot q^2}{\pi^2 \cdot d^5} \right)$$

$$24 = 9.81 \cdot H \cdot q - 0.0324 \cdot \frac{H \cdot q^3}{d^5}$$

$$0.0324 \cdot \frac{H}{d^5} \cdot q^3 - 9.81 \cdot H \cdot q + 24 = 0$$

The only unknown is the flow rate q. By giving the value of head, H, and the pipe diameter, d, at the above equation the respective flow rate of the water is calculated. Usually there are three roots from that equation but one of them is negative so it is not possible to have a negative flow rate. From the other two the smaller value is chosen because the lowest flow rate as possible is needed in order to keep the losses in minimum. In the site the exact head that the lower reservoir is going to be situated was not known for this reason a range between 60m to 120m is used, as it is seen on the spreadsheets.

The figure 4.3 shows the flow rates of the water in the pipe and the efficiencies of different pipe diameters against the head.

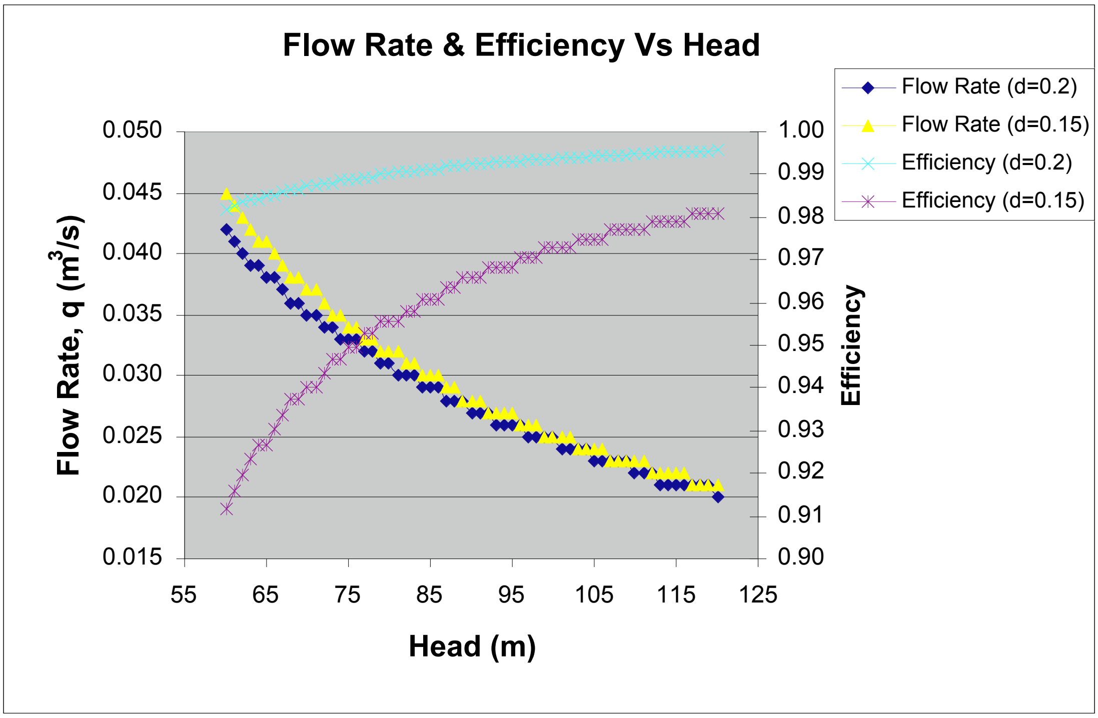

Figure 4.3: Flow Rate & Efficiency Vs Head

The figure 4.4 shows the speed of the water in the pipes and the time that required for empty the upper reservoir against the head.

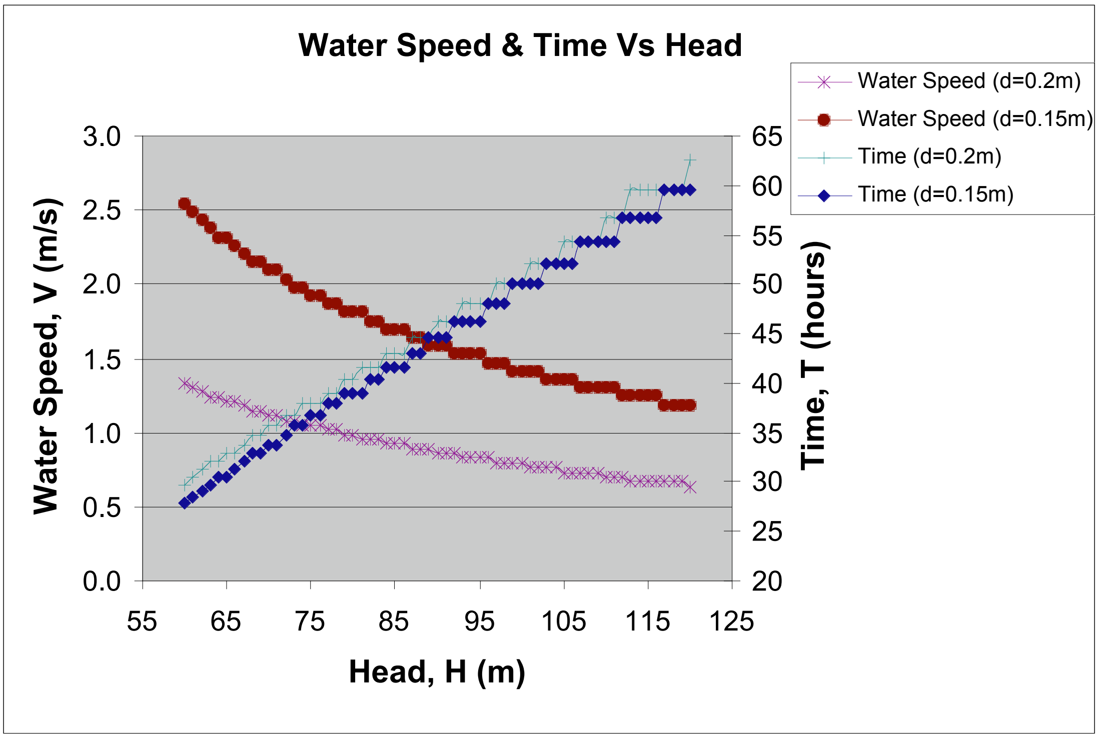

Figure 4.4: Speed of water & Time Vs Head

4.2.2 Pipe Diameter

The calculation of the flow rate, q, has been made in two different pipe diameters which values were 0.15m and 0.20m. The conclusion is that by using a pipe of 0.20m high values of efficiency are gained. That means that it is more than enough for the power requirements to be covered. The 0.15m pipe diameter gives high values of efficiency as well which also meets the power requirements. However, this efficiency is not as great as the efficiency of the first pipe. In case of future expansion of the village both pipes will be suitable for use because the flow rate of the water in the pipes for both diameters is small. We do not know what will be the cost difference between the two pipes. By the way the pipe of diameter at 0.15m would be cheaper than the one of 0.20m. The table 4.3 below shows an example of different values of the flow rate, the velocity and the efficiencies that we get from each different pipe diameter.

Head, H (m)	D_{pipe} (m)	Flow Rate, q (m^3/s)	Velocity, V (m/s)	Time, T (hours)	Efficiency _
100	0.15	0.025	1.415	50	0.9728
100	0.20	0.025	0.796	50	0.9935

Table 4.3

4.2.3 Pelton Turbine

As it is discussed at Chapter three a Pelton Turbine was chosen to be installed because it is easy to operate and it is very reliable. On the Pelton Turbines there is a nozzle at the end of the pipe which increases the speed of the water which runs on the blades. This nozzle diameter can be adjust any time after the installation at the appropriate diameter in order to produce the power wanted.

In order to calculate the maximum power that the turbine produces we must consider that the power output depends on the flow rate, Q in m^3/s or liter/sec, and the jet speed at the nozzle exit, V_{nozzle} in m/s, which both of them depend on the diameter of the nozzle, D_{nozzle} in meters, and the head losses, h_L, associated with the supply pipe.

That is:

$$Power\ output\ _{(\max)} = \rho \cdot q \cdot V_{bucket} \cdot \left(V_{bucket} - V_{nozzle}\right)\left(1 - \cos\beta\right)$$

where: _ is the density of the water, 1000kg/m3

q is the flow rate m^3/s

the angle _ is the angle of the blades, a typical value is 165^o

Decisions made for the diameter of the runner, D_R in meters - which influence the runner speed, $\_{R}$ in rpm - and the diameter of the tube D_{tube} in meters. The diameter of the nozzle D_{nozzle}, given by the formula below, in order to have the maximum power output:

$$D_{nozzle} = \frac{D_{pipe}}{\left(2 \cdot f \cdot \frac{l}{D_{pipe}}\right)^{1/4}}$$

To calculate the jet speed at nozzle exit, V_{nozzle}, we know the head, H is equal to:

$$H = \frac{V_{nozzle}^2}{2g} + h_L$$

where: head loss, h_L, is given in terms of the friction factor, f, as:

$$h_L = f \cdot \frac{l}{D} \cdot \frac{V^2}{2g}$$

There are minor losses associated with the pipe entrance and the nozzle so:

$$H = \left(1 + f \cdot \frac{l}{D_{pipe}} \cdot \left(\frac{D_{nozzle}}{D_{pipe}}\right)^4\right) \cdot \frac{V_{nozzle}^2}{2g}$$

By solving this equation in terms of V_{nozzle} we get the jet speed at nozzle exit:

$$V_{nozzle} = \left(\frac{2g \cdot H}{1 + f \cdot \frac{l}{D_{pipe}} \cdot \left(\frac{D_{nozzle}}{D_{pipe}} \right)^4} \right)^{1/2}$$

By solving the derivate of the equation of the maximum power output, with respect of the tangential to zero, we get that:

$$V_{bucket} = \frac{V_{nozzle}}{2}$$

To calculate the runner speed, ω_R, in rpm we know that:

$$V_{bucket} = \omega_R \cdot R_R = \frac{V_{nozzle}}{2} \Rightarrow \omega_R = \frac{V_{nozzle}}{2 \cdot \frac{D_R}{2}} \cdot \frac{60}{2\pi}$$

where: R_R is the radius of the runner in meters

D_R is the diameter of the runner in meters

The flow rate of the water in the pipes, q, is given by the equation below:

$$q = A \alpha V$$

where: A is the area of the pipe or nozzle in m^2

V is the speed of the water in the pipe or nozzle respectively in m/s

In order to calculate the water speed in the tube, V_{pipe}, we use the formula:

$$q_{pipe} = q_{nozzle} \Rightarrow A_{pipe} \cdot V_{pipe} = A_{nozzle} \cdot V_{nozzle} \Rightarrow$$

$$\Rightarrow V_{pipe} = \frac{A_{nozzle} \cdot V_{nozzle}}{A_{pipe}}$$

The power output of the turbine is now calculated which is given by the formula which was described at the beginning:

$$Power\ output_{\max} = \rho \cdot q \cdot V_{bucket} \cdot (V_{bucket} - V_{nozzle}) \cdot (1 - \cos \beta)$$

The figure 4.5 shows the maximum power that the turbine can produce and the rpm against the head.

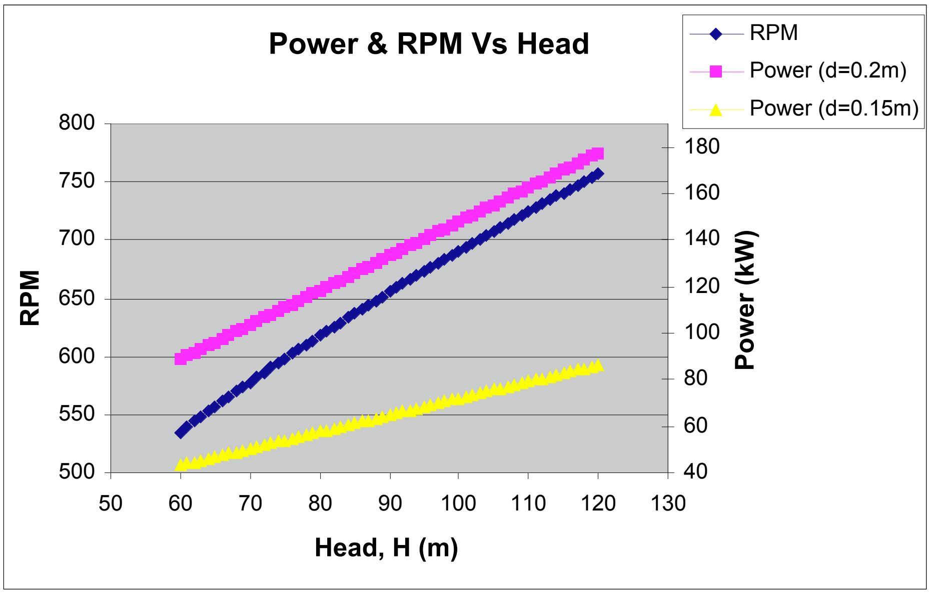

Figure 4.5: Max. Power & RPM Vs Head

The speed of the water at the nozzle exit as well as the speed of the water in the pipe against the head are shown at figure 4.6

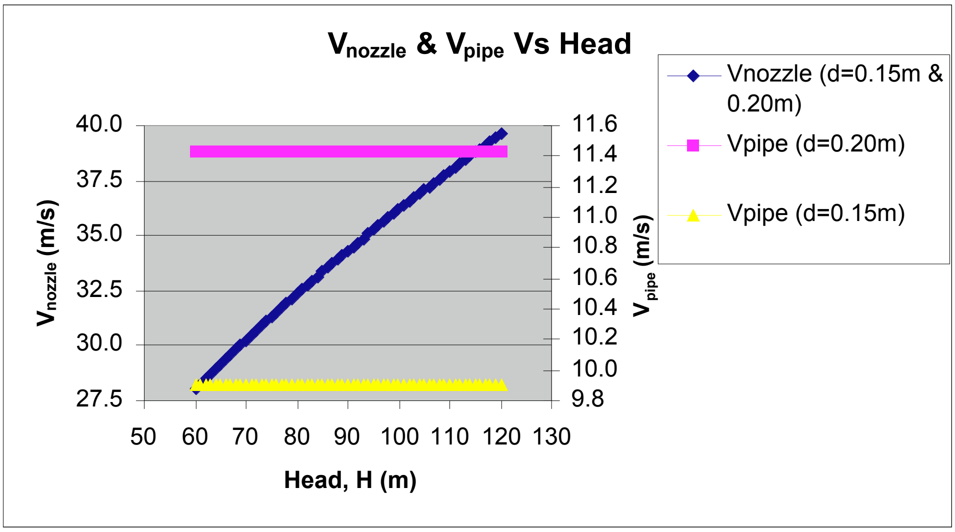

Figure 4.6: V_{nozzle} & V_{pipe} Vs Head

4.2.4 Pump Size Calculation

When the upper reservoir empties all the water is going to be collected at the lower reservoir. In order for the system to produce power again all the water must be driven back to the upper reservoir. This is going to happen during days that enough power exists from the other renewable sources of energy like the wind or the solar. A pump is going to drive the water from the lower reservoir to the upper reservoir (see figure 4.7).

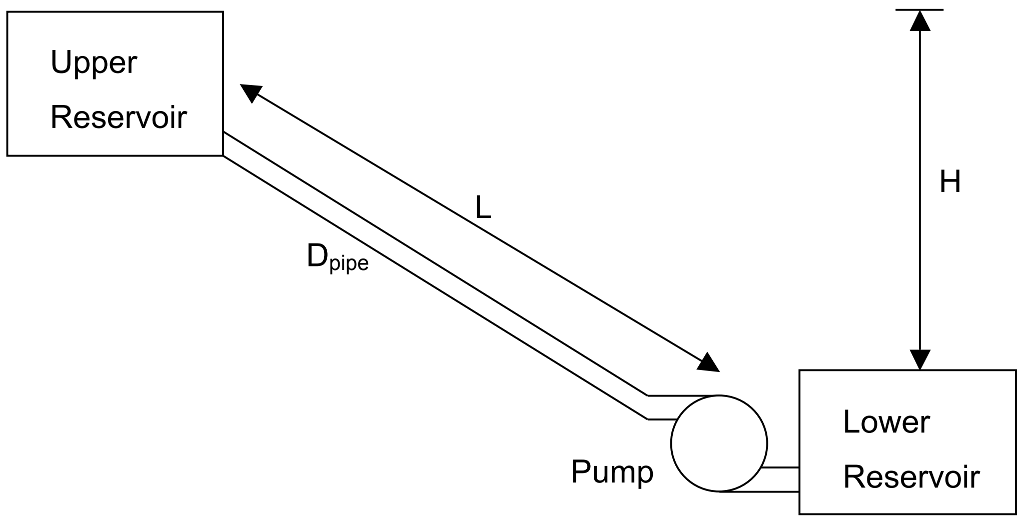

Figure 4.7: Micro-Hydro System Layout (Pump)

In order to calculate the size of the pump almost the same procedure is followed as we have done previously for the calculation of the turbine size. From the formula below:

$$Power\ input\ (kW) = \dot{m}\cdot W_{in} = \dot{m}\cdot\left[g\cdot H + 4\cdot f\cdot l\cdot\frac{\overline{V}^2}{2}\right]$$

$$Power\ input\ (kW) = p\cdot q\cdot\left[g\cdot H + 32\frac{f\cdot l\cdot q^2}{\pi^2\cdot d^5}\right]$$

where: p is the density of water 1000 kg/m^3

q is the flow rate of the water in m^3/s

g is the gravity of the 9.81 m/s^2

H is the head of the upper reservoir from the lower reservoir in meters

f is the friction factor 0.005

l is the length of the pipe in meters, $l = H / sin30^0 = 2 \cdot H$

d is the diameter of the pipe

The flow rate of the water depends on the pipe diameter, d, and the velocity of the water, V:

$$q = A \cdot V = (\pi \cdot d^2 / 4) \cdot V$$

If d,V _ 0 then the flow rate, q _ 0. As the flow rate decreases we expect the power that is required to decrease as well consequently, for q _ 0, the power _ 0. As the power of the pump decreases the time that is required for the upper reservoir to be filled with water increases, hence power _ 0, and t _ . This is the reason why the most appropriate pump must be chosen.

By choosing the diameter of the pipe, d, and the velocity of the water that it is needed to be pumped to the upper reservoir, the flow rate of the water in the pipe can be calculated. Then by using the above equation and giving the values of the head, H, the size of the pump in kW can be estimated. At the end power has to be divided with the efficiency of the pump in order for the requirements to be met.

It is better to choose a large diameter of the pipe for that occasion as well as to avoid any replacements in a future expansion of the village as we have done previously for the turbine calculation. Four different power calculations have been done by choosing a different pipe diameter and a different velocity of the water each time.

The table 4.4 below shows the results of the power input in kW for a head of 100m according to the different pipe diameter and the different velocity of the water each time. The values are found more analytically on the spreadsheets.

Velocity \ Diameter	0.15m	0.20m
1 (m/s)	24.77 kW	44.05 kW
2 (m/s)	49.53 kW	88.10 kW

Table 4.4

The figure 4.8 shows the Power and the Efficiency of diverent size pumps against the head of the site.

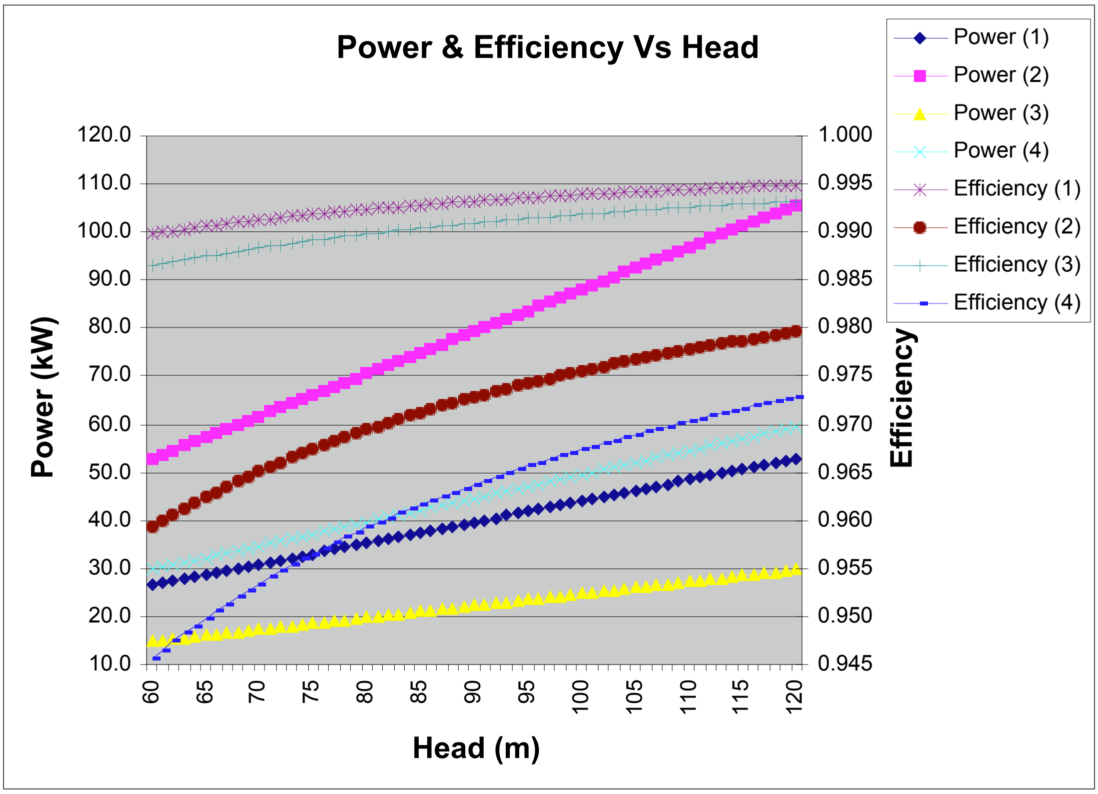

Figure 4.8: Power & Efficiency Vs Head

4.2.5 Volume Of The Reservoirs

As discussed in Chapter three the volume of the upper reservoir is 4500m^3. The same volume must have the lower reservoir as well, because the whole system is going to run as a back up energy supply. That means that all the water that will release from the upper reservoir should be collected at the lower reservoir.

In order to calculate the time all the water takes from the upper reservoir to run down to the lower reservoir and also from the lower reservoir to pump the water to the upper reservoir we need to use the flow rate, q of the water in the pipe, which have been already calculated. By the equation below we can estimate the total time it needs:

$$Total\ Time = \frac{Volume\ \lfloor m^3 \rfloor}{Flow\ rate\ \left[\frac{m^3}{s}\right]} \cdot \frac{1}{3600\ \sec}$$

4.2.6 Future Expansion Of The Village

The primary thought is that the village is going to be consisted of fifteen houses, one community house and a hotel. But in the future the village might expand and a number of new houses might be built. That is a very imprortant issue that we have to take in mind for the design and installation of the whole hydro-power system and generally for all the installation units. For this main reason we decided to choose a diameter of pipe at 0.1.5m in order to avoid any future replacements. That diameter of the pipe is enough to give more power to the village if it is needed by increasing the flow rate of the water in the pipe. The initial thought of the volume of reservoir was to be at 4500m^3 water and it might be better if we increase the volume of it from the beginning by avoiding digging it again at future. By increasing the depth of it from 3m to 5m will have a reservoir of volume 7500m^3 water.

The problems that we might face are that we do not know what kind of ground is under the already natural reservoir and that may be produce some difficulties at the digging stage. Also by increasing the volume of the upper reservoir we have to increase the volume of the lower reservoir to be able to collect all the amount of the water. That will increase the whole cost of the project as well as it will affect the aisthetics of the village.

4.2.7 Energy Demand of the Ecovillage

An estimation of the total hourly energy that the ecovillage will need in order to operate has been done according to the hourly data that we had for one house. To be able to calculate the energy that required for the ecovillage an assumption has to be done that all the houses are going to operate the same.

At figure 4.9 and figure 4.10 were presented the total energy that, the fifteen houses, the community house and the visitors/education centre, required for the summer and the winter respectively against the hours of one day. There are all the domestic systems that a house needs as light, Hi-Fi, PC, TV, laptop, video, Stereo, kettle, coffee machine, iron, vacumn cleaner, washing machine, fridge and a freezer. A categorized have been made in order to be easier to presented them as a graph.

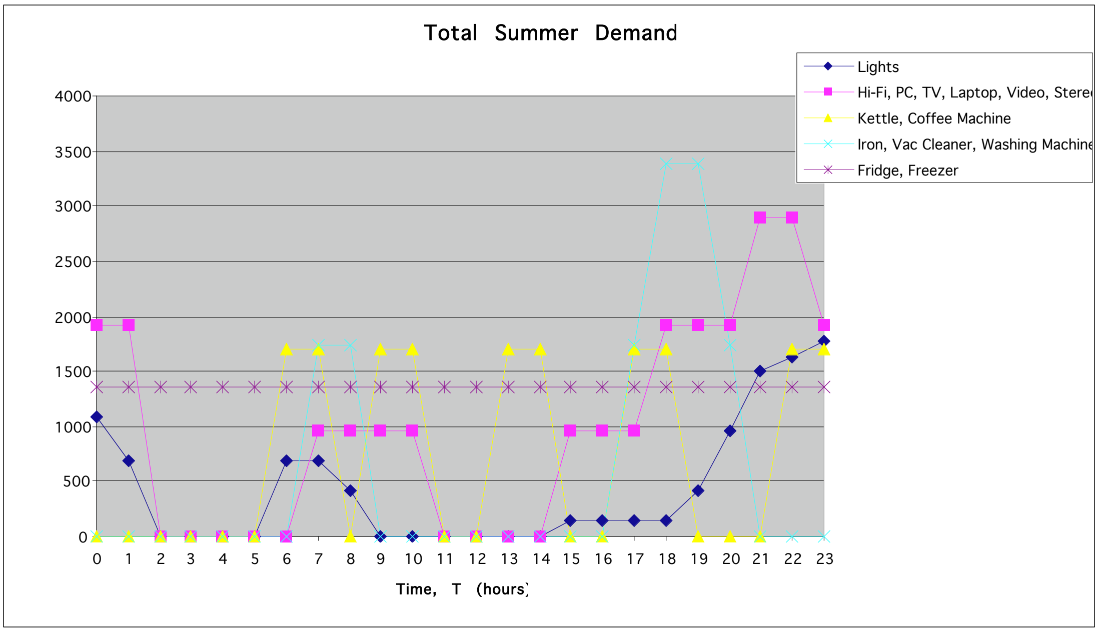

Figure 4.9: Total Summer Demand

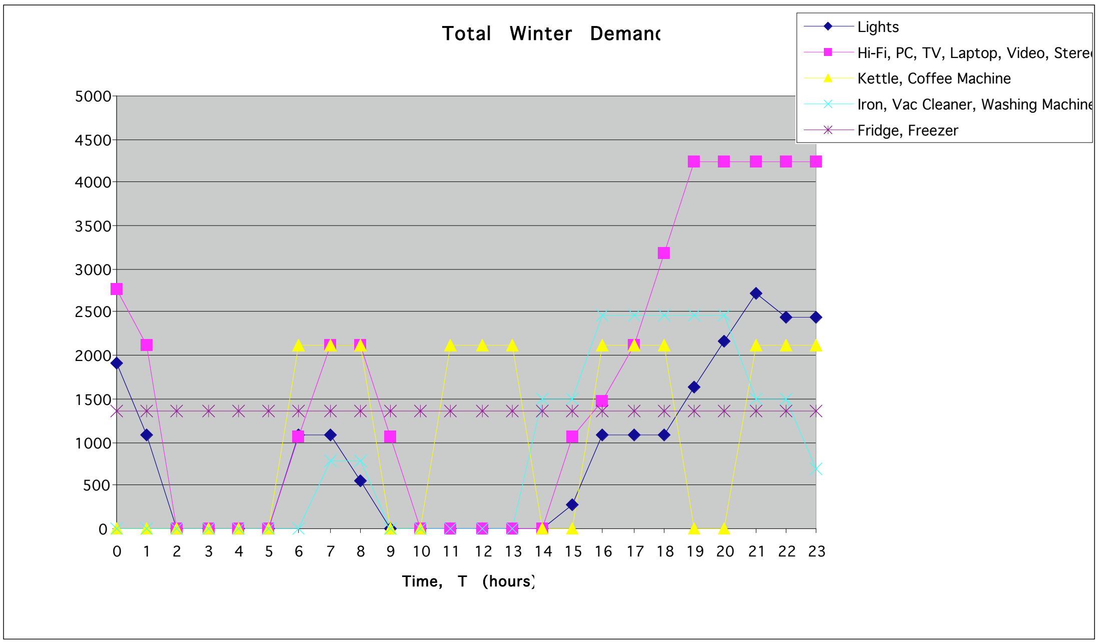

Figure 4.10: Total Winter Demand

At figure 4.11 and figure 4.12 there are presenting the total power needed from the ecovillage during the summer and the winter respectively.

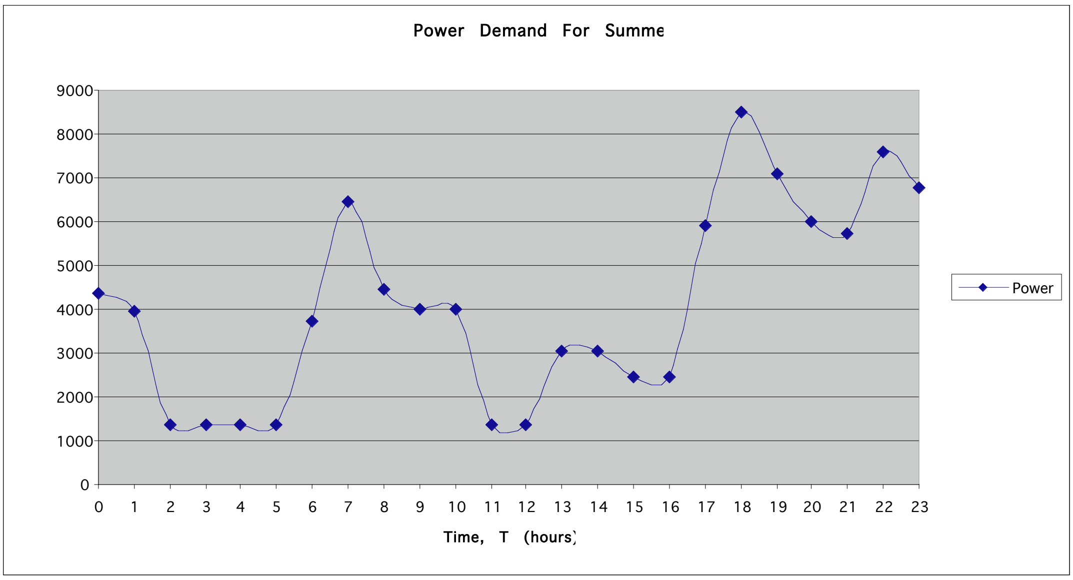

Figure 4.11: Power Demand For Summer

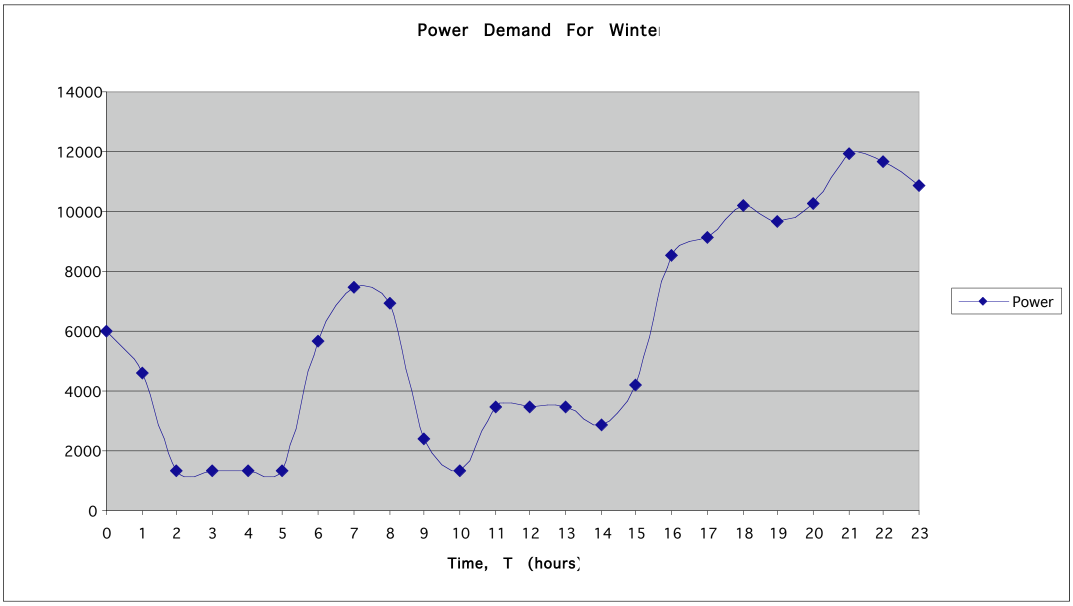

Figure 4.12: Power Demand For Winter

4.2.8 Wind Power Estimation

A wind turbine is going to be installed in order to produce power for the village and also to produce power to pump the water from the lower to the upper reservoir. The power that is needed for the village has been estimated above (see table 4.4).

The village needs power equal to 130000kw-hrs/year which is almost 14.84kW.

Power output (kW)	Wind Turbine Efficiency	Power Output (kW)	Wind Turbine Power (kW)
15	0.35	42.43	70

Table 4.5

The power of the turbine should be around 70kW but by choosing a bigger wind turbine will avoid any replacement in a future expansion of the village (see Table 4.5).

In order to calculate the power that the turbine can produce an hourly wind speed data was collected for a whole year at the area of Bishopton, Glasgow.

NGR = 2418E 6711N

Altitute = 59 meters

Latitude = 55:91 N

Longitude = 04:53 W

Due to the fact that wind speed data of the Tweed Valley area was not available it was decided that Glasgow's data should be used instead. Both places are very close so it is believed that the same results will be drawn. The wind data comes from year 2001 which was one of the most non windy years. Hence, the results of the power that the wind turbine is going to produce can not be less than the values which have been calculated, because that was one of the worst situations. The units of wind speed data were at knots and a transformation was made to m/s by using the equation below:

1 knots = 0.51444 m/s

Also that was the speed of the wind at a height 10m above the ground level but the wind turbine will be install higher than 10m approximatelly at 20m. So, to be more accurate the wind speed at that level will be given from the formula:

$$\frac{V_{20}}{V_{20}} = \left(\frac{h_{20}}{h_{10}}\right)^{1/n} \Rightarrow V_{20} = V_{10} \cdot \left(\frac{h_{20}}{h_{10}}\right)^{1/n}$$

where: n is the ground roughness coefficient, 6

A calculation has to be done for the radius, R, of the turbine blades in order to be sure that the turbine is going to meet the power demand that is required, from the formula below:

$$P = c_p \cdot \frac{1}{2} \cdot \square \cdot \square \cdot R^2 \cdot V_R{}^3$$

where: P is the power in Watts

c_p is the coefficient factor 0.4

_ is the density at 1.2kg/m3

R is the radius of the blades in meters

V_R is the rated speed in m/s

We also choose as a cut-in speed, V_{cut-in} a value of 4m/s, as a rated speed V_{rated} a value of 11m/s and as a cut-out speed, $V_{cut-out}$ at 20m/s. At the figure 4.13 there is presenting the power output that we are expecting to get from the wind turbine and can be shows clearly the points of the V_{cut-in}, V_{rated} and $V_{cut-out}$.

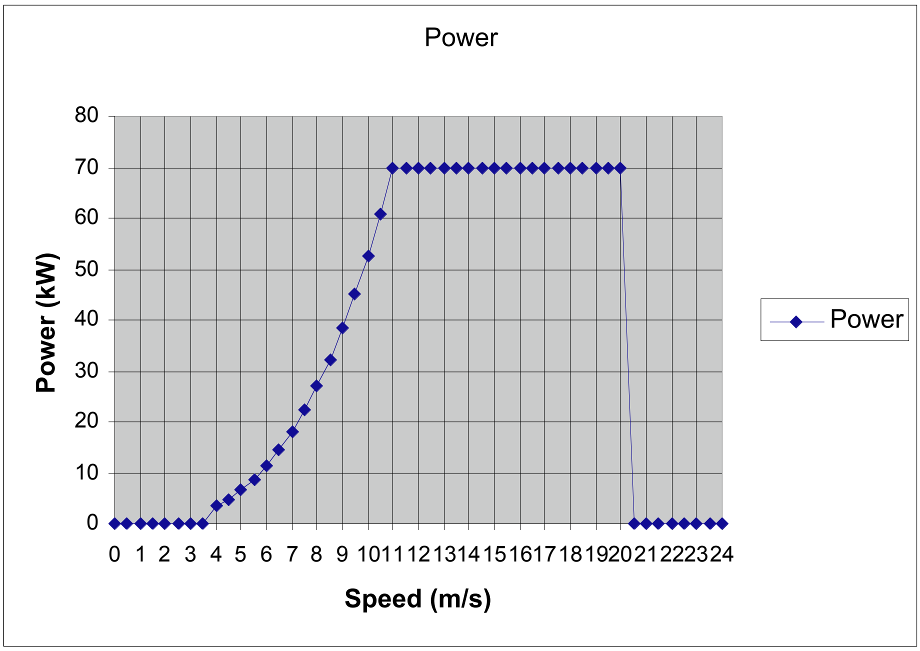

Figure 4.13: Power from Wind Turbine

From the wind data of year 2001 we calculate the power output, P, for each hour for the whole year that the wind turbine will produce by giving the hourly wind speed by using the formula below:

$$P = c_p \cdot \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot V^3$$

In order to do this calucaltion a period of time has been choosen for the summer from 06/06/2001 until 21/06/2001 and for the winter from 20/11/2001 until 05/12/2001. At figure 4.14 and figure 4.15 were presented the power output that the wind turbine can produce for ecovillage against the wind speed for the chosen summer period and for the chosen winter period respectively.

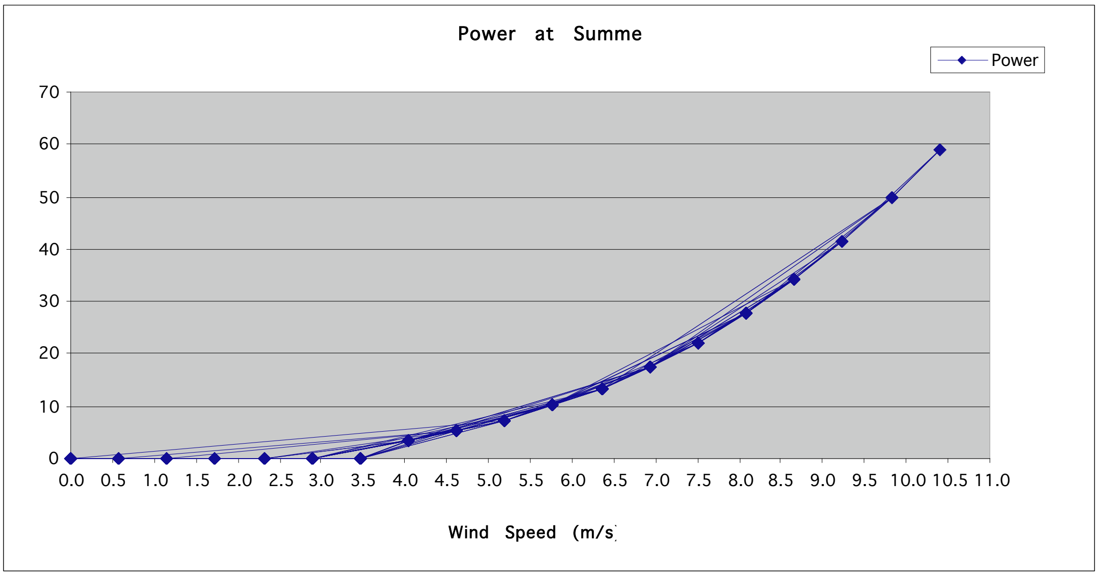

Figure 4.14: Power from Wind Turbine During Summer

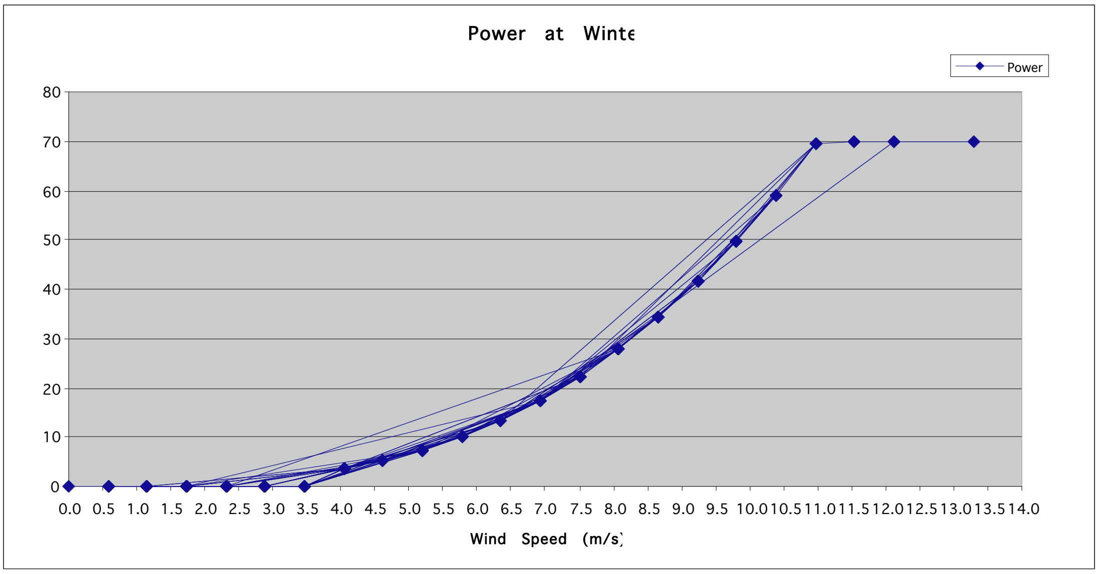

Figure 4.15: Power from Wind Turbine During Winter

According to the figures 4.14 and 4.15 at the winter we can get much more power from the wind turbine because of higher winds.

Both figures 4.16 and 4.17 present the power that the wind turbine can produce at the period of time that we have mentioned previously for both summer and winter.

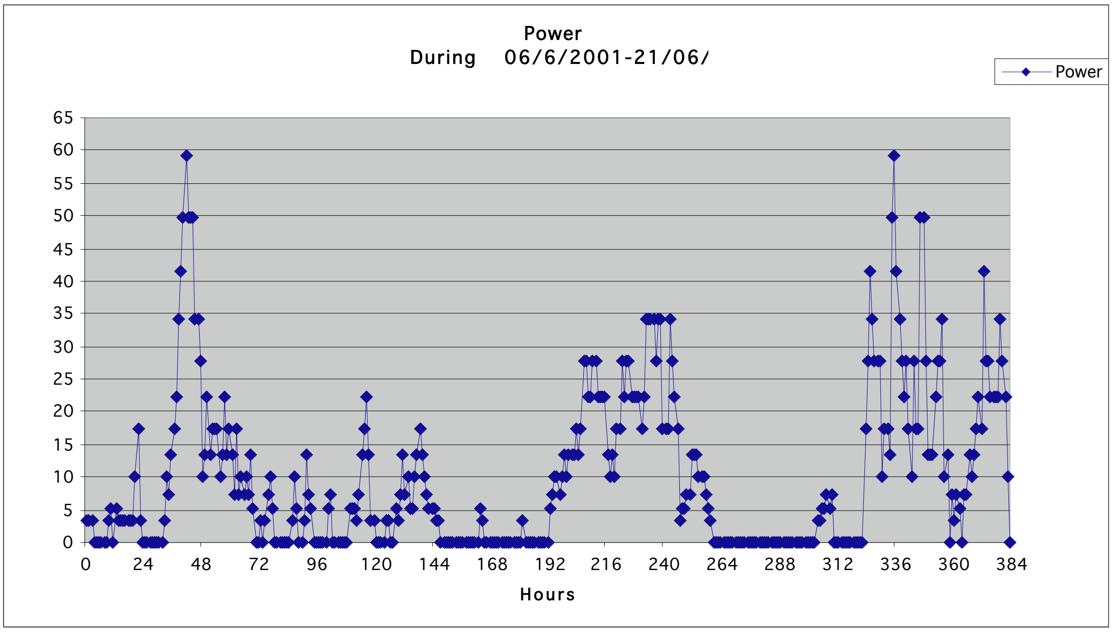

Figure4.16: Power from the Wind Turbine During 06/06/01-21/06/01

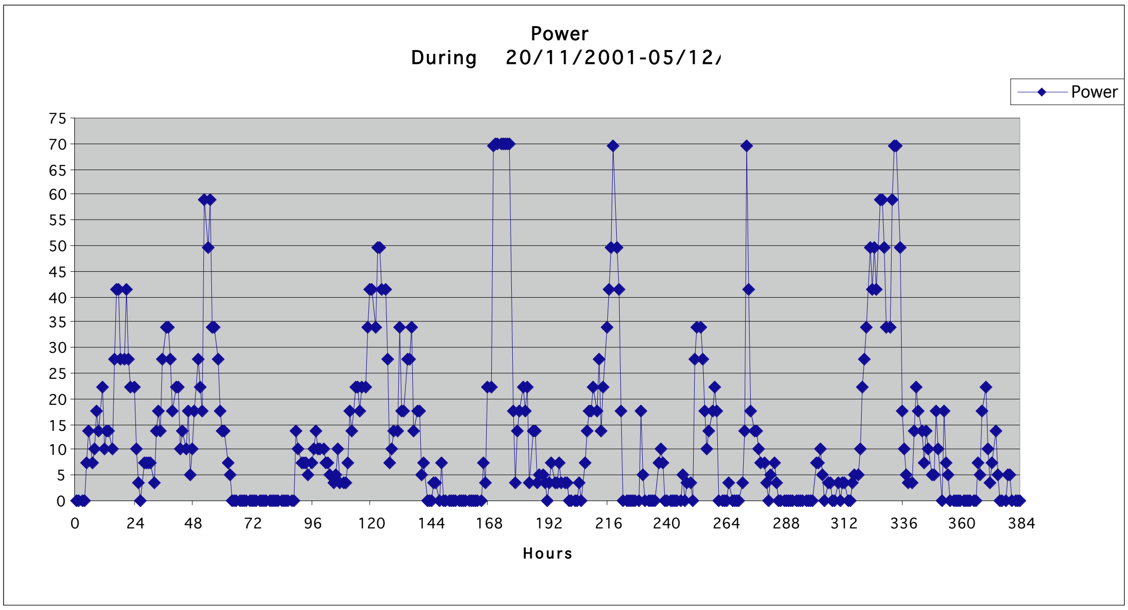

Figure 4.17: Power from the Wind Turbine During 20/11/01-05/12/01

As an example we have choose a period of two days from the period of sixteen days as you can see at figure 4.18 and figure 4.19 for both summer (14-15/06/01) and winter (24-25/11/01) in order to present more clearly the power that the wind turbine can produce according to the wind speed data that we had in that period of time.

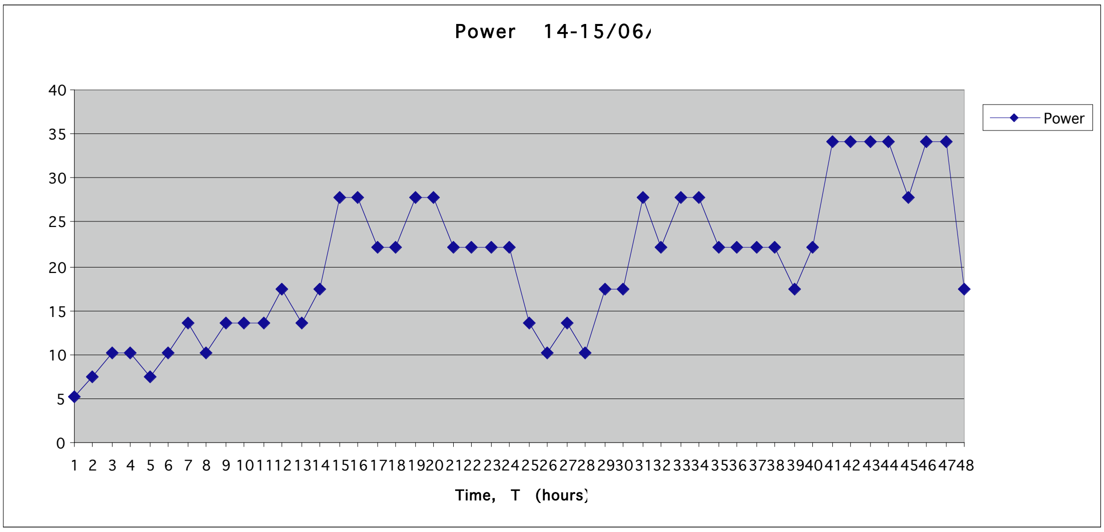

Figure 4.18: Power from Wind Turbine During 14-15/06/01

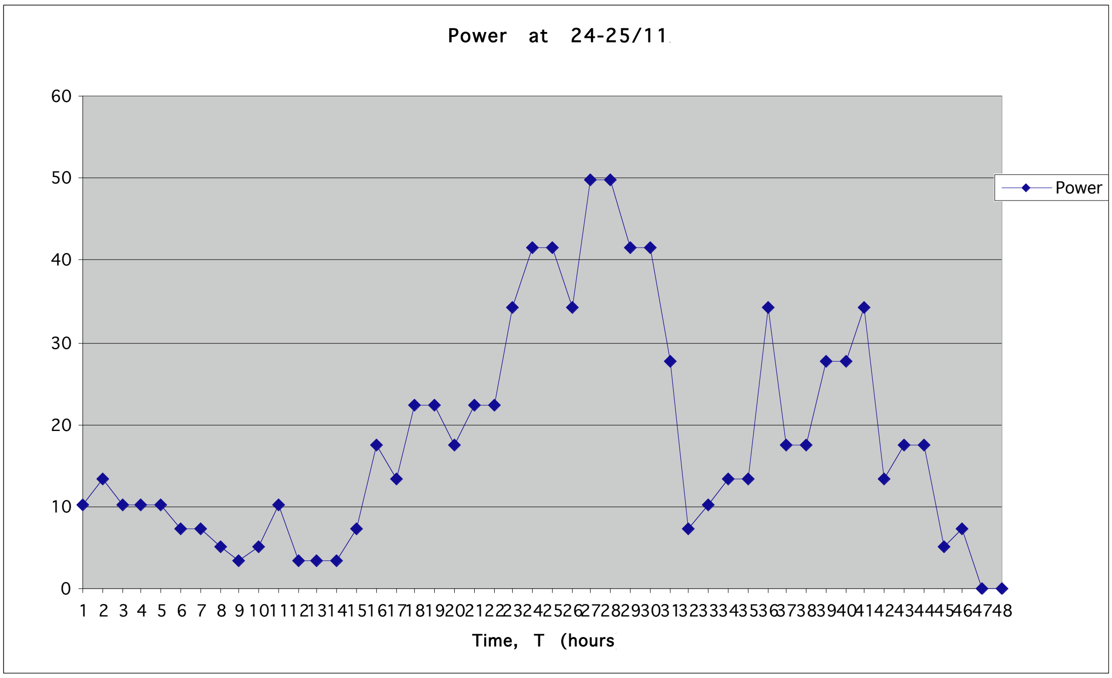

Figure 4.19: Power from Wind Turbine During 24-25/11/01

After the calculation of the power that the wind turbine produce we can check if this power is enough to cover the ecovillage needs according to previous calculations of the hourly power that the ecovillage required. If the power that the wind turbine produces is plenty to cover the needs of the ecovillage, the remaining of the power will operate the pump for driving the water to the upper reservoir. The pump will operate only for conditions of power more that 10kW in order to maximise its operating life. But some times the power from the wind turbine is not enough to cover our needs so we need more power. By using the micro-hydropower station we will provide the rest of the power that the ecovillage require.

4.2.9 Calculation of the water level in the upper reservoir

Calculation of the water level and the volume of the reservoir has to be done. When the power that the wind turbine produces is not enough for the needs of the ecovillge, the water turbine will cover the remaining power that required by releasing water down from the upper reservoir. But as we have mention before when the power from the turbine is plenty the remaining power will pump the water up.

An example from the spreadsheet that has been produces shows at table 4.6 below in order to figure out the procedure.

Date	Time (GMT)		Wind - Mean Speed		Power	Power needed	Power remain	Flow rate, q	Velocity	Flow rate, q	V_{upper}	Height, h
	(hours)	(knots)	10m high (m/s)	20m high (m/s)	(kW)	(kW)	(kW)	(m^3/s)	(m/s)	(m^3/s)	(m^3)	m
20/11/01	0000	5	2.572	2.887	0.000	6.023	-6.023	0.009632	0.545	34.675	2965.325	1.9769
20/11/01	0100	4	2.058	2.310	0.000	4.570	-4.570	0.007296	0.413	26.266	2939.059	1.9594
20/11/01	0200	2	1.029	1.155	0.000	1.360	-1.360	0.002167	0.123	7.801	2931.258	1.9542
20/11/01	0300	5	2.572	2.887	0.000	1.360	-1.360	0.002167	0.123	7.801	2923.457	1.9490
20/11/01	0400	9	4.630	5.197	7.382	1.360	6.022	0.000000	0.000	0.000	2923.457	1.9490
20/11/01	0500	11	5.659	6.352	13.478	1.360	12.118	0.012000	0.679	43.200	2966.657	1.9778
20/11/01	0600	9	4.630	5.197	7.382	5.634	1.748	0.000000	0.000	0.000	2966.657	1.9778
20/11/01	0700	10	5.144	5.774	10.126	7.485	2.641	0.000000	0.000	0.000	2966.657	1.9778
20/11/01	0800	12	6.173	6.929	17.498	6.941	10.557	0.011000	0.622	39.600	3006.257	2.0042
20/11/01	0900	11	5.659	6.352	13.478	2.421	11.057	0.011000	0.622	39.600	3045.857	2.0306
20/11/01	1000	13	6.688	7.507	22.247	1.360	20.887	0.021000	1.188	75.600	3121.457	2.0810
20/11/01	1100	10	5.144	5.774	10.126	3.485	6.641	0.000000	0.000	0.000	3121.457	2.0810
20/11/01	1200	11	5.659	6.352	13.478	3.485	9.993	0.000000	0.000	0.000	3121.457	2.0810
20/11/01	1300	11	5.659	6.352	13.478	3.485	9.993	0.000000	0.000	0.000	3121.457	2.0810
20/11/01	1400	10	5.144	5.774	10.126	2.852	7.274	0.000000	0.000	0.000	3121.457	2.0810
20/11/01	1500	14	7.202	8.084	27.786	4.185	23.601	0.023000	1.302	82.800	3204.257	2.1362
20/11/01	1600	16	8.231	9.239	41.476	8.516	32.960	0.032000	1.811	115.200	3319.457	2.2130
20/11/01	1700	16	8.231	9.239	41.476	9.153	32.324	0.032000	1.811	115.200	3434.657	2.2898
20/11/01	1800	14	7.202	8.084	27.786	10.214	17.572	0.018000	1.019	64.800	3499.457	2.3330
20/11/01	1900	14	7.202	8.084	27.786	9.694	18.092	0.018000	1.019	64.800	3564.257	2.3762
20/11/01	2000	16	8.231	9.239	41.476	10.238	31.238	0.031000	1.754	111.600	3675.857	2.4506
20/11/01	2100	14	7.202	8.084	27.786	11.941	15.844	0.016000	0.905	57.600	3733.457	2.4890
20/11/01	2200	13	6.688	7.507	22.247	11.669	10.577	0.011000	0.622	39.600	3773.057	2.5154
20/11/01	2300	13	6.688	7.507	22.247	10.880	11.367	0.012000	0.679	43.200	3816.257	2.5442

Table 4.6

So as we can see from the last column the volume of the upper reservoir and the height of the water in it varies in each situation. For the calculation of the volume and the height changes we assume that the volume of the water in the upper reservoir is 3000m^3. The remaining 1500m^3 of water are at the lower reservoir.

Figure 4.20 and figure 4.21 present the changes of the volume of the upper reservoir and the height of the water in it, against the sixteen days period during the summer and the winter.

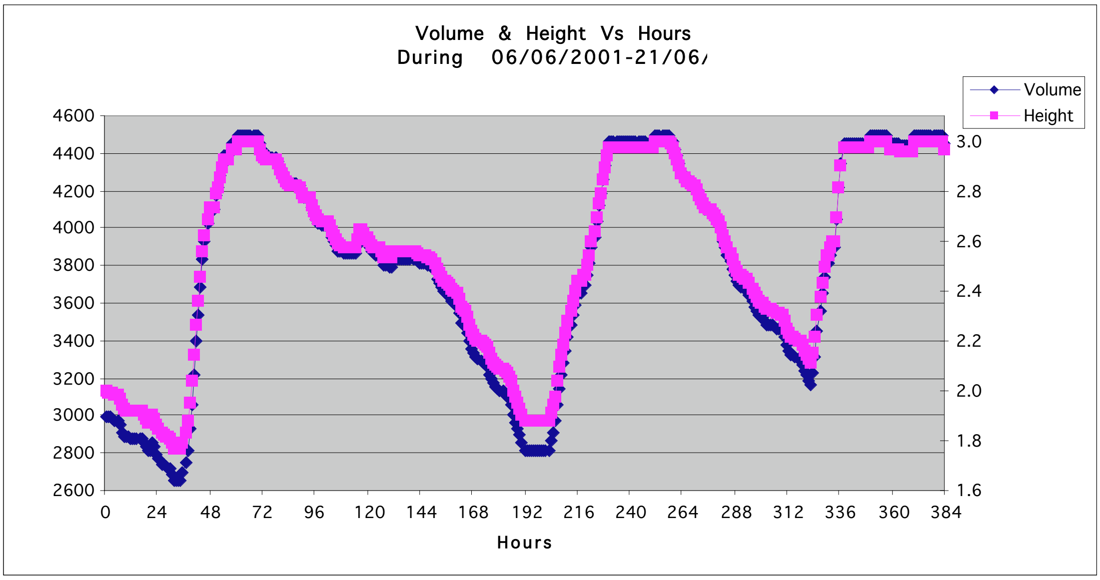

Figure 4.20: Volume & Height of the Upper Reservoir Vs Hours During 06/06/01-21/06/01

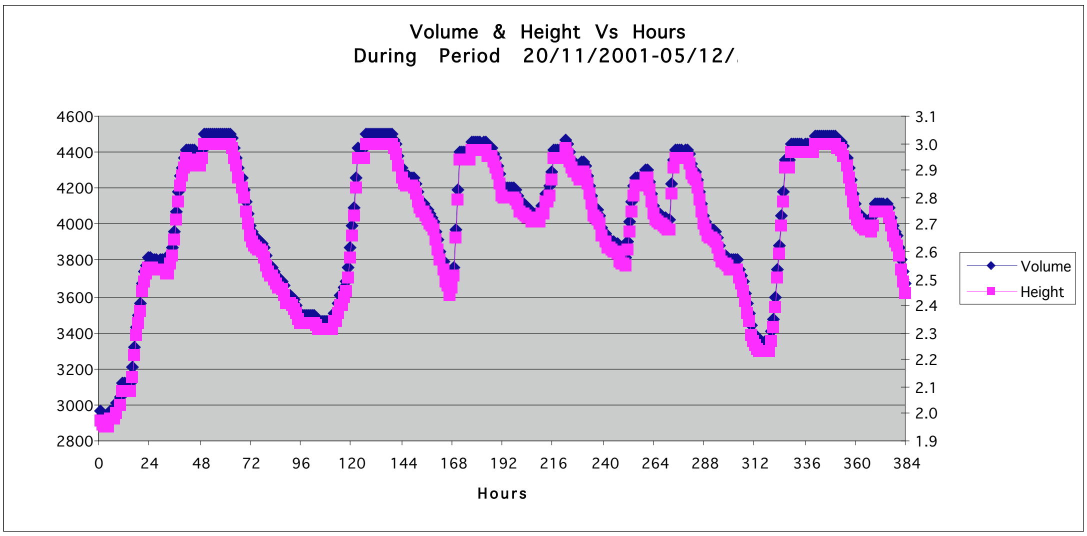

Figure 4.21: Volume & Height of the Upper Reservoir Vs Hours During 20/11/01-05/12/01

Both figures 4.22 and 4.23 present the volume of the upper reservoir and height of the water in it against the two days periods, for the summer (14-15/06/2001) and for the winter (24-25/11/2001) respectively, in order for the results to be more clearly.

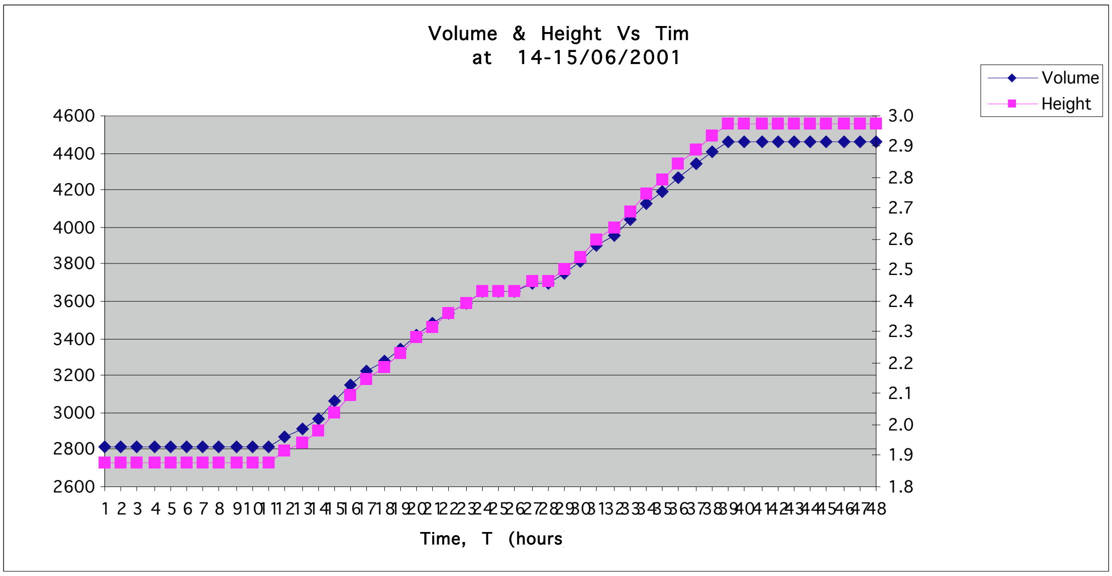

Figure 4.22: Volume & Height of the Upper Reservoir Vs Hours During 14/06/01-15/06/01

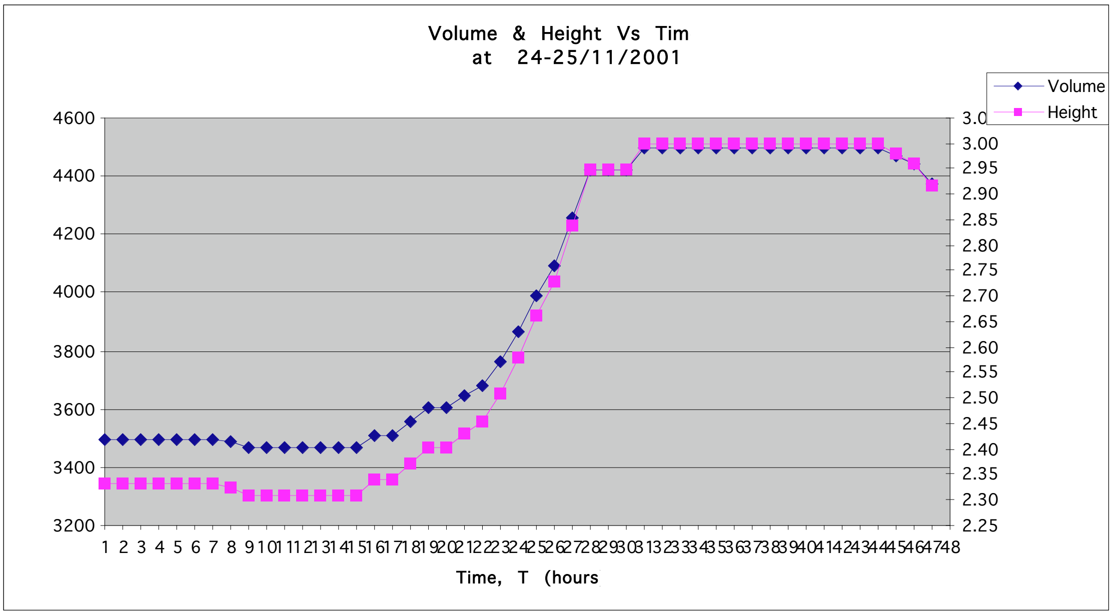

Figure 4.23: Volume & Height of the Upper Reservoir Vs Hours During 24/11/01-25/11/01

4.3 Discussion

The turbine will produce the power the ecovillage needs according to the head. We managed to have small flow rate of water in the pipe with high values of efficiency which this means less losses in the pipes. Hence, in the case of future expansion of the ecovillage we will be able to have bigger power values without needing to replace any of the parts of the system except maybe from the turbine. The volume of the water in the reservoir is sufficient to run the turbine, but a bigger reservoir might be needed in order to run the turbine for longer. The main problem is that we have to build a lower reservoir for collecting the water and precautions must be taken in order not to affect the aesthetics of the ecovillage. In addition, a selection site for this reservoir must be chosen carefully. A first thought was to use the river as the lower reservoir and then pump the water to the upper reservoir but that was not possible due to the fact that the river is environmentally protected.

For driving the water from the lower reservoir to the upper reservoir a pump is needed. In order to choose the appropriate size of the pump many characteristics such as the velocity of the water in the pipe and the pipe diameter which will give us the flow rate must be taken into mind. As we have mentioned above, for small flow rate, a small power input is needed but the time that is required to transfer the water up will be increasing.

The whole hydropower system is going to work only as a back up system for the non-windy days. A wind turbine will be installed to provide the power that is needed. During the days that the power is produced by the wind turbine it will be plenty to cover the needs of the ecovillage, the remaining of the power will operate the pump for driving the water to the upper reservoir. We have chosen a sixteen-day period, summer (06/06/01 - 21/06/01) and winter (20/11/01 - 05/12/01), during which the ecovillage will operate properly with the combination of the wind turbine and the micro-hydro power station. As we have already mentioned the wind turbine will operate only at wind speeds above 4m/s. This is not always achievable as it is observed at the wind data of 2001 at figure 4.24. There are many periods throughout the year when the wind speed is less than 4m/s hence, the wind turbine will not produce any power for the ecovillage as well as for the pump. So, the upper reservoir might empty after a few days and the ecovillage to stay out of power.

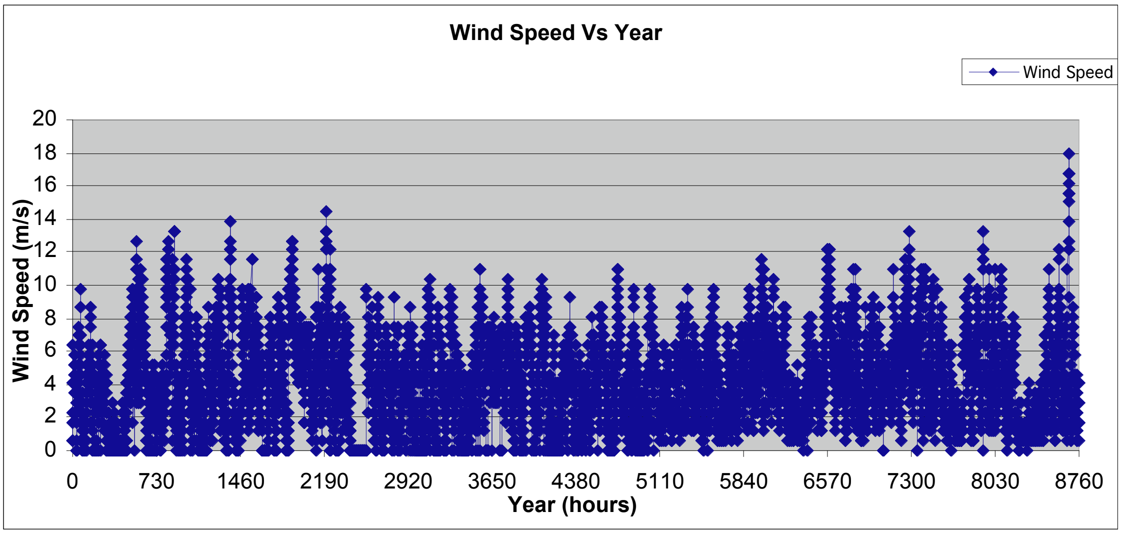

Figure 2.24: Wind Speed Vs Year

In order for the graph to be more viewable we chose to present the wind speed during the period 08/12/01 – 19/12/01, at figure 4.25. This is a winter period when people usually spend the most of their day and night inside the house because of the cold days and a big amount of power is required to cover their needs. According to that figure the ecovillage will run out of power for a period of 11 days. This is when we faced a big problem; for this main reason other renewable energy sources are required as well in order to be used for a back up energy supply system.

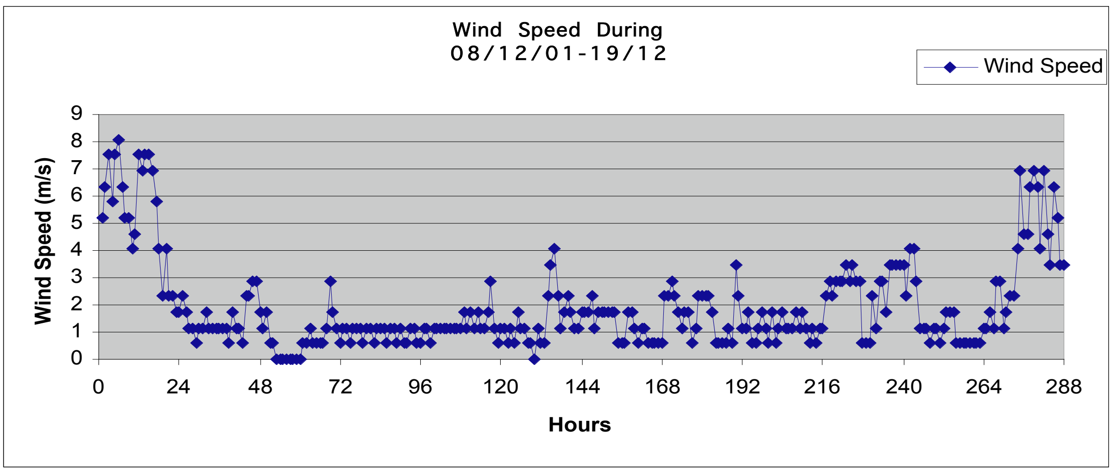

Figure 2.25: Wind Speed During 08/12/01-19/12/01

Chapter 5

5.1 Conclusion

The aims of this dissertation, which were pronounced in chapter one, have been accomplished successfully. A broad study of the three renewable sources of energy, solar, wind and hydro has been presented. As it came out from the research all three sources of energy can be used to provide energy to the fifteen households, the community house and the visitors/education centre at the ecovillage at Tweed Valley.

The total energy that the ecovillage requires in order to operate successfully has been calculated at 130,000kW-hours/year which is average approximately 15kW.

The total energy that the ecovillage needs during both summer and winter, is presented at the figures 5.1 and 5.2 respectively.

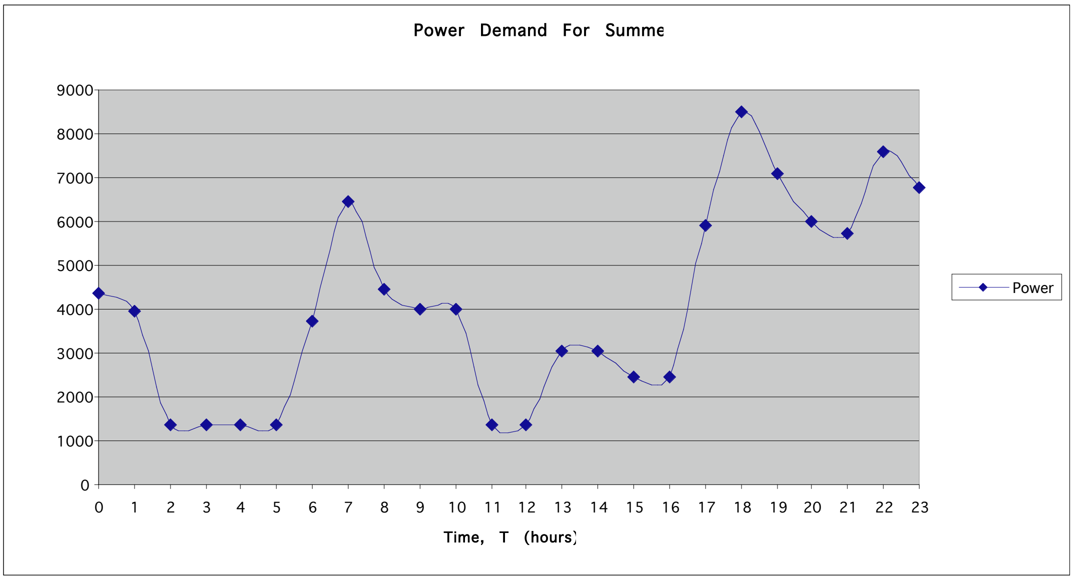

Figure 5.1: Power Demand of the Ecovillage during the summer

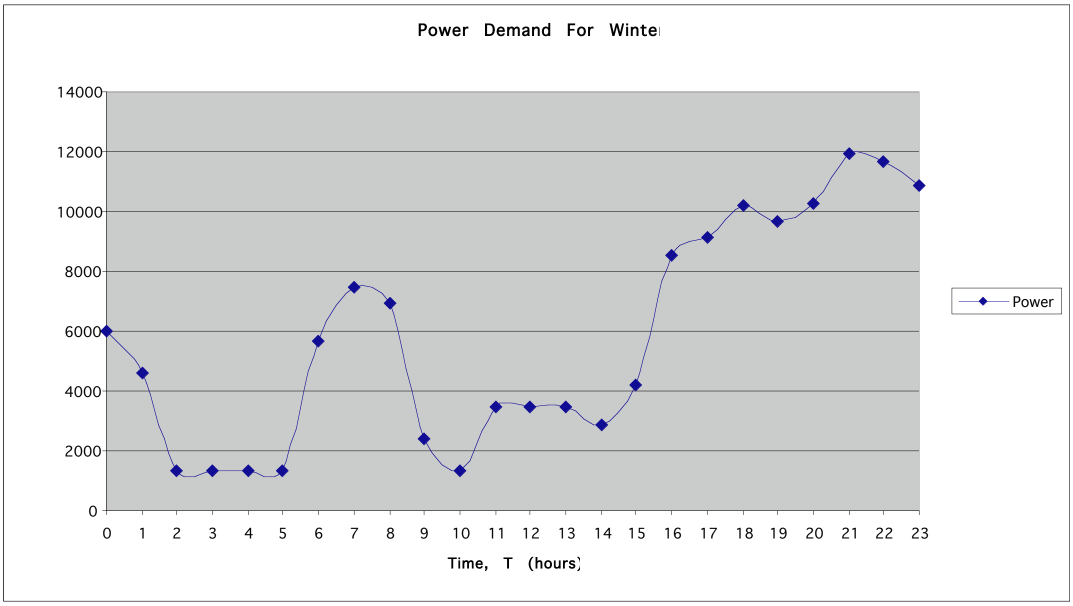

Figure 5.2: Power Demand of the Ecovillage during the winter

In order to provide the amount of the power that the ecovillage requires, a wind turbine is going to be installed. For the non-windy days as well as a micro-hydro power station is going to operate as a back up system.

Both figures 5.3 and 5.4 present the power that the wind turbine can produce for the ecovillage during the chosen periods, according to the wind data of the year 2001 which it was one of the non-windy years.

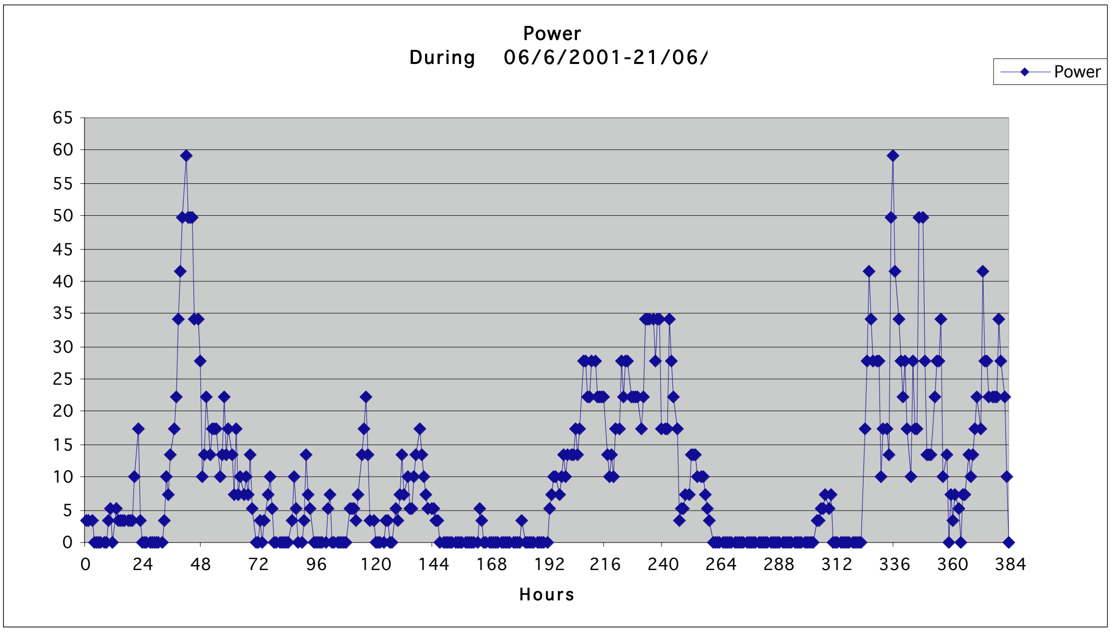

Figure 5.3: Power from Wind Turbine During 06/06/01-21/06/01

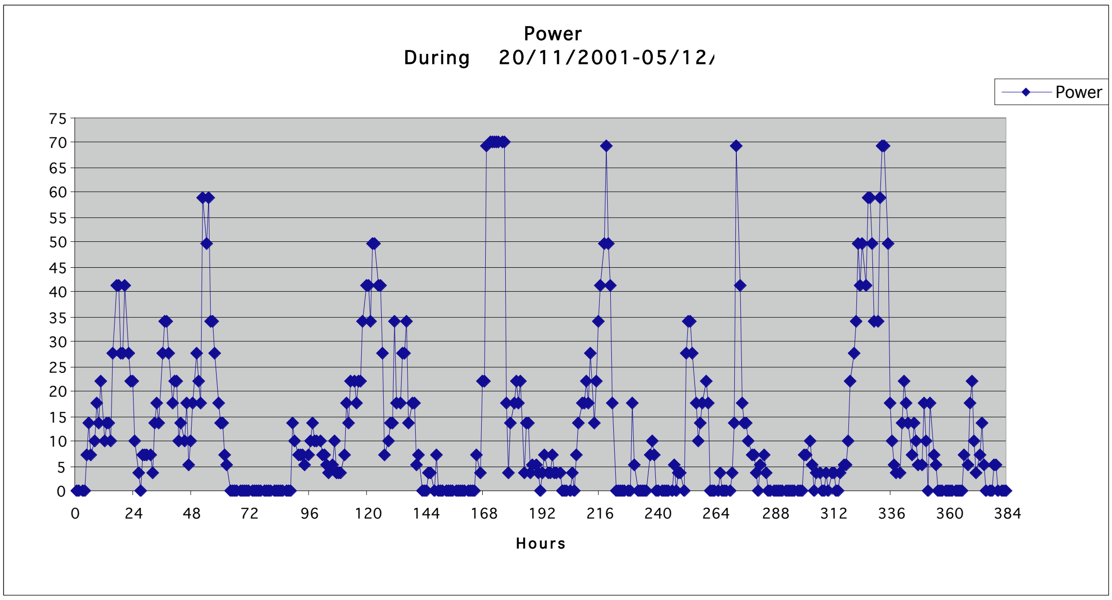

Figure 5.4: Power from Wind Turbine During 06/06/01-21/06/01

The power that the water turbine has to produce in order to meet the ecovillage's requirements was calculated at 24kW. The figure 5.5 shows the flow rate and the efficiency according to different pipe diameters against the head.

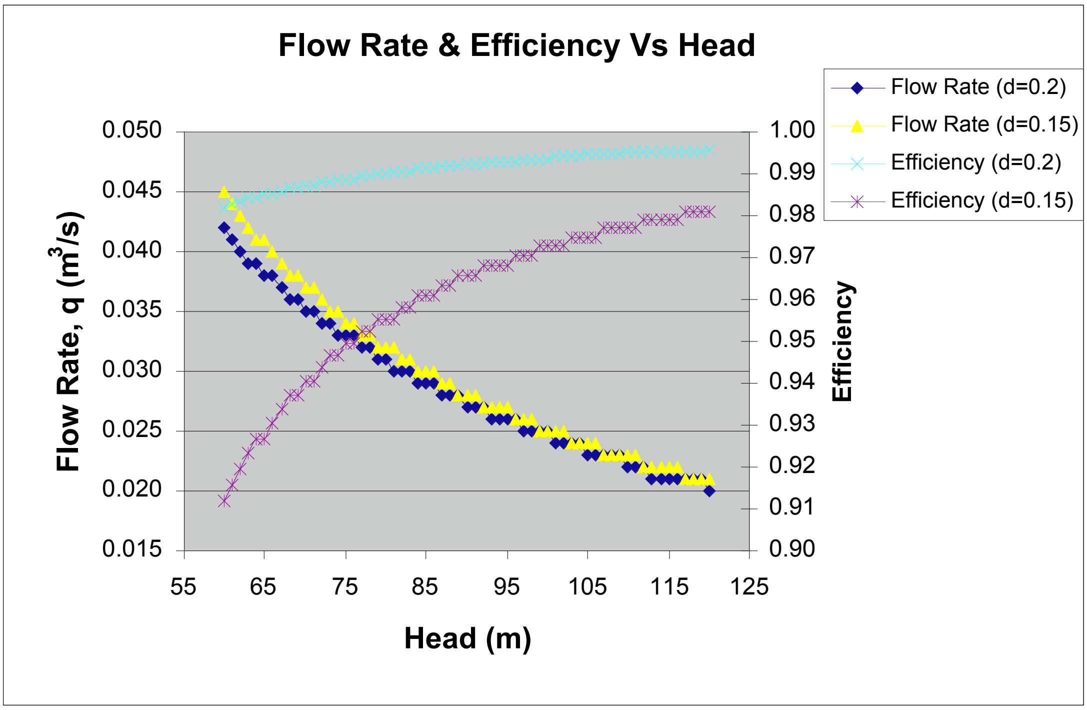

Figure 5.5: Flow Rate & Efficiency Vs Head

The volume of the water of the upper and the lower reservoir is 4500m^3 each.

The figure 5.6 presents the water speed and the time at different pipe diameters that the upper reservoir needs to empty against the head of the site.

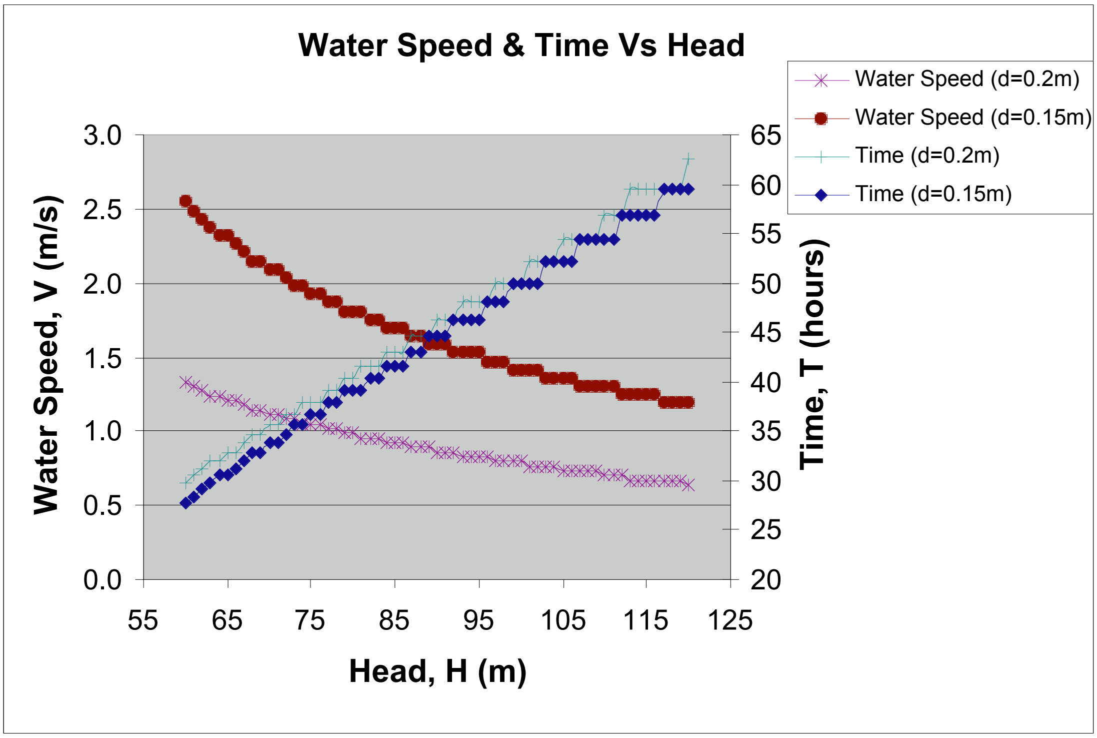

Figure 5.6: Water Speed & Time Vs Head

It would be better to use a bigger reservoir because during the non-windy days the micro-hydro station will provide power to the ecovillage for a longer period of time.

In order for the reservoir to fill again with water a need of a pump is required to drive the water up to the upper reservoir from the lower reservoir. This process is going to take place when the wind turbine is producing plenty of power for the ecovillage. So, the remaining of the power will be used to pump the water up.

The power and the efficiency of the pumps according to different sizes of the pumps against the head are presented at the figure 5.7.

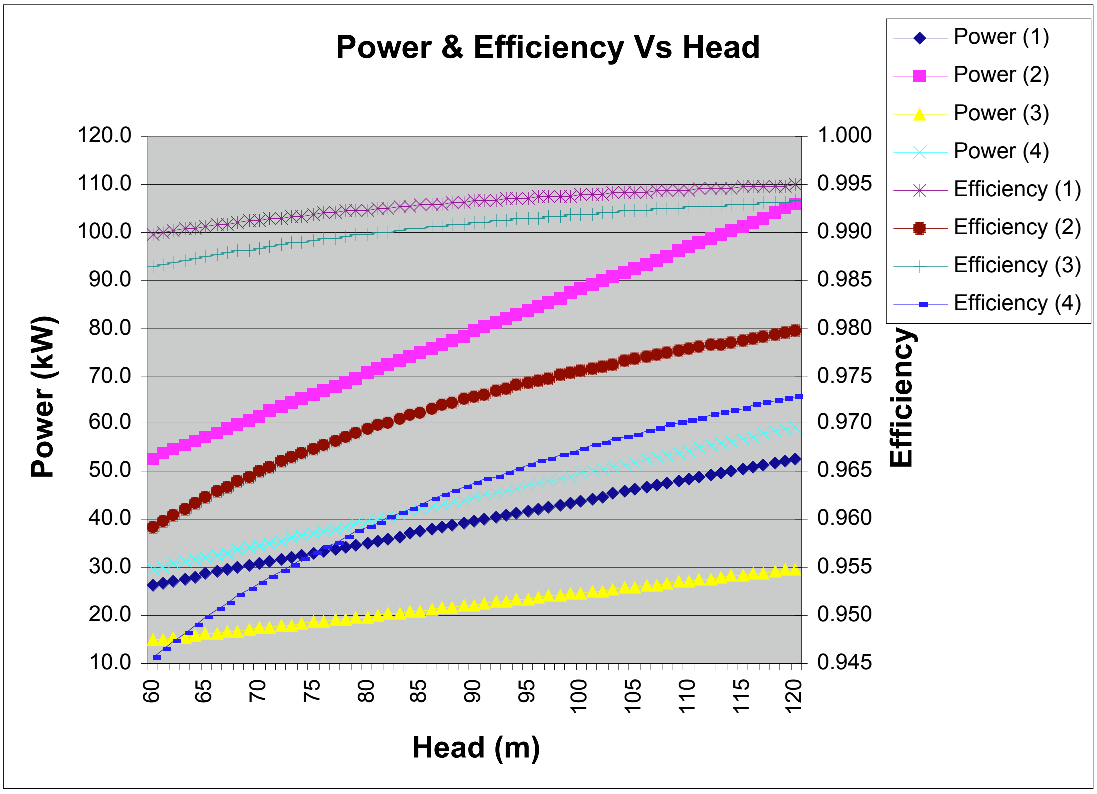

Figure 5.7: Pump Power & Efficiency Vs Head

When the power that the wind turbine produces is not enough for the needs of the ecovillge, the water turbine will cover the remaining power that is required by releasing water down from the upper reservoir. But as we have discussed before when the power from the turbine is plenty the remaining power will pump the water up. Figure 5.8 and figure 5.9 present the changes of the volume of the upper reservoir and the height of the water in it, against the sixteen days period during the summer and the winter.

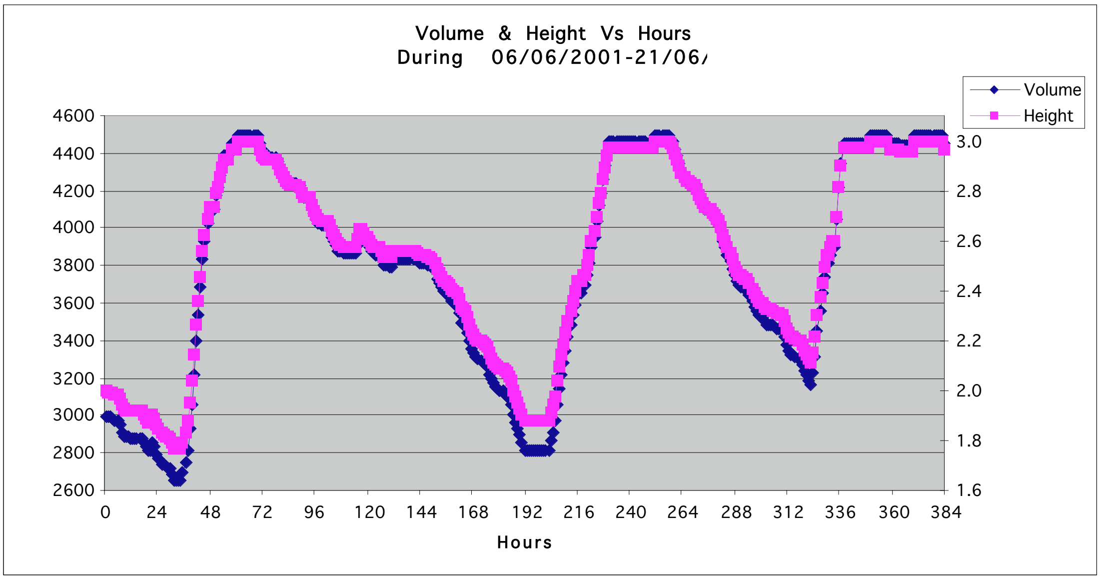

Figure 5.8: Volume & Height of the Upper Reservoir Vs Hours During 06/06/01-21/06/01

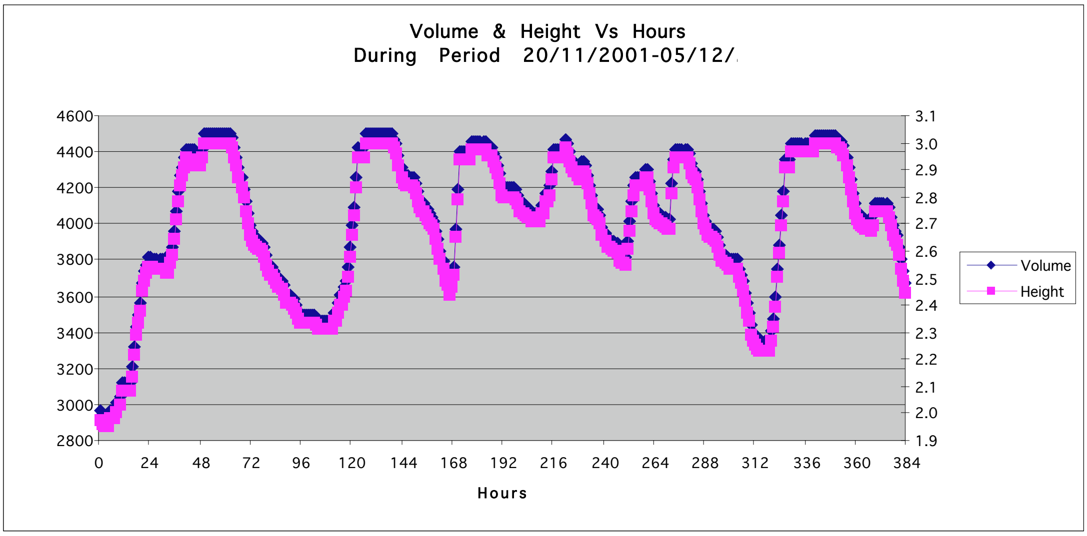

Figure 5.9: Volume & Height of the Upper Reservoir Vs Hours During 20/11/01-05/12/01

There are a number of days throughout the year that the wind speed is less than 4m/s and the wind turbine does not operate at those low ranges of wind speed, as figure 5.10 shows.

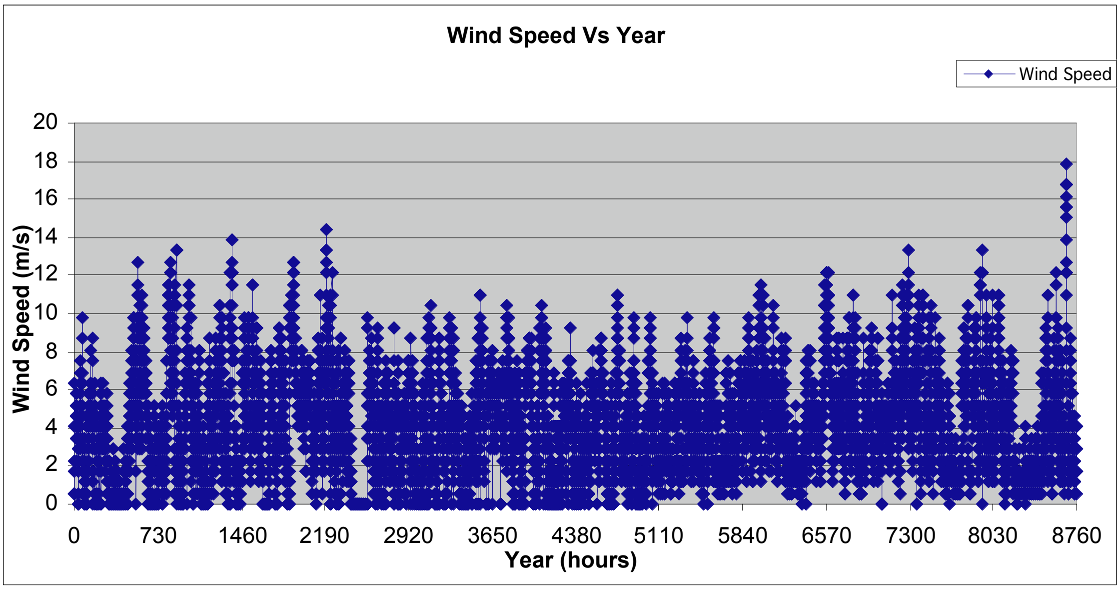

Figure 5.10: Wind Speed Vs Year

In occasions like that the micro-hydro power station will provide the power needed for the ecovillage but after a period of days the upper reservoir will empty and the ecovillage will stay out of power. For this main reason other renewable energy sources are required in order to be used for a back up energy supply system.

If the ecovillage is successful and manages to produce a totally sustainable community, which can withstand alone without any power from the grid, it will attract quite a number of curious tourists, companies and enterprises. It would therefore contribute to the economical development of the area, even if it is a small community at the beginning. The community could be extended in the future, if the first one is successful.

The results of this research might have been slightly different if the wind data was coming from the exact location of the proposed ecovillage. However, due to availability problems the wind data comes from Bishopton, Glasgow. That was the only problem faced throughout this research.

Having completed this dissertation I am convinced of the benefits of using renewable sources of energy for building new communities based on sustainable development.

5.2 Recommendations

Before any project development the families who are going to live at the ecovillage must be well informed by the construction company and by the environmentalists about the kind of systems, which are going to be installed as well as the greenhouse effect and any other environmental impact that may occur.

The right head of the lower reservoir has to be decided and its location as well as the location of the water turbine and the generator in order to get more accurate values of water flow rate. Attention should be given at the location of the wind turbines to get the maximum wind speed. If the wind data of the area is known, then the wind turbine power output can be calculated more accurately.

It would be of great interest if we estimated the power that the photovoltaic panels can produce especially during the winter. Furthermore, a future research could be that of finding out whether the combination of the wind turbines and the photovoltaic panels would provide the ecovillage with the exact energy, which is needed to operate successfully.

In addition, a cost analysis of the whole project should be done.

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Appendices

At the same CD-Rom there are all the excel spreadsheets that have been produced during this thesis as well as graphs and calculations.

<u>List of Excel Spreadsheet</u>

1. Flow Rate

   At this spreadsheet are presenting the flow rates of the water for the water turbine and the pump according to different pipe diameters. Also there are graphs for both water turbine and pump.

2. Maximum Power

   This spreadsheet presents calculations of the maximum power that the water turbine and the generator can produce. Also shows the runner speed and the flow rates of the water in the pipe.

3. Power Demand for the Ecovillage

   This spreadsheet shows the power demand that the ecovillage needs according to the domestic applications in order to operate successfully during the summer and the winter. Also graphs are presenting as well for each both seasons.

4. Wind Speed

   This spreadsheet presents the wind data of the whole year 2001 at Bishopton, Glasgow. Also present calculations of the power that the wind turbine can produce to the ecovillage and to the pump, in order to pump the water to the upper reservoir when the power is plenty, according to that wind data. Calculations have been done as well for the power that the water turbine has to produce in order to cover the needs of the ecovillage when the power from the wind turbine is not enough. At the end calculations of the flow rate of the water has been done and the changes of the volume and the height of the upper reservoir have been made.