Community development projects for the supply of heat and electricity from renewables in the Isles of Barra and Vatersay

By SESAM students 2009:

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Executive Summary

Castlebay

The project focused on the viability of a District Heating System (DHS) for a cluster of 80 households, Public and commercial buildings in Castlebay. Our survey established that the houses have an annual average heat demand of 12,386kWh/household. The annual heating demand for all households is 991 MWh. The annual heat consumption for public buildings is 3850 MWh with the Castlebay community schools being the biggest consumers of heat, contributing 85% of the annual heat consumption for public buildings.

The overall heat consumption of the area is 4.841 MWh/ year. To meet this demand, the supply options of using Biomass, Wind or a combination of both resources were considered. A wet bound system was considered for both options. Due to unavailability of biomass within Barra we considered sourcing the same from Sleat or Knoydart at a cost of 117 pounds per tone.

On power generation from wind, the nearest possible location for the wind turbine is Carnan, about 5 km away from the project area. The total cost of putting up 11kV, 5km long transmission line to deliver the power generated will be £125,000 (£22/meter).

The piping network of the district heating system (DHS) will be 2650 metres long. Utilization of the existing utility line for water will provide a chance for reducing the pipeline installation cost. The total cost of the piping (including trenching and refilling) will be 847,960 pounds.

Two supply options were analyzed; biomass for base load and oil for peak load and, wind for base load and oil for peak load. The heat supply options were analyzed under the following assumptions: 2.5% inflation rate, 8.0% discount rate and 20 years project life

A tariff of 4.4 pence per kWh was analyzed. This tariff is about 25% lower than the current heat tariff. Under this tariff, the wind-oil supply option with 50% subsidy is viable, with a simple payback period of 5.6 years.

A second option of 5 pence per kWh was also analyzed. Under this tariff option, the biomass-oil option is not viable either with or without a subsidy but the wind-oil supply option is viable in both cases with an annual profit of 171,943. With the subsidy the payback period is 4.7 years while without the subsidy the payback would be 9.4 years.

Therefore, the recommended option is the wind-oil boiler hybrid option. This option would save 1896 ton CO_2/year.

Vatersay

The project focused on the feasibility of a DHS for a cluster of 20 houses in the Am Meall area. The clusters of houses were found to have an annual average heat demand of 15,418 kWh per household. Overall the considered study area has an annual energy consumption of 309 MWh for heating. This figure was used to assess supply options.

A water bound system was considered for both biomass and wind systems. The biomass option utilizing wood fuel as feedstock was found not to be feasible due to the high initial investment cost needed and no income from renewable energy obligations (ROC). This system would only become viable with full subsidy. The investment for a water bound system running on wind power was similar to the biomass option. Though ROC's are available for this option, it would only become viable at rates higher than the present heating tariff (5.9 p/kWh)

Wind2heat technology was assessed for three different wind turbine capacities (50 kW, 20kW and 2x20kW). For business opportunities comparison between the different supply options, the heating tariff was set at 2.5p/kWh. The most feasible option considering a 20 years project life, 8% discount rate and 2.5% inflation rate was the single 50 kW turbine option. The project would yield £2,944 annuity, with a net present value (NPV) of £28,902 and an internal rate of return (IRR) of 15%. Higher returns from the £95,500 (at a 50% grant scheme) investment can be achieved by setting the tariff to rates closer to the present heat tariff. This option would save 98 ton of CO_2/year and overall lifetime savings of 1,958 ton CO_2.

For successful development of this option (Wind2heat), further R&D efforts have to be undertaken to develop an innovative control system

Barratlantic Fish Factory

The project aimed at assessing the possibility of meeting part of the energy demand of Barratlantic Fish and Shell Fish Processing Company limited using wind energy. The company uses electricity mainly for cooling, production of ice to chill the fish, processing of the fish and to smaller extent running the workshop equipment. Other uses involve office and canteen, space and water heating.

The study established that the cold store consumes about 39% (228MWh/year) of the total energy demand, 591.47MWh/year, of the factory. Although the blast freezer contributes to the high peak load, its annual energy demand is less than that of the cold stores since it only operates for few hours/day as compared to the cold stores which run for 24 hours/day.

While both supply options considered were found to be technically feasible, the first option (80kW) wind turbine would be more financially viable than the 160kW turbine. With an estimated total investment cost of £98,718, a Grant of £100,000 and ROCs factored, this option would generate an annual profit of £10,566 with a payback period of four 3 years. The factory would save £ 3,900 on their electricity bills.

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ACRONYMS

AEA	AEA Energy & Environment
AGL	Above Ground Level
B-C	Benefit Cost
BP	British Petroleum
CB	Circuit Breaker
CBAB	Coimhearsnach Bharraidh agus Bhatarsaidh Limited (Barra and Vatersay Community Limited)
CO_2	Carbon Dioxide
DAAD	German Academic Exchange Service
DEFRA	Department for Environmental, Food and Rural Affairs
DH	District Heating
DHS	District Heating System
DN	Diameter Nominal
DTI	Department of Transport and Industry
HDD	Heating Degree Days
HH	Households
HHP	Hebridean Housing Partnership
IC	International Classroom
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
KAAD	German Catholic Academic Exchange Service
NEG	Neg Micon, USA.
NHS	National Health Service

NPV	Net Present Value
O&M	Operation and Maintenance
R&D	Research & Development
RET	Retscreen Software
RHG	Renewable Heat Group
ROC	Renewable Obligation Certificate
SEEM	Saving Energy, the Environment and Money
SESAM	Sustainable Energy Systems and Management
UK	United Kingdom
USA	United States of America
VFD	Variable Frequency Drive

LIST OF UNITS

£	pound (British)
°C	degree centigrade
hrs	hours
kg	kilogram
km	kilometre
km^2	square kilometre
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
ltrs	litres

m	metre
m/s	meters per second
m^2	square metre
m^3	cubic metre
MJ	mega joule
mm	millimetre
MWh	megawatt-hour
p	pence (British)
t	tonne
yr	year

1. Introduction

1.1. Purpose and Background of the Study

The purpose of this study was to assess the technical and economic potential of supplying electricity to the Barratlantic Fish factory and heat to a cluster of households, a school, a hospital and other facilities in Castlebay and Vatersay areas. In the former case the possibility of using wind energy to supply electricity was analysed and in the later case, the possibility of supplying heat from wind and biomass resources was analyzed.

The study was conducted in collaboration with the Barra and Vatersay Community Ltd whose interest was to assess the business potential of investing in the aforementioned renewable energy supply options. Furthermore, the study was undertaken as a fulfillment of part of the requirements of the University of Flensburg for the master's programme in Sustainable Energy Systems and Management (SESAM). In this regard, a total number of eight students, under the supervision of their lecturer conducted the study. The study provided the students with a platform not only to put into practice the theoretical knowledge obtained during one year of classroom work in German, but also to prepare for undertaking of the individual work on master thesis.

The study area was suitable for this study because the area is rich in renewable energy resources, specifically wind energy, and therefore provided an ideal learning environment which would enable the students to apply the knowledge and skills acquired in their own countries.

Map of the study area. Source: Google Earth, 2009

1.2. Study Objectives

The main objective of the study was to identify business opportunities for the Barra and Vatersay Community Organisation in the field of renewable energy. The study was guided by three specific objectives as high-lighted below:

i. Elaborate suggestions on possible sources of energy for heating of Horve area, Castlebay from biomass, wind, and waste resources.

ii. Give suggestions on how to meet the heat demand of cluster of house-holds in Vatersay from wind power or biomass

iii. And finally assess the potential of wind power in meeting the electricity demand of the fish factory at Aird Mihdhinis.

1.3. Methodology of the Study

For the fish factory the information was collected through face to face interviews with the technical staff. The face to face interviews also included talking to other people from relevant organisations such as the Castlebay and Vatersay community organisation, Scottish and Southern Energy, School, Hospital and Learning Centre administrators among others. For Castlebay and Vatersay, the main method used for data collection was questionnaire interviews. In Castlebay, most of the questionnaires were filled in by the respondents themselves while in Vatersay the respondents also had face to face interviews with some of the study team members.

1.4. Literature Review

The literature review involved review of reports of studies, maps, standards and other relevant literature. The study reports used in this study include the "S*aving Environment Energy and Money*" (SEEM) report (2008) and West Coast Energy Ltd report (2006) on *Barra And Vatersay On-Shore Wind Energy potentia*.

Barra and Vatersay maps from Scottish Water Company were used to map the pipeline network supply line. Soil map from national mapping agency of Great Britain was used to analyse the land formation for the district heating pipeline network.

Equipments technical specifications such as power curves for the turbines were obtained from relevant websites of the manufactures such as Vestas and Enercon

1.5. Structure of the Report

Chapter one of the report deals with the background, the purpose, the methodology, and the limitations of the study. In Chapter two the district heating project in Castlebay is dealt with and gives the present heating situation, energy demand and the supply options considered to meet the heat demand. Chapter three deals with the District Heating in Vatersay and includes an assessment of the present heating demand and the possible supply options. Chapter four discusses the assessment of the electricity demand for the fish factory and the possibility of meeting the demand from wind energy. Lastly, Chapter five presents the conclusions and recommendations of the study.

2 District Heating in Castlebay

2.1 Introduction to the Project

A district heating system is a centralized system for supplying heat (for space heating and hot water production) to a group of buildings. In a typical DHS a central boiler heats water which is then pumped to the buildings through an insulated pipe network. In the buildings the heat energy is transmitted to water bound heating system through a heat exchanger. The main advantages of DHS compared to the individual space heating are not only a constant heat supply and comfortable temperature compared to electrical heating, but also the fact that renewable energy sources, such as woodchips, which would not be feasible for individual heating systems, can be used. For the economic feasibility of such a system a high heat demand, concentrating on a small area is decisive to keep the distribution cost low.

Horve area, Castlebay has a high concentration of households clustered together and therefore offers a good opportunity for a district heating system (DHS). Besides heat supply to households, the presence of large heat consumers such as the School, swimming pool, and hospital, which are all close to the residential area, provides significant demand for heat energy. Even though the heat demand is relatively lower in summer, the swimming pool still requires a relatively high amount of heat which can considerably improve the economic feasibility of the project.

This project concentrates specifically on the feasibility of a DHS for Castlebay using renewable energy. Wind energy and biomass are the main energy resources for DHS investigated.

2.2 Present Heating Situation

2.2.1 Households

A total of 80 questionnaires were distributed within Horve area through hand delivery and post. Feedback was received from 37 households representing 44% of the total questionnaires distributed. Therefore, the findings on the households in this area is extrapolated to the 80 households and also backed up with information from the planning report "Barra and Vatersay Local Plan"1.

[1] Barra and Vatersay Local Plan, Western Isle Council, May 1996

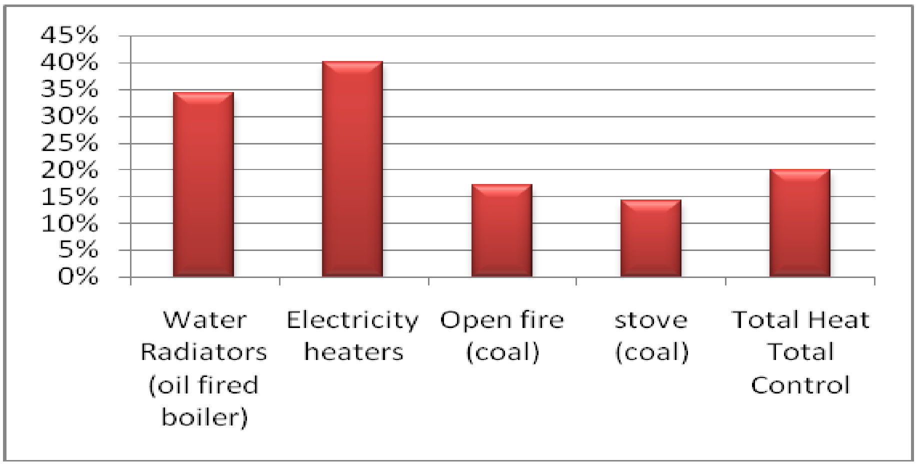
Of the houses surveyed 46% are council owned, 43% privately owned and 11% privately rented. The houses were constructed between 1908 and 1997. 10 houses of the 37 that returned the questionnaires have undergone renovation works within the last five years. The renovations done were mainly cavity walls filling and installation of double glazed windows and doors to improve heat insulation.

Majority of the houses in Horve are semi-detached (49%), followed by detached (34%) and the rest are terraced. This share covers the entire 80 households in the study area.

Space heating system

From the survey the following five different types of space heating systems were identified: water radiators, electrical heaters, open fire, stoves and total heat total control system. The share of different systems is described in figure 1.

Figure 1. Types of space heating system



Source: Authors

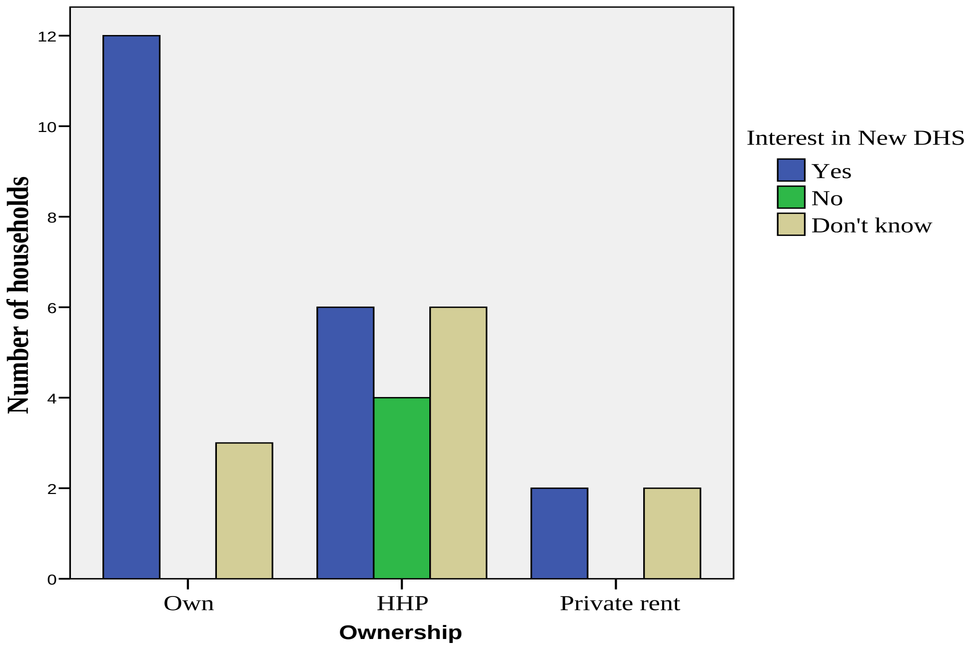
The survey shows that 60% of the households use electricity for heating whereas 34.6% and 33.5% used oil and coal respectively. Some households use a combination of two or more types of heat sources. These percentages have been extrapolated to the 80 households under the study.

Water Heating Systems

Of the 35 houses surveyed, 28% use both immersion and instantaneous water heater, 44% use instantaneous heater and central heating system, and 28% use central heating only.

The survey also showed that 57% of the respondents would be interested in connecting to a new District Heating System. This is more so among private house owners as shown in figure2. Some of the reasons advanced for the interest were that the existing heating system is quite expensive and slow. Moreover, 31% of households are willing to pay from 1000 pounds to 2000 pounds for investment cost to be part of the new system.

Figure 2. Interest in Connecting to a new Heating System



Source: Authors

2.2.2 Public and Commercial Buildings

2.2.2.1 Hospital

The hospital has a total of 15 bed rooms (5 bedrooms in the Hospital side and 10 bedrooms in the home for the elderly). The hospital has 19 staff members who work in three shifts (10 works from 0730 to 1600hrs, 5 from 1600 to 2130 and 4 from 2130 to 0730). The hospital is administrated by the Western Isle Council and the National Health Services (NHS). The heating system in the hospital is supplied by 2 boilers of 120 kW each. The boilers are about 30 years old and they operate 24 hours a day, 7 days a week. According to the maintenance staff, there is an intention to replace the boilers by May this year. The hospital has 49 radiators. Hot water is supplied at 60^{o}c temperature and returns at around 42^{o}c. The total heated area of the hospital is about 860m^{2}. Total annual oil consumption amounts to 42,480 liters. The hospital management usually makes special contracts with oil companies like BP hence paying lower than the average market rates, in the range between 25 to 30 pence per liter. The NHS and the Council jointly pay this bill.

2.2.2.2 Children Centre/Café

The center was constructed in 2002 and it operates 60 hours a week. The heated area of the center is 305.64 m^2 and is heated by a central oil boiler. The boiler consumes approximately 3550 liters of oil annually with its thermal power output ranging from 21.6 to 40.6 kW.

2.2.2.3 Learning Center

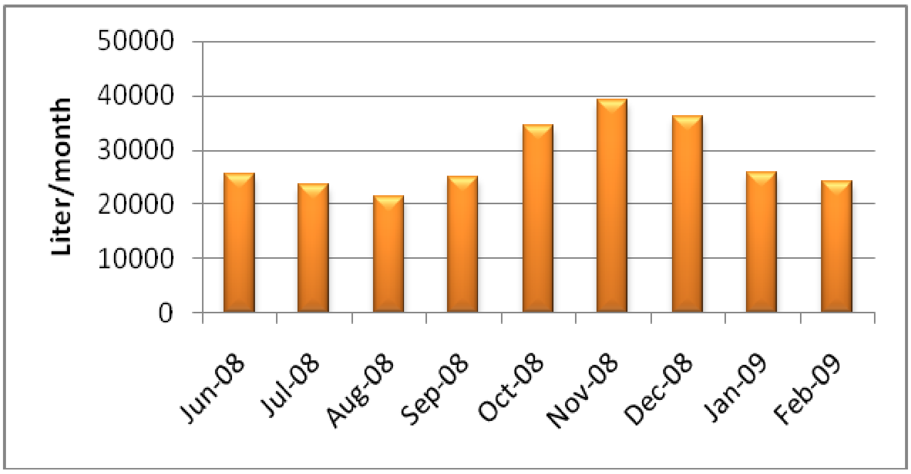
The average heated area of the learning center is 260 m^2 and the system operates throughout the year (8760 hours). The center has nine rooms all of them under-floor heated by an electricity driven heat pump.

2.2.2.4 Schools

The school survey was conducted through face-to-face interview as well as inspection of the installed infrastructure (heating system and classrooms). The school includes primary and secondary levels as well as one swimming pool. The schools use oil-fired boilers for its heating. There are four boilers in total; one for primary school and the rest are for secondary school and swimming pool. The primary school boiler is stand alone, meeting the entire heat demand of this section of the school. The other three boilers work in parallel to supply the heat demand of the secondary school and the swimming pool area. Normally, only two boilers run at the same time, the third boiler only fires when there is high heat demand especially during winter time.

The boiler operation data such as oil consumption, operation status, heat generation and temperature setting are monitored in the Western Isle Council headquarter-Stornoway. According to Mr. Donald MacSween, Principal Engineer, Comhairle Nan Eilean Siar, the monthly oil consumption is as presented in figure 3:

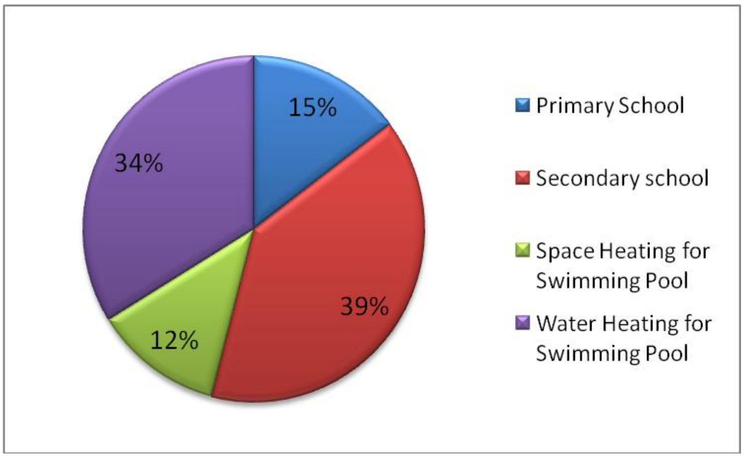
Figure 3. Monthly oil consumption of school



Source: Monitored data from Comhairle Nan Eilean Siar

Normally high consumption months are from October to March; but the graph show that in January 2009 oil consumption significantly reduced. This was as a result of the ongoing renovation works of the swimming pool. Considering that, according to the distribution of heating degree days, the demand in January should have been similar to December, we can assume that 10,243 liters which is the difference between December 2008 and January 2009 is the monthly oil consumption required to meet the heating demand for swimming pool space and water. To determine the oil consumption for space and water heating of the swimming pool, we assume that the heat demand for space heating in the swimming pool is the same as the primary school because of the similarity in the size of the areas. The share of the annual heat consumption for the schools and the swimming pool is illustrated in the following pie chart:

Figure 4. Share of annual heat consumption in the schools



Source: Authors

The above figure is explained in more detail in table 1 below:

Table 1. The heating system in the schools

No.	Description	Heated area	Oil boiler capacity	Oil consumption for heating
		M^2	kW	Liters/year
1	Primary school	867	150	39,138
2	Secondary school	2,773.6	3 x 266	105,167
3	Swimming pool area	722.00		32,592
4	Swimming pool	180		90,324

Source: Authors

2.2.3 Energy Demand

2.2.3.1 Household

From the survey, the average heat consumption per household is 12,386 kWh/year with an average heating index of 112 kWh/m^2/yr. The lowest heating index is 51.84 kWh/m^2/yr while the highest heating index is 400kWh/m^2. Extremely low heating indexes were mainly caused by frequent absence of the occupants. The average heat index from the survey, 112kWh/m^2/yr, is quite low compared with the average heat index, 197.09 kWh/m^2, for Scottish households as contained in the "Energy Issues for Scotland" Report (June 2006) [3].

[3] The Royal Society of Edinburgh. Inquiry into Energy Issues for Scotland. Final Report.June 2006 p. 67

The Scottish Government estimates the average heating index for Scottish households as 250kWh/m^2/yr[4]. In the SEEM report[5], the annual heating demand for households in the area was found to be 15,900kWh/HH. This figure is still higher than the survey finding, which is 12,386 kWh/HH. Possible reasons for the differences could be:

- In the study area a significant percentage of the people work away (sailing, fishing, oil industry) and they are seldom at home.
- Due to relatively lower income, some house occupants in the area hinted that they minimize on their heating duration so as to reduce their heating expense.

Table 2 below gives a comparison of different Heating Indexes according to the sources.

Table 2. Comparison of heating indexes of survey and other sources

Region	Heating Index kWh/m2	Source
Horve, Castlebay	113.3 kWh/m^2	Survey SESAM 2009
Barra and Vatersay	199 kWh/m^2	(Pendrey, 2008 p. 19).
Scotland	250 kWh/m^2	(Renewable Heat Group (RHG), 2008 p. 35)

Source: Author

2.2.3.2 Public Buildings

Table 3 below presents heating data for the public buildings in the area.

[4] Renewable Heat Group (RHG), 2008 p. 35

[5] Pendrey, 2008 p. 19

Table 3. The heating data of public buildings in Horve

Name	Area	Oil consumption	Annual Heat consumption	Heat index
	m^2	ltrs/yr	kWh/yr	kWh/m2
Primary School	867	39,138	422,690	487.53
Secondary school	2773.55	105,167	1,135,798	409.51
Swimming pool area (space heating)	722	32,592	351,998	487.53 (assumed)
Swimming pool (water heating)	180	90,324	975,495	n/a
Children center/Café	305.64	3,550	38,340	125.44
Learning center	260	use heat pump	10,500	40
Hospital	860	42,480	458,784	533.47

Source: Authors

The heat index of the learning center is quite low compared to other public buildings because they use a heat pump system. The high heat index of the hospital may be as a result of the low efficiency of the boilers which are almost 30 years old. The heating index for the schools and the swimming pools is high in spite of the fact that the boilers are only two years old. A professional energy audit would therefore need to be undertaken to identify the weaknesses in the building envelope and the possible improvements that can be made in the energy management of the building.

2.2.3.3 Expected future development of heat demand

According to the Scottish government9, between 1990 and 2002 there was a 12% increase in domestic energy consumption across the UK. The average temperature in homes also rose by 1.5ºC during the period between 1991 and 200010. On the other hand, this overall increase in demand has been counterbalanced by energy efficiency measures instituted.

[9] Renewable Heat Group (RHG), 2008 p. 17

[10] DTI (DEFRA), 2005

The annual heat demand per household from the survey was 12,386 kWh/HH. An average 250 kWh/m²/yr5 consumption per household per annum, as estimated by the Scottish government, would translate to a consumption of 20,000 kWh/HH5.

According to Scottish government fuel poverty data11, the Western Isles have an increasing fuel poverty trend in comparison to Scottish average. 50% of the Western Isles households were considered fuel poor in 2008. This can explain the difference in the annual heating demand. Fuel poverty has various causes such as low income, poor insulation of the house, expensive fuels and no access to centralized heating networks. In Horve, Castlebay, the low heating consumption is mainly caused by the cost of fuels and inconvenience of the existing heating system.

With implementation of a DHS in Castlebay the heat demand is likely to increase sharply during the first few years due to the change to a more comfortable and affordable heating system. However, energy efficiency measures will increase and this would lead to a decrease of the heat consumption to lower values than the present heat demand. Therefore it is assumed that the present heat demand of 12,386 kWh/HH will increase by 30% to reach 16,101 kWh/HH after installation of a DHS. This is because the households will get a more affordable and convenient heating system. The heat supply system needs to be dimensioned with these considerations in mind. In this study the average heat demand of 16,101kWh/HH is used to assess the different supply options as shown in figure 6: Heat index development for Horve, Castlebay.

For the public buildings, we assume the energy audit will be carried out and applied in 2010 for the schools. We can assume the heating consumption can be reduced by 10% in 2010 and continue decreasing after implementing more energy saving measures in the following years.

In the hospital, as mentioned before the heat index from the secondary energy input will be low. The efficiency of the current boiler can be around 40% to 50% only. Therefore, it is assumed that the heat index of the hospital decreases from 533.5 to 320 kWh/m2.

Figure 5.Annual Heat Consumption development for Horve, Castlebay

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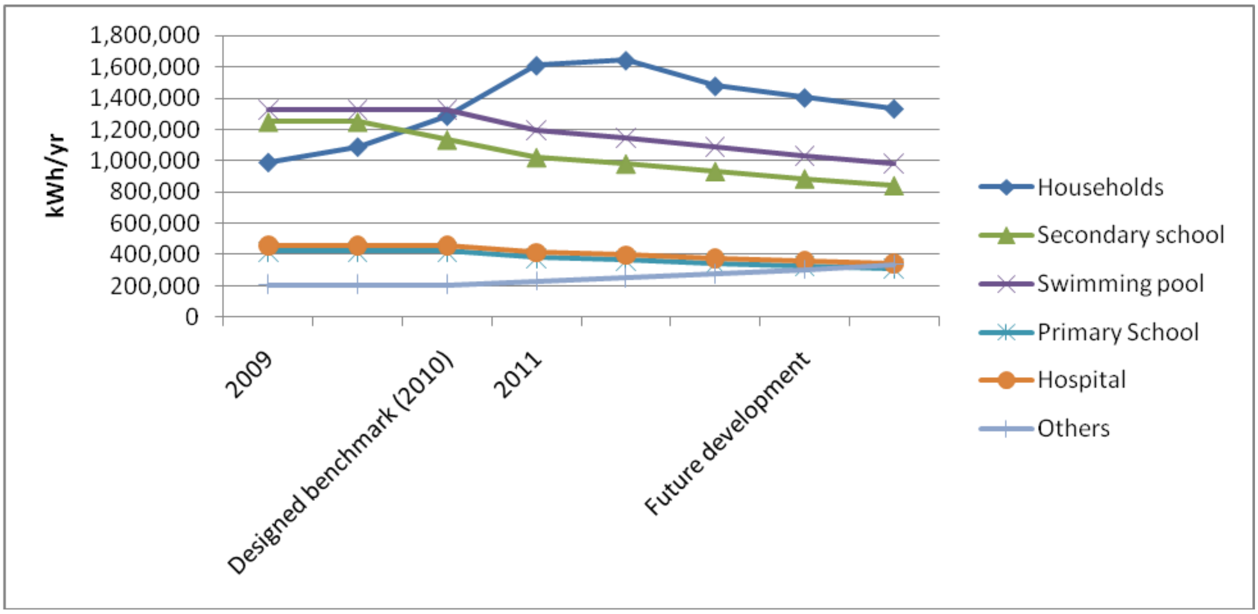
[11] Source: Compiled from (Comhairle nan Sair), WESTERN ISLES LOCAL HOUSING STRATEGY,ANNUAL REVIEW JULY 2008, FUEL POVERTY POSITION STATEMENT http://www.scotland.gov.uk/Topics/Built-Environment/Housing/access/FP/FPFORUMEVIDENCE101008, 14.11.2008

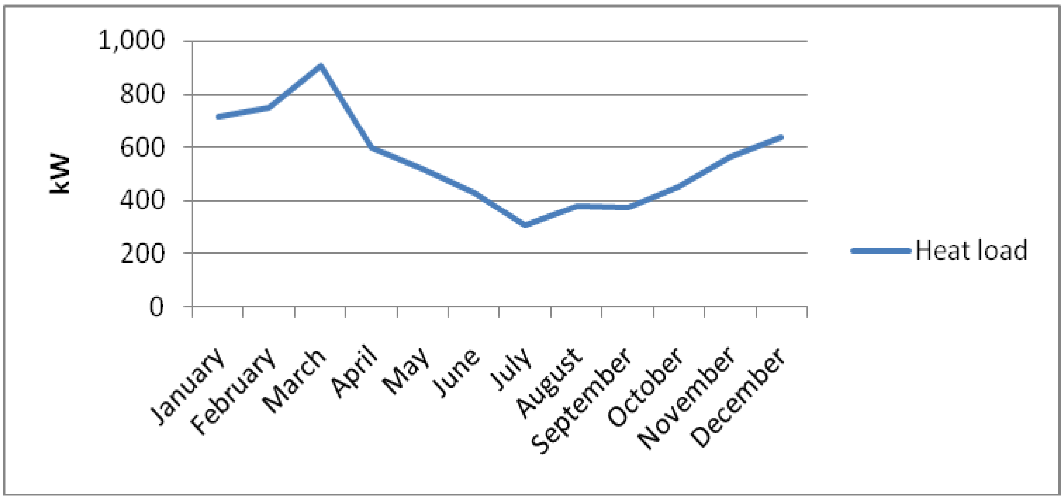


Source: Authors

The annual heating consumption profiles for Horve are shown in figure 7 and are based on the heating degree days (hdd) taken from Carbon Trust of the United Kingdom.

Finally the total annual heating demand of this area is 4,841MWh. This amount is also the total capacity of the DHS. Below is the design heat load curve for Horve area which was used to plan the DHS.

Figure 6. Heating load of Horve, Castlebay



Source: Authors[15]

From the heat load curve, the specifications of a DHS are:

[15] Using Retscreens software

- Base load: 305kW
- Peak load: 903kW
- Total annual heat production: 4,841 MWh.

2.3 District Heating Network

This consists of a network of pipes and sub-stations connecting the power plant(s) and the consumer (s) . The pre-insulated type consists of a steel carrier pipe with polyurethane foam insulation. The pipe and insulation is 'sealed' with a high density polyethylene outer casing that forms a protective barrier to external conditions.

2.3.1 Horve Piping Network

The piping network will be approximately 2650m long. Table 4 summarizes the different lengths and the diameters of the pipes that will form part of the DHS network.

Table 4 Summary of Piping Network

Pipe Nominal Diameter (mm)	Pipe Length (m)	Total pipe installation cost** (£/m)	Total Cost (£)
100	1500	362	**543,000**
65	110	294	**32,340**
50	150	274	**41,100**
40	60	262	**15,720**
25	830	260	**215,800**
Grand Total	2650		**847,960**

**Includes the cost double loop pipe per metre, bends, trenching and refilling costs.

Source: German Online database17

[17] http://www.nahwaerme-forum.de, 08.03.2009

Pipelines are installed either aboveground or underground. For underground installation there are two options, those directly buried in the soil and those encased in concrete tunnel. For Castlebay and Horve area in particular which is characterized by *peaty soils with the landform being rugged dissected lowlands*[18] considerable amount of work will be needed for underground piping.

Utilization of the existing utility line for water provides a chance for reducing the pipeline installation cost. We recommend the incorporation of the pipeline system within the current utility line wherever possible. This will help in saving costs since excessive primary trenching will be avoided.

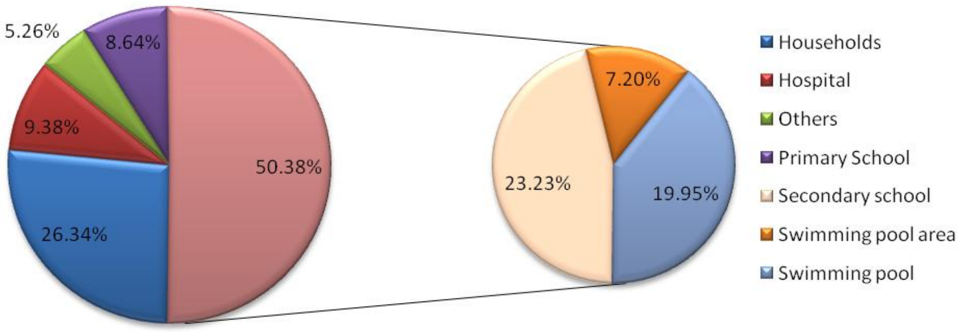
2.3.2 Substations

The proposed network will have three substations located at different points as Annex 2.5 shows. One substation supplies the schools, one the hospital and one all other consumers. The households will be supplied, applying a direct system as this is suitable for small networks and cheaper than the option with heat exchangers in the houses, explained in chapter 2.1. In a direct system all customers are supplied by one loop. The substations will separate the primary supply loop from the secondary and will be fitted with pumps, strainers and heat exchangers.

The heating network will include 80 households, schools, children centers/café, learning center, hospital and some small shops. Figure 7 below gives a breakdown of the heat demand:

Figure 7. The share of demand side in Horve, Castlebay

[18] Soil Survey of Scotland (The Outer Hebrides) describes the soil as being peaty gleys, peat, peaty rankers, and some peaty podzols. The landform is rugged dissected lowlands and hills with gentle and strong slopes and very rocky (The Macaulay Institute for Soil Research, Aberdeen Scotland)



Source: Authors

The supply design divides the total demand into base load (303kW), and peak load (903kW). It is also considered that the school, the learning centre and the hospital have their own boilers which can be used as back-up and for peak load supply. The supply options will cover the total heat demand through the use of biomass and wind resource. The operation principle of both biomass and wind based DHS is the same. In both systems, water is used as a heat transfer fluid and is circulated in a closed loop system (primary loop). Both systems consist of a central thermal storage tank of capacity of 390m3 designed for one autonomous day19. Table 5 gives specifications of thermal storage tank.

[19] The storage can store sufficient energy to provide for the demand for one days without it being recharged

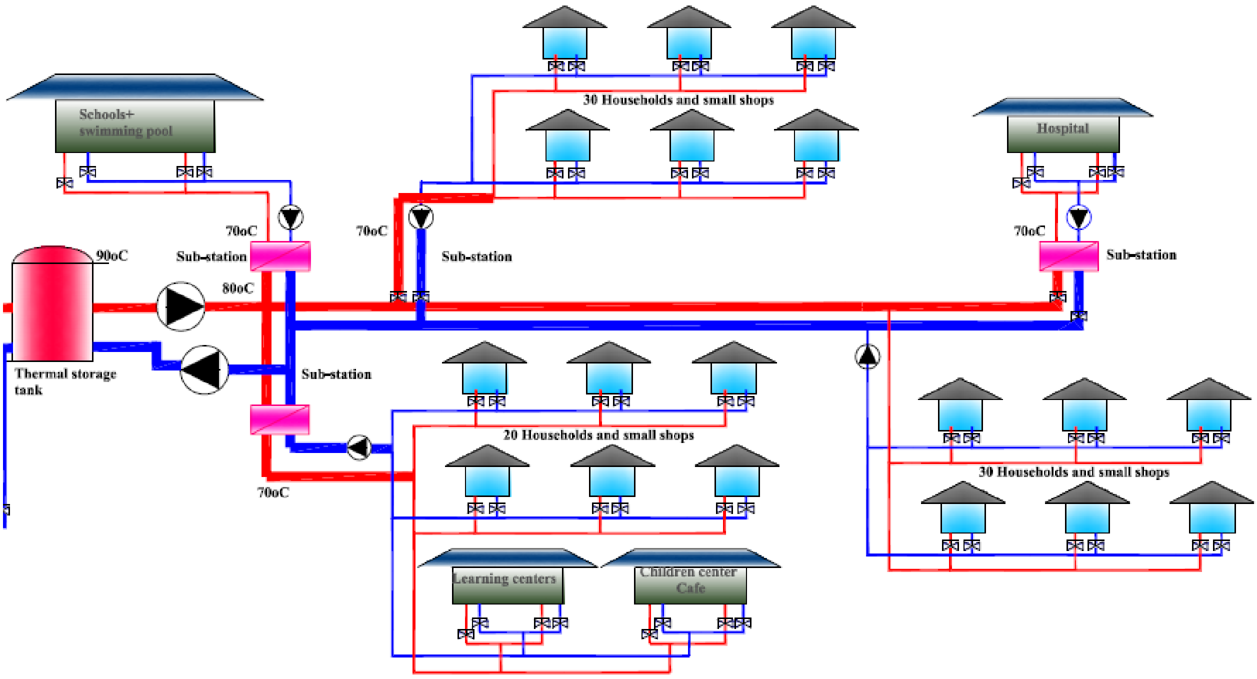
Table 5. Specification of thermal storage tank

Annual heat production	4,841	MWh
Storage capacity	13.3	MWh/day
Volume	390	m3
Diameter	10	m
Height	5	m
Area of storage tank	78.5	m2

Source: Authors

Based on the peak load requirement of the end-users, three substations are considered for each system. The heated water leaves the storage tank at a temperature range of 900C to 1000C where it is pumped through the main supply pipes to the different sub-stations. Within the substations (heat exchangers), the heat is exchanged over from the hot water to a secondary loop which contains the return water. The water in the secondary loop is raised to a temperature of about 700C and is circulated through the distribution pipes to the buildings where it flows through the radiators to heat the space. (Figure 11)

Figure 8. The DHS schematic of demand side in Horve



Source: Authors

Using thermal storage tank reduce the size of boiler system especially when using wind energy. The tank can store the excess wind power in the form of heated water

2.3.3 Wind Turbine Location

Based on the West Coast Energy Consulting Company report, the nearest potential site for wind turbine location is Carnan which is about 5 km away. The site has a wind speed of 11 to 12m/s. The other sites, Decca, Ardmhor and Greian are considered too far away. The cost of putting up 11kV, 5km long transmission line between the wind turbine site (Carnan) and the power plant sites, will be approximately £125,000 (at a rate of £22/m).

An alternative site is site 2 located in the area above Castlebay School. This site is about 150m and 320m away respectively from the two proposed sites of the power plant. From the wind map data by West Coast Energy report, this area has an average wind speed of about 9.5-10.0m/s annually. For the 150m distance, the transmission cost will be about £3,750, while for the 320m distance; the cost will be approximately £8,000.

Though this site offers low investment costs for the transmission line we do not to consider this site as careful analysis needs to be carried out to ascertain its suitability.

Figure 9. Google Map snap shot of Turbine Location Sites

Source: Author

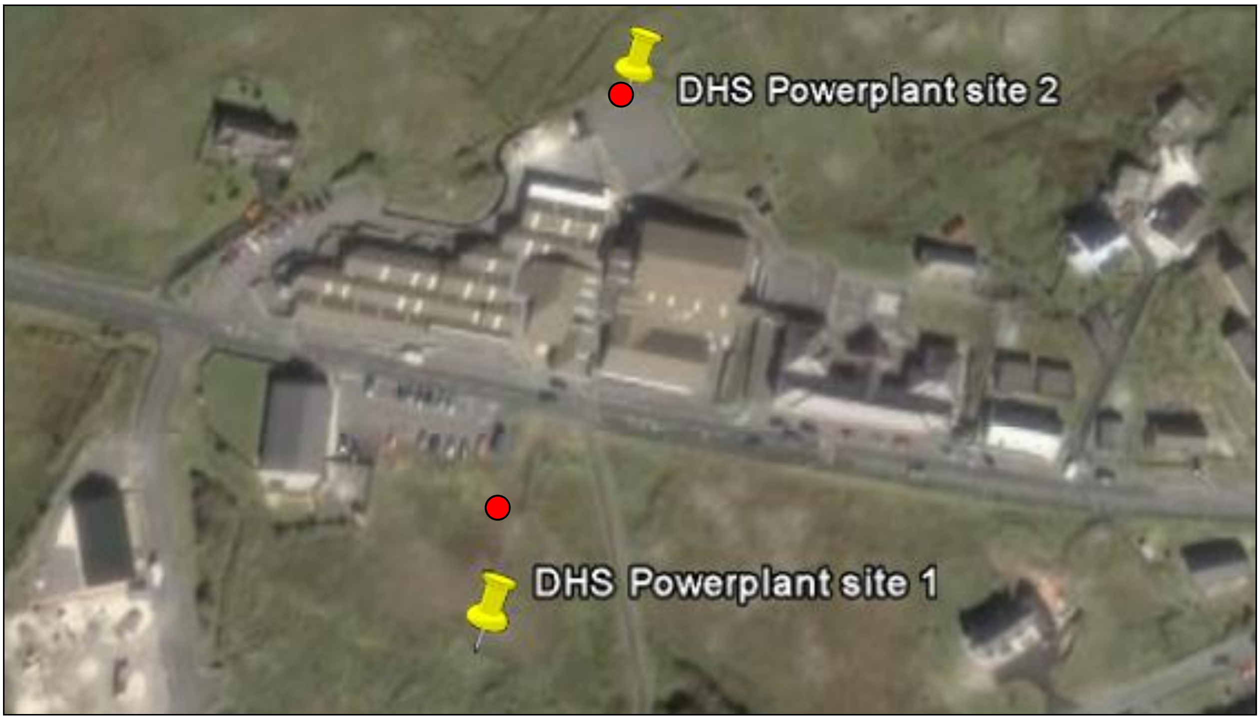
2.3.4 Power Plant Location

There are two ideal sites for the power plant location. One site considers the location of the power plant within the industrial zone, near the proposed new Corporative Supermarket (see figure 9). This site is the most central location for the system. It represents almost an equal distance between the farthest points of the DHS (Horve Hospital and Ciosmul Cottages, which are approximately 330m and 270m respectively from the Power plant). As a system design consideration it is important to keep the farthest reaches of the piping network within an acceptable range so as to minimize pressure drop.

With one supply option considering the use of biomass, this site is easily accessible to trucks transporting the wood chips and there is enough land (about 6000m^2) for putting up woodchip storage bins structure.

The second site is the area above the Castlebay Schools. This site is located close to the school. Locating the power plant at this site will make economic sense. It will be easier to integrate the two Boiler systems (to act as a back up or peak load carrier) and less piping work between the two plants will be needed. On the other hand, this site is far from the pipeline network with the farthest consumer (Horve Hospital) being 510m away. This will lead to increased pressure drop in the pipeline. But this can be mitigated against with the help of a substation or use of slightly bigger diameter pipes. The site is also suitable for biomass Boilers and there is enough area for woodchip storage.

Figure 10. Google Map snap shot of Power plant Location Sites

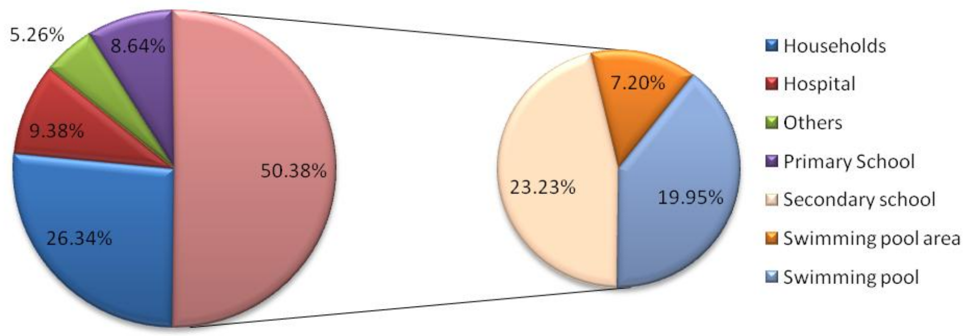


Source: Adapted from Google Earth, 2009

2.3.5 Demand side of DHS in Horve, Castlebay repitition

Demand side for Horve will include 80 households, schools, children centers/café, learning center, hospital and some small shops. Figure 11 below gives a breakdown of the heat demand:

Figure 11. The share of demand side in Horve, Castlebay



Source: Author

The supply design divides the total demand into base load (303kW), and peak load (903kW). It is also considered that the school, the learning centre and the hospital have their own boilers which can be used as back-up and for peak load supply. The supply options will cover the total heat demand through the use of biomass and wind resource. The operation principle of both biomass and wind based DHS is the same. In both systems, water is used as a heat transfer fluid and is circulated in a closed loop system (primary loop). Both systems consist of a central thermal storage tank of capacity of 390m^3 designed for one autonomous day[20]. Table 6 gives specifications of thermal storage tank.

Table 6. Specification of thermal storage tank

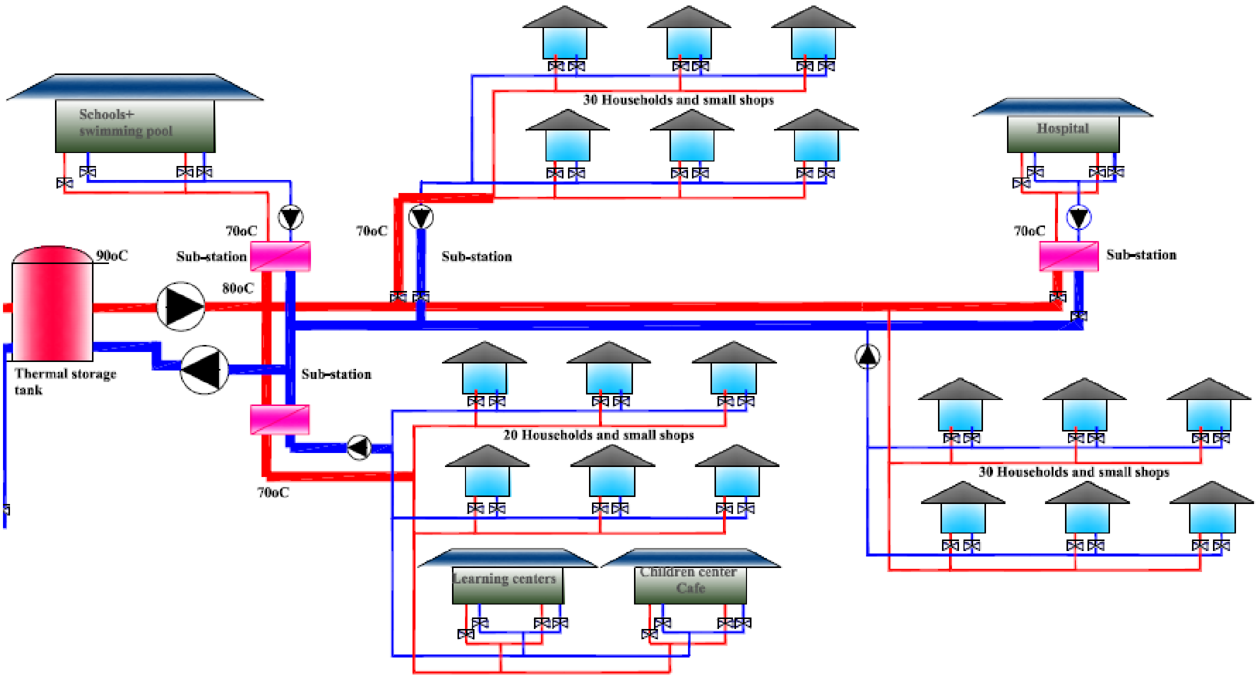
Annual heat production	**4,841**	**MWh**
Storage capacity	13.3	MWh/day
Volume	390	m^3
Diameter	10	m
Height	5	m
Area of storage tank	78.5	m^2

Source: Authors

Based on the peak load requirement of the end-users, three substations are considered for each system. The heated water leaves the storage tank at a temperature range of 90^0C to 100^0C where it is pumped through the main supply pipes to the different sub-stations. Within the substations (heat exchangers), the heat is exchanged over from the hot water to a secondary loop which contains the return water. The water in the secondary loop is raised to a temperature of about 70^0C and is circulated through the distribution pipes to the buildings where it flows through the radiators to heat the space. (Figure 12)

[20] The storage can store sufficient energy to provide for the demand for one days without it being recharged

Figure 12. The DHS schematic of demand side in Horve



Source: Authors

Using thermal storage tank reduce the size of boiler system especially when using wind energy. The tank can store the excess wind power in the form of heated water.

2.4 Energy Sources

2.4.1 Biomass

One of the options considered for the supply of heat energy in Barra is woodchips. Due to unavailability of biomass resources in Barra, the study team looked at the possibility of sourcing the same from Sleat in Skye or from the Knoydart peninsula. Two methods of transporting the wood chips were considered as shown in table 6 below. Transportation by vessel would go direct from Sleat or Knoydart to Barra, a distance of about 78 miles.

Table 7. Wood Chip Transportation Costs[21]

Item	Transportation by vessel /80ton load *
Transport Cost (£)	3000
Wood Chip Cost (£)***	6400
Total Cost (£)	9400
Landing Cost/ Tonne (£)	117

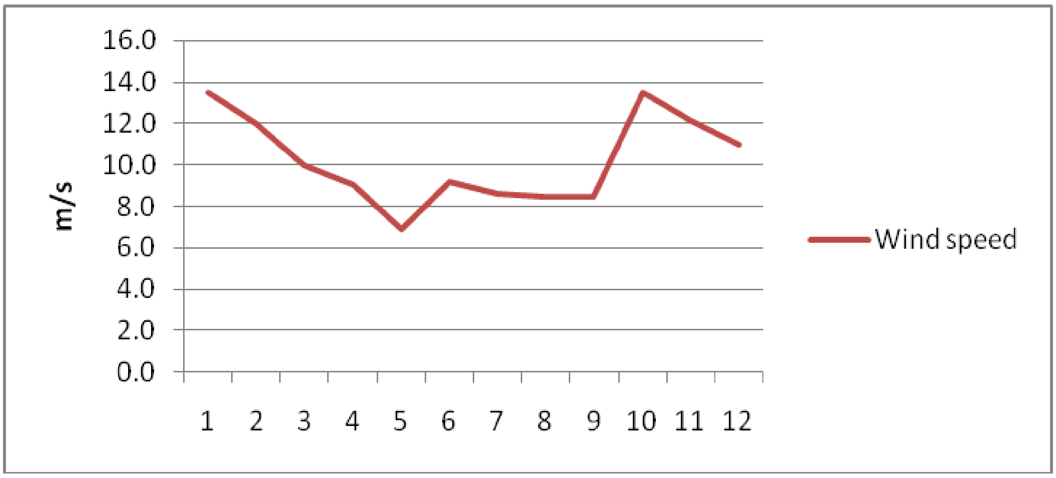
Source: Authors

Getting biomass from Sleat or Knoydart seems to be an option worth considering provided that the reliability of the supply both in terms of woodchip availability and transportation can be ascertained.

2.4.2 Wind

According to the feasibility study report (2006) by West Coast Energy Consulting Company the average wind speed in Barra is 10.2m/s at 40 meters which is sufficient speed for wind energy generation. Figure 13 below shows the wind speed profile.

Figure 13. Monthly averages of wind speed in Barra, at 40meter[22]



Source: Authors

[21] Source: Ferguson Transport, Fort Williams *

Barratlantic Transport Company, Barra**

Sleat Renewable, Skye***

[22] West Coast Energy Project Report, 2006

Carnan which is about 5km from central Horve is recommended as the site for locating the wind turbine, providing an average wind speed of 10m/s. (see section 2.4.3)

2.4.3 Waste

Waste as fuel to provide heating was also considered. Heating values used in this report for anaerobic digestion and thermal treatment calculations are based on AEA Energy and Environment Group's report to the Scottish Environmental Protection Agency.[23] Based on waste generation data from Community Energy Scotland, covering the period July 2007 to May 2008, the following two categories of waste were considered;

2.4.4 Energy from Anaerobic Digestion of Organic Waste

A preliminary assessment of the potential of biogas from organic waste generated within Barra to generate enough energy for a District Heating System (DHS) showed that it is not enough as presented in table 7.

The amount of organic waste can only contribute about 1% of the total required heat energy. Therefore this option is not viable.

[23] Evaluation of Energy from Biowaste Arisings and Forest Residues in Scotland, 2008

Table 8: Potential Energy from Biogas (Based on waste for the period April 2007-May 2008)

Description	Amount	Unit
Amount of Organic Waste	109.30	tones
Biogas Yield	125.00	(m3/tonne)
Calorific Value	35.70	(MJ/m3)
Total Biogas Yield	13,662.50	m3
60 % Methane Content	8,197.50	m3
Total Calorific Value	292,650.75	(MJ)
Total Energy yield	81,291.88	(kWh)
20% (Heat Supply to digester)	65,033.50	(kWh)
Assumed Boiler Efficiency	75	%
Final Energy Yield	**48,775.13**	(kWh)

Source: Author[24]

2.4.5 Energy from Combustible Waste

Figures for combustible waste considered are for the period January to December, 2008. Since there was no desegregation of the figures the total figures for Barra were calculated based on the assumption of 15% contribution by Barra.[25]

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[24] based on AEA Energy and Environment 2008, p 34 for the heating values and biogas content, and Community Energy Scotland for waste amounts

[25] This percent was arrived at on the basis of the other figures provided for organic waste and residue waste which were desegregated by region of origin.

Table 9.Energy Potential from waste combustion (January to December 2008)

Energy from Thermal Treatment of Waste		
Cardboard	3180	kg
Oil filters/absorbents/rags	260	kg
Papers /Newsprint for Recycling	106260	kg
Plastic for Recycling	24980	kg
Tyres	4380	kg
Waste Oil	33440	kg
Total	**172500**	kg
Excluding recycled waste	41260	kg
Amount Generated in Barra (Assumed to be 15%)*	6189	kg
Thermal Treatment Potential Yield	9.4	MJ/kg
Total Energy Generated	58176.6	MJ
Total Energy Generated	16160.16667	kWh
Assumed Boiler Efficiency	75	%
Final Energy	**12120.125**	kWh

Source: Authors[26]

The amount considered as a potential source for energy excludes the waste sent for recycling. The total amount of heat energy which can be generated from the 6,189 kg of combustible waste was calculated as 12,120 Kwh. This amount of waste is not sufficient to contribute significantly to the heat demand of the community which is 4,841 MWh per annum.

2.5 Options for the DHS system in Horve, Castlebay

As discussed in part 2.4, the specifications of the district heating system (DHS) in Horve, Castlebay will be as below:

- Base load: 305kW
- Peak load: 903kW

[26] Thermal Treatment Potential Yield Based on AEA report 2008, p 36

- Total annual heat production: 4,841 MWh.

The two main technical options which were considered to meet the heat demand for Castle Bay are Biomass and Wind Energy.

2.5.1 Biomass

Biomass to supply Base and oil to meet Peak load

The considered option was using Biomass to supply the base load and oil to meet the peak load demand. Oil was considered as an option due to the fact there are already, four (3x 266kw and 1x 150 kW) boilers at the school and two (120kw each) at the hospital which could be used as part of the DHS.

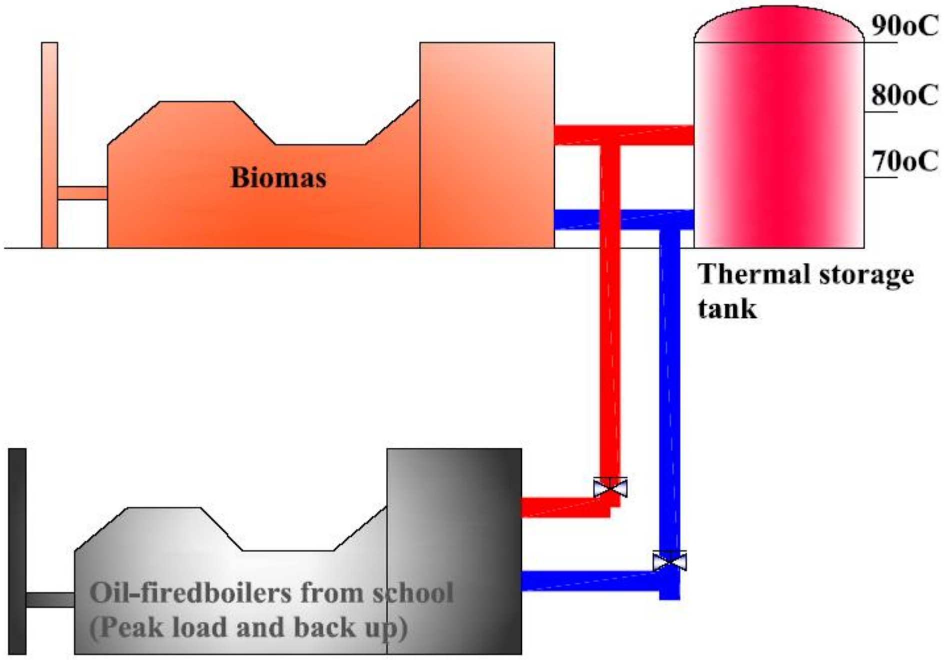
Table 10. Biomass and Oil Scenarios for DHS

Biomass and Oil Scenario				
Heat demand	Capacity	Heat delivery	Fuel type	Fuel consumption
	kW	MWh/yr		
Base load	600	3968	Biomass	1,225 t/yr
Peak load	266x2	490	Oil	59,578 l/yr

Source: Authors

The assumption used in this model is that the Community organization and the school are in a position to enter into a rental agreement for the use of the boiler to meet the peak demand 490MWh per annum.

Figure 14. Schematic diagram for biomass and oil fired boilers DHS



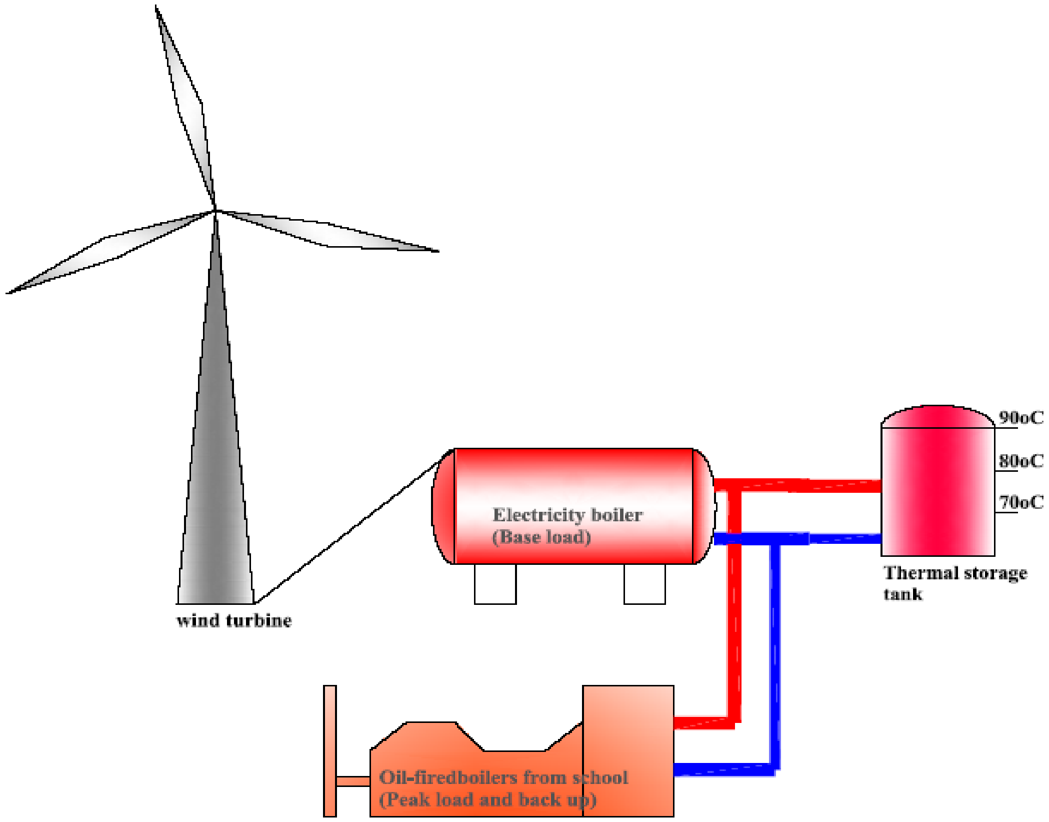
Source: Author

The temperature in the thermal storage tank needs to be maintained between 70°C and 90°C. In case the load increases during a certain period, the temperature in the lowest part of the tank will reduce to less than 70°C, then the oil boiler will run, so that the storage tank is always charged.

2.5.2 Wind

The concept of using wind energy as a primary energy resource for district heating system (DHS) is illustrated in the following figure 15:

Figure 15. The schematic of wind energy for DHS



Source: Authors

The proposed system is combining wind energy and oil-fired boilers which already exist in the schools and in the hospital. The wind turbine will produce electricity and feed it to the electricity boilers.

The electricity boilers is a boiler which includes several electrical heating elements for heating water to maximum of 120^{o}C. A 600kW boiler will have 12 units of 50kW heat element each. The input power for the boiler is 600kW.

The boilers will heat up the water which is transferred to the thermal storage tank. The controlling system will set the working temperature for water from boiler to the tank at 90oC. If the temperature is not enough, the pumping system will not transfer the water through to the storage tank. This will help to make sure that the temperatures in the tank are always maintained at 90oC.

Like the biomass system, the temperature in the thermal storage tank needs to be maintained between 70^{o}C and 90^{o}C. Due to the intermittent nature of wind, the power output will not be constant throughout the day. Therefore the power to the electricity boilers will be variable as well. The suggested electrical boiler has several heat elements, each with a capacity of 50kW[27]. The boiler is designed such that the wind power can be captured and utilized as much as possible.

To control the output temperature from DHS to the end-user, exit water temperature from the storage tank must be above 90^{o}C. The water storage capacity will be similar to the one suggested in the biomass system. When the temperature in the lowest part of tank reduces to less than 70^{o}C, the backup boiler comes on stream, to recharge the storage tank.

Wind combined with Oil Boiler

Table 11 . 600kW Wind Turbine for Horve, Castlebay

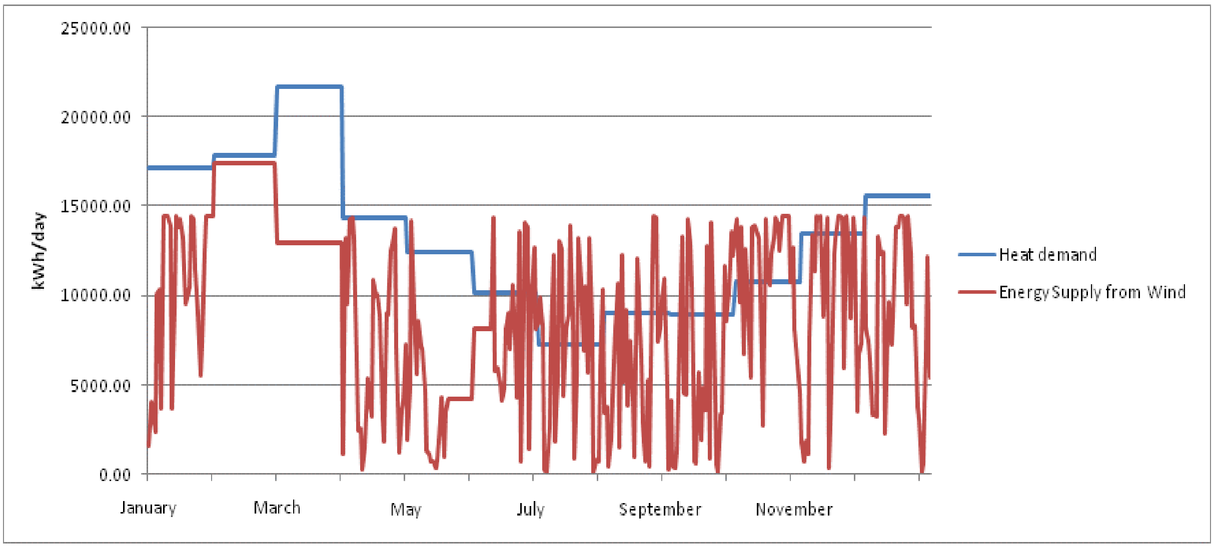
600kW Nordex , SÜDWIND S.46/600 - 51.5m, hub height 51.5m			
Annual heat demand	Boiler	Wind annual energy output	Capacity factor for wind turbine
MWh/yr	kW	MWh/yr	
4,841	600 (electricity)	3,372	64%
	266 (oil fired boiler in schools)	1,469	

Source: Authors

The capacity factor of the wind turbine is quite high in our calculation because the wind data used is not for the whole year. For the three missing months, assumptions were made so as to be able to calculate the power output.

[27] Reimers-Electra Steam, USA boiler supplier

Figure 16. Heat load vs. 600 kW Turbine Power output



Source: Authors

In this system, the wind turbine will meet the base load and medium load and the peak load will be met by oil fired boilers from the Castlebay schools.

2.6 Economical Analysis of Heat Supply Options

To analyze the economical viability of the heat supply options, 4.4 and 5 pence per kilowatt hour heat tariffs have been assumed. The tariffs were chosen because they are lower than the current tariff for heat and would therefore make it more attractive for the residents to be part of the district heating system. The heat supply options were analysed under the following assumptions:

(i) 100% self financing, alternatively availability of 50% subsidy

(ii) 2.4% Inflation Rate

(iii) 8.0% Discount Rate

(iv) 20 years Project Life

In both cases, the following supply options were analysed:

(i) Biomass for base load and Oil for peak load

(ii) Wind for base load and Oil for peak load

2.6.1 Scenario 1: 4.4 Pence Tariff Option

This tariff is about 25% lower than the current heat tariff. Under this tariff, only the wind-oil supply options with a 50% subsidy are viable, with the former being the most financially attractive option. It has a simple payback period of 5 years.

Table 12. Financial Analysis of Heat Supply Options in Castle bay at 4.4 pence/kWh

Proposed tariff: 4.4 pence/kWh			Biomass+Oil		Wind
Project costs and savings/income summary			grant	without grant	grant
Initial costs					
Boiler system			120,000	120,000	48,000
Distribuition piping network			882,704	882,704	882,704
Thermal storage tank			39,000	39,000	39,000
Boiler house/station			10,000	10,000	10,000
Wind turbine			-	-	625,000
Transmission line for wind option		£	-	-	125,000
Total initial costs		**£**	**1,051,704**	**1,051,704**	**1,729,704**
Incentives and grants		**£**	**525,852**	**0**	**864,852**
Annual costs and debt payments					
O&M		£	12,000	12,000	12,000
Oil boiler renting cost		£	4,482	4,482	4,482
Contingencies	10%	£	1,200	1,200	1,776
Fuel cost - proposed case					
Biomass cost		£	143,408	143,408	0
Oil cost		£	39,322	39,322	50,567
Total annual costs		**£**	**200,412**	**200,412**	**68,825**
Heat production		MWh	4841	4841	4841
Heating tariff		£/kWh	0.044	0.044	0.044
Production lifetime		yr	20	20	20
Heat production income		£	213,004	213,004	213,004
Annual income			**213,004**	**213,004**	**213,004**
Annual Profit		**£**	**-45,311**	**N/A**	**72,202**
Financial viability					
IRR		%	-4.3%	-17.6%	16.4%
Simple payback		**yr**	**0.0**	**0.0**	**5.6**
Net Present Value (NPV)		**£**	**-444,868**	**Negative**	**623,154**
Benefit-Cost (B-C) ratio					1.36

Source: Authors (Based on Retscreen Calculations)

2.6.2 Scenario 2: 5 Pence Tariff Option

With this tariff option, none of the biomass options are viable. With subsidy or self financing, the wind and oil option are attractive

Table 13. Financial Analysis of Heat Supply Options in Castle bay at 5 pence/kWh

Proposed tariff: 5 pence/kWh				Biomass+Oil		Wind+Oil	
Project costs and savings/income summary				grant	without grant	grant	without grant
Initial costs							
	Boiler system			120,000	120,000	40,000	40,000
	Distribuition piping network			882,704	882,704	882,704	882,704
	Thermal storage tank			39,000	39,000	39,000	39,000
	Boiler house/station			10,000	10,000	10,000	10,000
	Wind turbine			-	-	625,000	625,000
	Transmission line for wind opt		£	-	-	125,000	125,000
	Total initial costs		£	**1,051,704**	**1,051,704**	**1,721,704**	**1,721,704**
	Incentives and grants		£	**525,852**	**0**	**860,852**	**0**
Annual costs and debt payments							
	O&M		£	12,000	12,000	12,000	12,000
	Oil boiler renting cost		£	4,482	4,482	5,764	5,764
	Contingencies	10%	£	1,200	1,200	1,776	1,776
	Fuel cost - proposed case						
	Biomass cost		£	143,408	143,408		
	Oil cost		£	39,322	39,322	50,567	50,567
	Total annual costs		£	**200,412**	**200,412**	**70,107**	**70,107**
	Heat production		MWh	4841	4841	4841	4841
	Heating tariff		£/kWh	0.05	0.05	0.05	0.05
	Production lifetime		yr	20	20	20	20
	Heat production income		£			242,050	242,050
Annual income				**242,050**	**242,050**	**242,050**	**242,050**
Annual Profit			£	**-16,265**	**-69,824**	**101,248**	**21,893**
Financial viability							
	IRR		%	-4.3%	-3.5%	16.4%	8.3%
	Simple payback		yr	0.0	0.0	4.7	9.4
	Net Present Value (NPV)		£	NA	**N/A**	908,331	43,479
	Benefit-Cost (B-C) ratio					1.34	1.03

Source: Authors, 2009 (Based on Retscreen Calculations)

At which Tariff does the Biomass-Oil option become Viable?

The Biomass-Oil supply option would be viable at 5.5 pence with 50% subsidy with payback period of 8 years. At 100% self financing it would be viable at 7 pence with payback period of 7.6 years.

Required Household Changes and Potential Benefits

To connect to the District heating system, about 60% of the households in castle bay would have to change from dry heating systems to wet ones. This would require an investment of about 2500 pounds per household. From our survey, the average annual heat demand is 12,378 kWh/year. An increase of 30% in the annual consumption is assumed due to the availability of cheaper and convenient energy. Taking into account the anticipated increase, this figure of 16,091kwh/year was calculated. The possible savings that would result from the cheaper energy were then considered as shown below:

Table 14.. *Possible Savings for Castle bay residents investing in new heating systems in their homes*

Description	Tariff £/kWh	Heat Demand (kWh/year)	Changing dry system Investment Cost £	Total Heat Cost £/yr	Savings £/yr	Simple Payback (years)
Current	0.059	16,091	-	949.34	-	-
Scenario1	0.044	16,091	2,500	708	241.34	10.4
Scenario2	0.05	16,091	2,500	804.5	144.75	17.3

Source: Authors

The first scenario looks attractive unlike the second one which requires 17.3 years to recoup the investment. Financing options such as the warm deal grant by the Scottish Executive which would help reduce the payback period should be looked at.

For the houses which already have water bound heating system, connecting to the DHS is an attractive option due to the savings they would gain as shown above.

2.7 Environmental Analysis

As presented in table 15 below, the carbon dioxide emissions resulting from the proposed heat supply options are all lower than the base case scenario. The carbon dioxide emissions are mostly from the use of oil boilers as back up.

Table 15. CO2 Emissions from Heat Supply Options for Castle bay

Energy Source	Emissions tCO2/ Year	Annual Emissions Reduction t CO2
Base Case *	1903	-
Biomass & Oil *	272	1631
Wind & Oil *	198	1896
Wood Transport by road **	9.8	

Source: Authors[28]

Conclusions

From our preliminary investigation, a district heating system would be a viable option depending on the supply option selected. Some of the public buildings and 40% of households in Horve, Castlebay have a wet bound heating system. This is an advantage in terms of transferring to a District heating system. However, those who do not have a water bound heating system will need to convert to a wet bound heating system if the project of District Heating is to succeed. We recommend a wind-oil supply system. For such a system, the possibility of making use of the already existing oil boilers at the schools and the hospital, at a fee is also suggested. At a tariff of 5 pence/kWh, the wind-oil supply option is viable even without the grant (see 2.7.2) On the other hand,biomass-oil option would only become viable at a higher tariff than the existing one.

[28] *Based on Retscreen

** Based on emission factor for transport: 1.046 kg/km for 27t load

3 District heating in Vatersay

3.1 Introduction to the project

Vatersay is an island on the south of Barra located at the latitude of 57° 03' N and longitude of 7° 45' W. Vatersay has significant renewable resources. Especially wind, wave and tidal power are viewed 'as prospects for future economic development.'[36]

Based on a previous study[37], the Barra and Vatersay Community (CBAB) showed interest in assessing the feasibility of a District Heating System (DHS) for high density clusters of houses in Castlebay and Vatersay.

This project concentrates specifically on the feasibility of a DHS for a cluster of 20 houses in Am Meall area, Vatersay and the assessment of the different supply options. The house owners/tenants showed keen interest in a DHS. A survey was conducted by administering a questionnaire to 20 households in Am Meall to explore the district heating system in Vatersay. The analysis and findings described here under are based solely on 16 households from which the team got complete responses, but they have been extrapolated to the total number of households where necessary.

3.2 General profile of dwellings

On average houses in Vatersay have three bedrooms. The average heated area of the houses was found to be approximately 80 m^2. In Vatersay there are two basic types of houses from a construction and ownership point of view. Regarding ownership, 6 (37%) belong to the HHP (Hebridean Housing Partnership), whereas 10 (63%) of the surveyed houses were found to be privately owned. 3 of them are privatized HHP houses. The HHP type houses are wooden houses, while the rest are non wooden. Four houses (2 HHP owned and 2 privately owned) were not occupied at the time of the survey but were included for the total heat demand estimation. Fourteen houses (88%) were found to be detached, whereas, the remaining 2 (12%) are semi-detached. Within the study area, the average number of occupants permanently staying in the house is three.

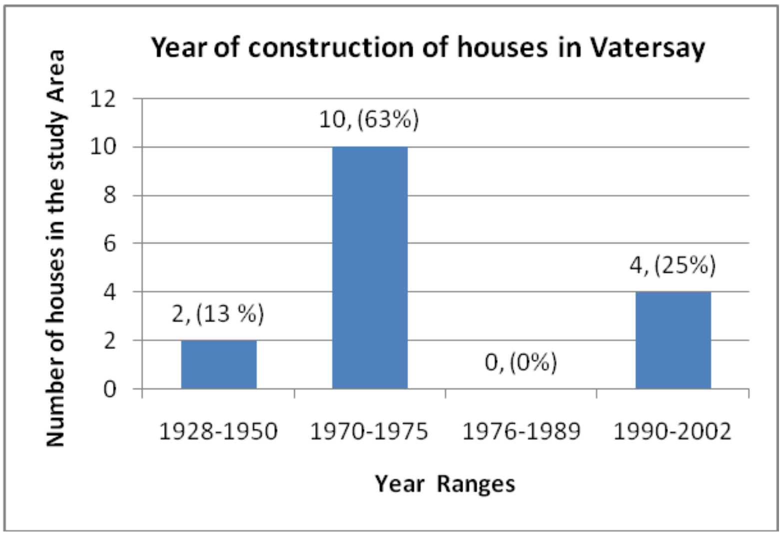
Most of the houses in the study area were constructed in the 1970's, as shown in the following figure 17.

---

[36] Coimhearsnachd Bharraidh agus Bhatarsaidh (Barra and Vatersay Community) Ltd., 2007 p. 9

[37] SEEM REPORT 2008

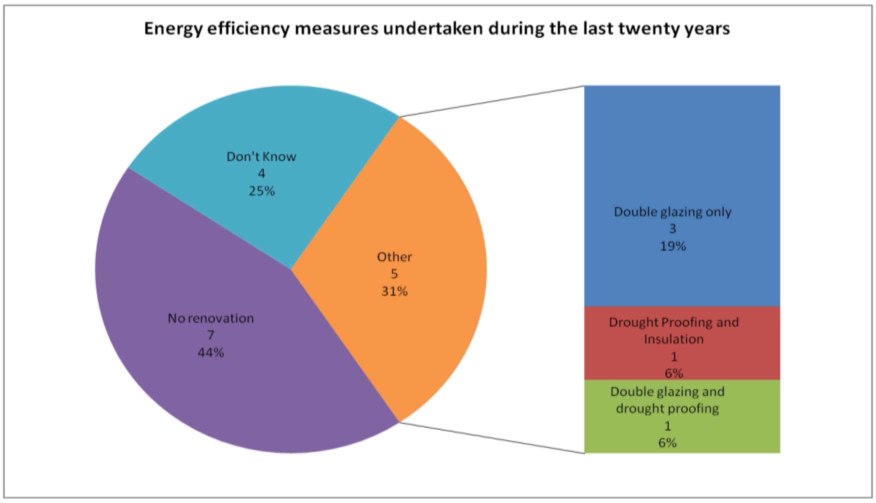
Figure 17: Year of construction of houses in Vatersay



Source: Authors

However, a number of renovations leading to energy conservation in the houses have been undertaken in the last two decades. The most relevant improvement being double glazing of windows and 7 houses (44%) have not undertaken any improvements in the last twenty years as shown in the following figure 18. Improvements in drought proofing have been undertaken in 2 houses, while 3 of the houses have installed double glazing in windows and doors. Six houses under HHP property have not carried out any renovations.

Figure 18. Energy Efficiency measures undertaken during the last twenty years

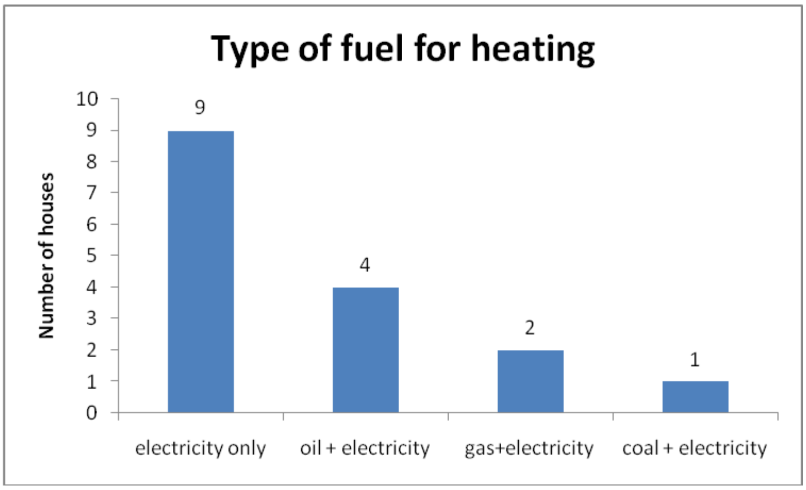


Source: Authors

3.3 Present heating situation

The majority of the dwellings use only electricity for heating purposes. The percentage of the fuels used by the households is shown in the following figure 19:

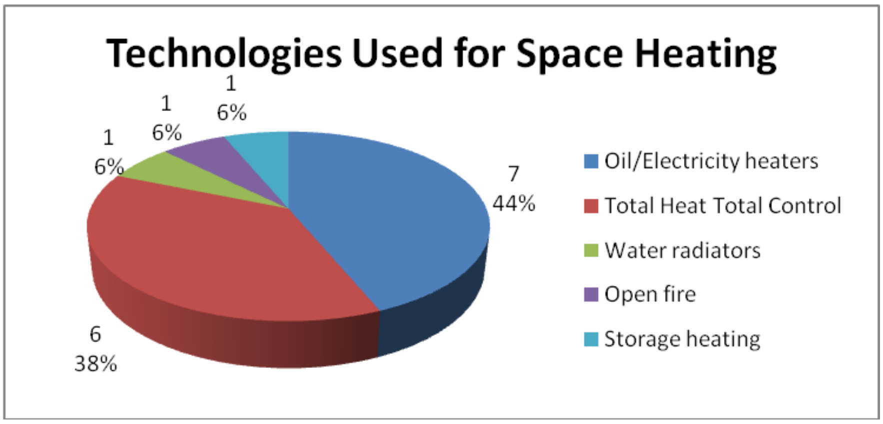
Figure 19. Fuel types used for heating.



Source: Authors

Regarding the space heating technology, most of the household use electrical heating technologies, while only one household has a water bound system (wet heaters) as shown in the following figure 20:

Figure 20. Technologies used for space heating.



Source: Authors

The average age of the heating systems in Vatersay was found to be 9 years old. 38% of the residents didn't know the age of their heating system. This probably can be explained by the fact that the houses were built in the 70's and people only recently moved into the houses.

For water heating, most of the houses use either immersion heaters or instantaneous water heaters.

The space heating and water heatings systems in Vatersay are strongly electricity based and the share of electricity usage for water heating in the study area is practically 100%.

3.4 Energy demand

3.4.1 Present energy demand according to survey

The total heat demand per household in the study area was found to be 15,417.60 kWh per annum or 193 kWh/m^2annum on average. This is in line with the heat consumption of average Scottish households which has been assumed to be 80% of the total household energy consumption in the "Energy Issues for Scotland" Report (June 2006) [38] resulting in an energy index of 197.09 kWh/m^2. The annual heating demand according to previous studies conducted in the area was found out to be 15 900 kWh/HH[39], resulting in an energy index of 199 kWh/m^2. This is also in line with the findings from this survey. A summary of the main heating parameters obtained from the survey is shown in the following table:

Table 16. Summary of the main heating parameters in the Vatersay study Area.

Parameter	Value from survey	
Average heated area of dwellings	78.2 m^2	
Average energy consumption /HH	19272 kWh per annum	
Average energy consumption for heating/HH	15,417.60 kWh per annum	
	Fuel Type	kWh/ annum
	Electricity	14,914.52
	Oil	103.66
	Gas	0
	Coal	399.43
Average energy index	246.3 kWh/m^2	
Average heating index	193 kWh/m^2	
Residents	3 persons/households	
Average number of bed rooms per house	3	

Source: Authors

The heating index for average Scottish households, according the Scottish Government is 250 kWh/m^2/yr[40]. Survey findings are compared to relevant sources in the following table:

[38] The Royal Society of Edinburgh. Inquiry into Energy Issues for Scotland. Final Report.June 2006 p. 67

[39] Pendrey, 2008 p. 19

[40] Renewable Heat Group, 2008, p.35

Table 17: Comparison of heating indexes of survey and other sources

Region	Heating Index kWh/m^2	Source
Vatersay	193 kWh/m^2	Survey SESAM 2009
Barra and Vatersay	199 kWh/m^2	(Pendrey, 2008 p. 19).
Scotland	197.09 kWh/m^2	"Energy Issues for Scotland" Report (June 2006)
Scotland	250 kWh/m^2	(Renewable Heat Group (RHG), 2008 p. 35)

Source: Authors

3.4.2 Expected future development of heat demand

According to the Scottish government[41], between 1990 and 2002 there was a 12% increase in the domestic energy consumption across the UK. Within this period the number of electrical appliances per household has increased as a result of increase in the number of dwellings due to single house occupancy. The average temperature in homes has increased by 1.5ºC for the period between 1991 and 2000[42]. On the other hand, this overall demand increase has been counterbalanced by energy efficiency measures.

The annual heat demand found from survey data was 15,417.60 kWh/HH. Nevertheless an average of 250 kWh/m²/yr[43] would lead to a consumption of 20, 000 kWh/HH[26]. According to Scottish government fuel poverty data[44], the Western Isles has an increasing fuel poverty trend in comparison to Scottish average, which can explain the difference in the annual heating demand (50% of the Western Isles households were considered fuel poor in 2008).

[41] Renewable Heat Group (RHG), 2008 p. 17

[42] DTI (DEFRA), 2005

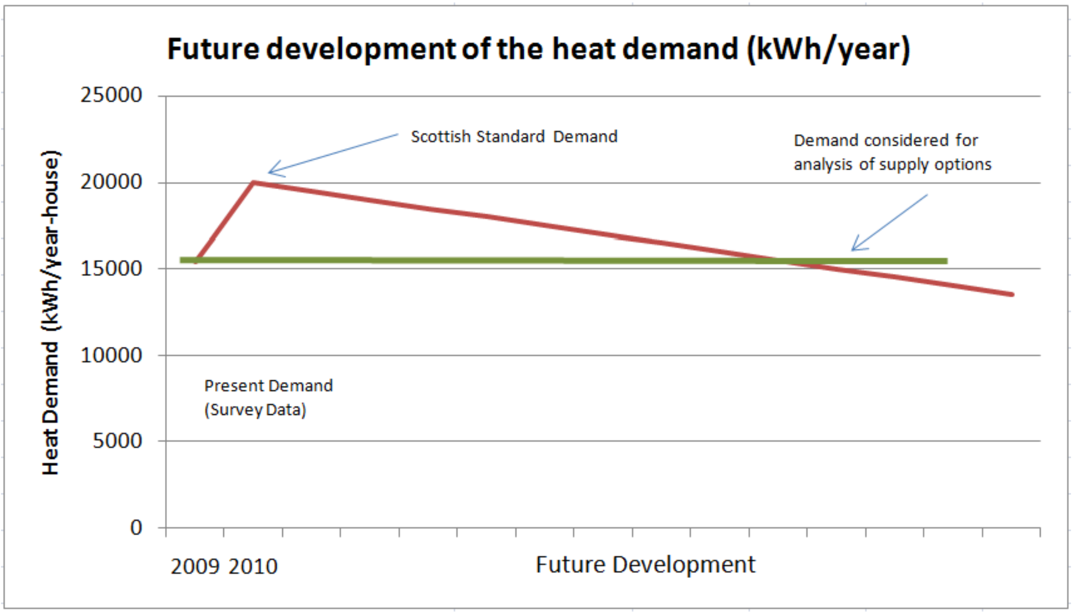
[43] Renewable Heat Group (RHG), 2008 p. 35

[44] Source: Compiled from (Comhairle nan Sair), WESTERN ISLES LOCAL HOUSING STRATEGY,ANNUAL REVIEW JULY 2008, FUEL POVERTY POSITION STATEMENT http://www.scotland.gov.uk/Topics/Built-Environment/Housing/access/FP/FPFORUMEVIDENCE101008, 14.11.2008

Fuel poverty has various causes such as low income, poor insulation of housing stocks, expensive fuels and no access to centralized heating networks.

If a DHS is implemented in Vatersay the heat demand is likely to increase sharply during the first year due to the change to a more comfortable heating system. However, energy efficiency measures will increase and this would lead to a decrease of the heat consumption to lower values than the present heat demand. Therefore the present heat demand of 15,417.60 kWh/household is utilized throughout the study to assess the different supply options as shown in following figure 21.

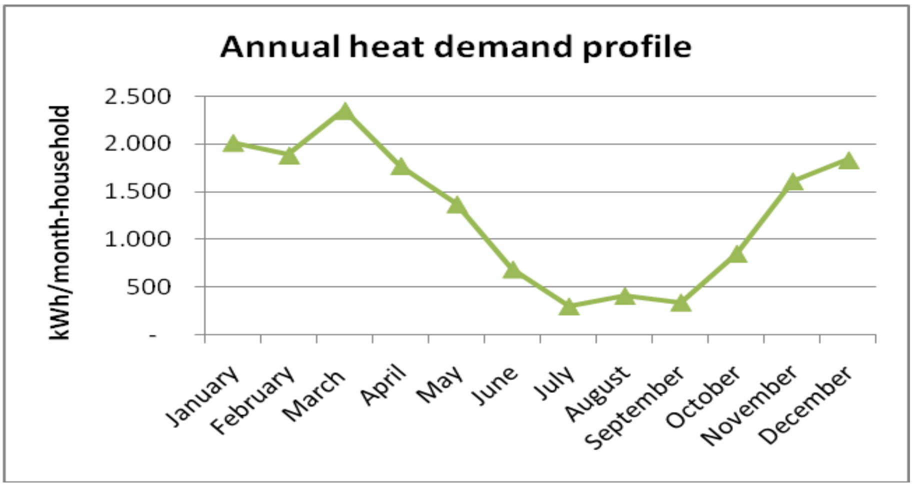
Figure 21: Probable Future Development of the heat demand.



Source: Authors

The current annual heat demand profile for Vatersay for an average household is shown in figure 22 and is based on the heating degree days (hdd) taken from data of North West Scotland[45]

Figure 22. Annual heat demand profile for Vatersay for an average household



Source: Authors

The profile shows that the maximum demand is reached in March, whereas the summer period has the lowest demand.

3.5 Supply options

A biomass and a wind2heat option are considered separately and described in terms of technical, economical and environmental aspects. The size of the study area is taken into account and affordability is prioritized. A third option considers a water bound district heating system (DHS) supplying wind electricity to an electrical boiler.

[45] Historical UK Degree Days Data, year 2006 from Carbon Trust

Economical analysis of all supply scenarios discussed in this report for a cluster of houses in Vatersay is based on the assumptions mentioned in the following table.

Table 18 : Assumptions for economical analysis

Description

Discount rate	8	%
Life span of plant	20	years
Inflation	2.5	%
Operation and maintenance (O & M cost)	2.5	%
Tax rate	0	%
ROC	0.046	£/kWh
Grid electricity price for heating	0.059	£/kWh
Wood chip cost (including transport from Skye or Knoydart)	117	£/ton

Source: Authors

3.5.1 System 1: Biomass boilers

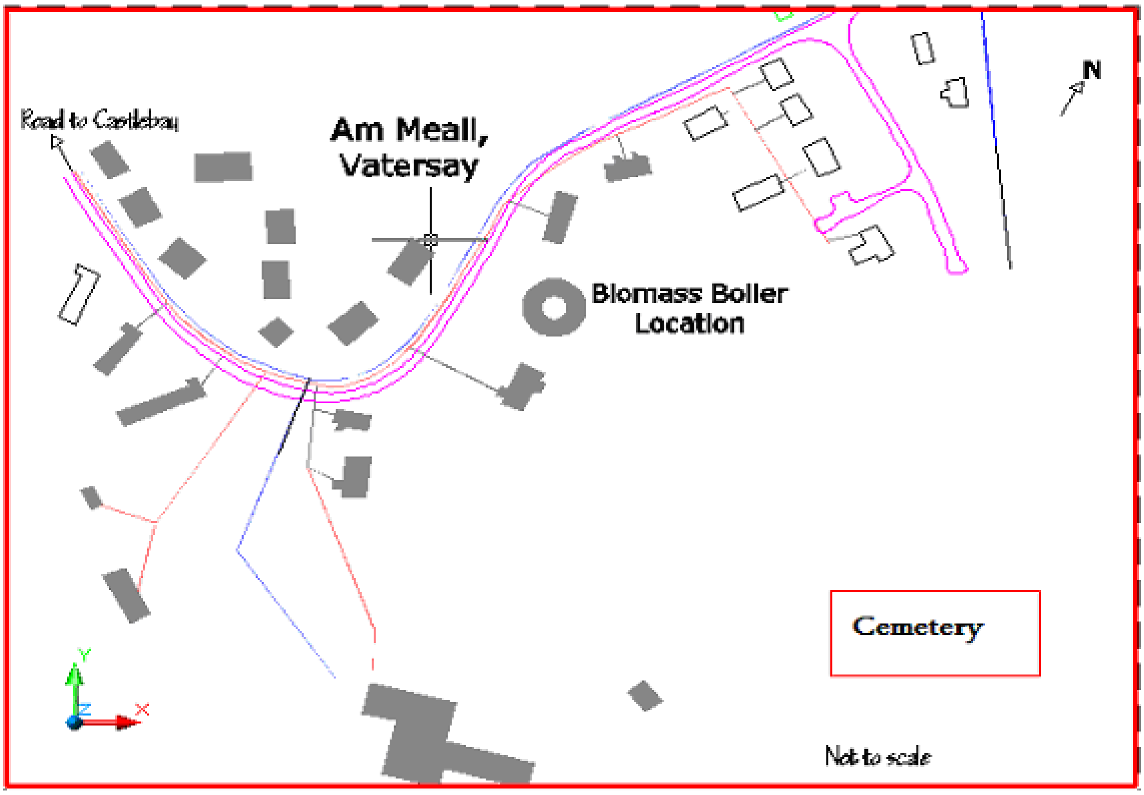
Technical description

Biomass boilers utilizing wood fuel as feedstock can be an option to supply heat. The main factors affecting the viability of a district heating system (DHS) are the housing density, and the type of heating system(s) being replaced.

Vatersay has two dense clusters of 5 and 10 houses each where a DHS might be feasible. (See chapter two for general description of a DHS and more detailed information on the biomass supply options) Nevertheless, the remaining 5 scattered houses have to invest approximately £9000 each for extra piping network because they are about 50 meters far from the proposed DHS supply pipe.

The following figure shows a possible location for the boiler house and biomass storage yard.

Figure 23: Possible site location for DHS boiler house plant, describe or show on map



Source: Authors

The installation of a biomass boiler would require the substitution of the current electric storage heating systems with a water bound space heating system (including new radiators). Derived from the heating demand the option of a 130 kW biomass boiler is considered to supply the heating for 100% of the heat demand.

Economic analysis

The option of a biomass based water bound DHS system was not found to be attractive if the present heat energy tariff (5.9p/kWh) is taken into account as the reference. This is caused by the low number of houses in the proposed DHS system. It is assumed that each household will contribute £3000 for installation of radiators in their houses. Other major assumptions for costing of the 130kW biomass boiler systems are the following;

- Biomass boiler cost: £30,000[46] including boiler house, accessories and installation.
- Piping cost per meter: £260[47]
- Heat exchanger and transfer stations: £440/household
- Pump cost: £2,300 per unit[48]

The economic parameters for this system are summarized in the following table,

Table 19: Economic factors for biomass boiler.

Parameters	**Value**
Capital investment without grant (£) (Includes: Boiler, piping, storage tank, pumps and heat exchangers.	260 700
Household contribution for radiators (£/household)	3000
Grant (£)	100,000
Annual fuel cost (£/year) at boiler efficiency of 85%	13,895
Annual maintenance costs including maintenance staff. (£/year)	6580
Heat tariff (p/kWh)	5.9
Average annual profit/loss	-16,085
Net Present Value (NPV) at 8% discount rate for a lifetime of 20 years	-157,930

Source: Authors

To make the DHS with water bound heating system economically feasible the community would need to set the tariff of heat energy at 11 p/kWh which would yield an IRR of 11% and

[46] Ash well Engineering, Leicester, UK

[47] http://www.nahwaerme-forum.de, date: 08.03.2009

[48] http://www.drain-system.co.uk/product/4382 (date: 13.03.2009

a NPV of zero, considering inflation rate of 2.5%. On the other hand, a grant of 75% is necessary to make DHS economically viable at a tariff of 5.9 p/kWh.

3.5.2 System 2: Wind2heat technology

Wind2heat technology is one of the best energy supply solutions for the islanders in Scotland, especially in dense clusters. The conditions of the island present average wind speeds above 10 m/s, which is currently not being exploited. The excellent available wind resources contrast with the low biomass, and hydropower potential in the island. Although there is also potential for wave and tidal projects, the investment for wind projects seems to be more affordable for community owned schemes.

An off grid community owned wind turbine that would directly supply the electricity to the houses could especially be an attractive option for Vatersay, due to the existing grid constrains. In this supply option, additional investment for a water bound system is not required. Additionally, such a scheme would be eligible for ROCs, making the project economically viable.

Technical description

For this supply option a 50 kW wind turbine is considered. The electrical storage heaters in the households are to be fed by wind power whenever available. Otherwise power will be drawn from the existing electrical grid. For this to happen there is need for a control system to regulate the power source and to enable a smooth operation of the wind2heat technology. The main purposes of such a control system would be the following

- maximize use of wind energy
- minimize the use of grid electricity
- guarantee availability of heat
- abrupt increase of consumer load and status of stored heat should be monitored (a possibility would be voltage sensors)
- regulate the grid response time

Regarding the storage electrical heaters, each household is assumed to have a storage capacity of 50 kWh. Two situations can arise due to the wind intermittence.

1. Surplus wind energy: The control system will allow the storage heater to be charged
2. Deficit in wind energy: The heat already stored in electrical heaters will be utilized to minimize the use of grid electricity.

The function of the control system is shown in the following table 20 for the different situations of the storage heaters.

Table 20. Function of control system

		Control system function	
Surplus wind energy		Yes	No
Storage heaters	Charged	Turn off the turbine	Use storage heaters
	Discharged	Charge the heaters	Connect to the Grid

Source: Author

A flow chart explaining the logic behind such innovative control system is shown in Annex 3.1.

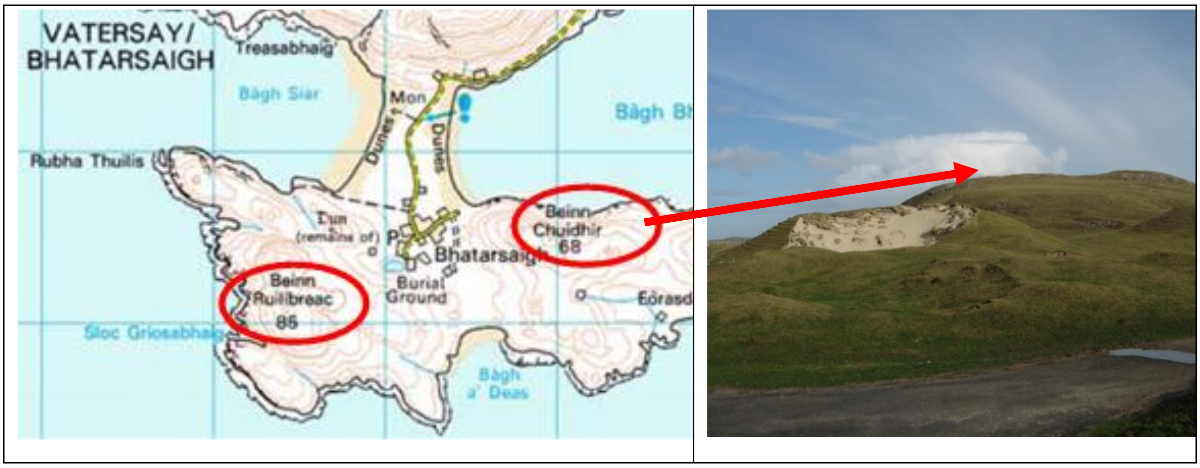
Possible geographical locations of wind turbine sites can be found in Annex 3.2.

Both identified sites have excellent wind potential ranging from 10.5 to 12 m/s on average[49]. One site (Beinn Chuidhir) is at the hill to the north-east of the main village (about 1 km far from the main cluster of houses.

This site is close to the village and offers relatively easy access. However, the hill is partially affected by interference from Beinn Ruilibreac to the west. The site is shown in the following figure 24:

[49] Wind speed measured at 75 meters. WEST COAST ENERGY LTD, 2006 p. Fig 3

Figure 24. Possible wind site at Beinn Chuidhir[50]



Source: Picture-Authors

Another potential site (Beinn Ruilibreac) is at the hill located to the south west of the village. This site is about 2 km far from the village, more difficult to access, but not shadowed by other hills to the west which is the prevailing wind direction. The ground surface is plane up to the bottom of this hill as well.

Economic analysis

A Wind2heat technology was assessed for three possible turbine options. Major assumptions for the economical analysis of this system are mentioned herewith,

- The community will get revenues from ROC (Renewable Energy Certificates) at the rate of £46 /MWh although the system is off-grid.
- The cost of the electrical distribution system were assumed to be £26,000 T&D?
- A price of £3000 per kW was considered for the turbine of 20 kW and a price of £2500 per kW was considered for the 50 kW option
- The power curve for the AOC 15/50 (Model AOC 15/50, manufactured by Entegrity Wind Systems) turbine and available wind data from Barra & Vatersay Community[51] were combined to yield a capacity factor of 0.36 (wind data has been taken from the West Coast Report, 2006 and adjusted to the lower average wind speed). Nine months

[50] Map-West Coast Report (2006),

[51] This data is taken from the West Cost Wind Feasibility Study Report, 2006.

data were available, whereas the missing months (February, March and May) were interpolated from the adjacent values.

- For comparison purposes, the second option of a 20kW wind turbine[52] was also assessed yielding a capacity factor of 0.34. Power and annual energy output curves for the two possible wind turbine types are attached in Annex 3.3. As a third option the installation of two 20kW turbines (total 40kW) was considered as well. The economic indicators for the three options are summarized in the table below.

[52] Vergnet GEV 10/20

Table 21: Economic parameters for wind2heat options.

Description	**Option 1**	**Option 2**	**Option 3**
Wind turbine capacity	50 kW	20 kW	40 kW (2x20 kW)
Investment wind turbine (£)	125,000	60,000	120,000
Investment distribution (£)	26,000	26,000	26,000
Investment control system*(£)	40,000	40,000	40,000
Total Investment without grant (£)	191,000	126,000	186,000
Investment with 50% grant (£)	95,500	63,000	93,000
Annuity of project at 8% interest rate and 20 years project lifetime	2,944	-2,289	-2,109
Electricity from wind (kWh/a)	238,814	90,444	153,643
Electricity from grid (kWh/a) totals should be the same	69,546	217,916	154,717
Annual maintenance costs as a percentage of the total investments	2.5%	2.5%	2.5%
Heat tariff (p/kWh)[53]	2.5	2.5	2.5
Total annual heat sales and ROCs (£/year)	16,955	6,421	10,909
Simple payback period with grant (years)	6	n/a	n/a
Simple payback period without grant and ROC (years)	32	n/a	n/a
Net Present Value (NPV) at 8% discount rate and 2.5% inflation rate	28,902	-22,472	-20,711
Internal Rate of Return (IRR) with grant considering inflation of 2.5% and a project lifetime of 20 years (Source: Authors 2009)	15%	5%	7%

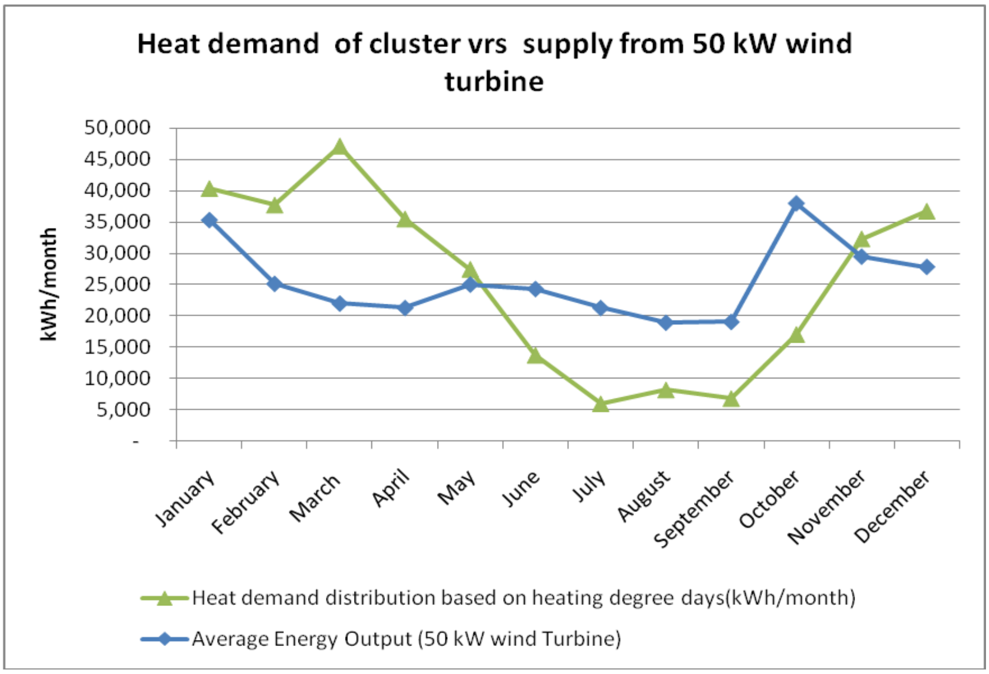
[53] For comparison purposes the same tariff was taken for every option, resulting in negative NPV for options 2 and 3. Nevertheless option 3 is feasible at 3.8 p/kWh (lower than the current heating tariff)

As this is an innovative system and readymade control systems are not available it has been assumed that the development of the control system will be financed with grants within an R&D project. The assumed investment represent the cost, the authors would consider as acceptable.

The heating tariff for all three options was taken at 2.5p/kWh . The tariff could go up closer to the present heating tariff of 5.9 p/kWh trying to maximize the revenues for the community. ROCs are considered for the NPV, IRR payback calculations. It can be suggested from the above table that the option of a single 50kW turbine (option 1) yields the best return on investment and the highest NPV, and is therefore the most attractive alternative.

Though the 50 kW turbine doesn't meet the total yearly demand of the village, during the summer period (June to October) a surplus can be expected as shown in the following figure

Figure 25: Demand and Supply Profile for Vatersay with wind2heat system



Source: Authors

3.5.3 System 3 Wet bound system fed by wind power

Technical design

This alternative looks at the option of replacing the electrical storage heaters with a wet bound system. A 50 kW turbine is considered to supply electricity to a 50 kW electrical boiler in the central station and hot water storage of 1 autonomous day (20,000 liters). This option requires the installation of a hot water distribution system and water radiators for every house within the considered area.

Economical analysis

The high investment (£302,900) at a grant of £100,000makes this option to be not economically viable. For it to become feasible at the current heating tariff (5.9 p/kWh), a grant of (£121,185) would be necessary.

Environmental benefits

The feedstock for the biomass based DHS need to be imported from the mainland by ferry or boat. Biomass is considered within the context of this report as a renewable energy source neutral to CO_2 emission and yields savings of 126 ton/year emission of CO_2.

By-products of burning of wood chips are limited to ash and flue gas. The flue gas contains nitrogen and sulphur dioxides which are negligible and significantly less than those of comparable fossil fuel power plants. Hence, the wood chip boiler can meet the relevant emission regulations. Some environmental issues associated with biomass based DHS are the following;

- Flue gas from the DHS plant is discharged to the environment through a chimney. Nevertheless, net CO_2 emission from the combustion of wood fuel is zero.
- Storage of large quantity of wood piles might sometimes produce liquids which could leach to watercourses. A collection ditch around the storage area would be required.
- "Wood ash is produced at a rate of around 1% of the total weight of wood burned, the ash may be usable in the manufacture of fertilizer."[54]

The utilization of wind based technologies has an important effect in the CO_2 emission savings.

[54] Department, Scottish Executive Delopment, 2002 p. 47

The CO_2 savings for the different wind based supply options and the biomass are shown in the following Table 22:

Table 22: Summary of the CO_2 savings from for the different supply options

	System1	System 2			System 3
Resource for heat generation	Biomass	Wind (direct)	Wind (direct)	Wind (direct)	Wind (wet)
Installed Power kW	130	50	20	40	50
Emissions savings (ton CO_2/year)	126[55]	98	37	63	98
Life project emissions Savings ton CO2	2529	1,958	742	1,260	1958
At present conditions the cluster's annual emissions due to heating purposes account to 126 ton CO_2/year					
Conversion Factor	0.41kg CO_2/kWh				
Source:	Scottish Energy Study 2006, p 23 and IPCC				

3.6 Conclusions and suggestions

The annual heating demand for a cluster of 20 houses in Vatersay was found to be 309 MWh. For a high density housing area like Vatersay, a district heating system could be one of the best options to supply cheaper heat. Due to the high availability of wind in the study region different wind based options were assessed. The Wind2heat alternative (System 2) was found to be the most attractive from the economical perspective. The option for an electrical heating system has the advantage that the heating systems in the houses do not have to be replaced. The high investment cost and longer payback period for a water bound system proved the Wind2heat option to be more feasible. For further progress of the Wind2heat alternative, the development of a control system is required. It is an innovative system that is worth of further considerations due to the potential replication in other communities. Possible sites for location of a 50 kW wind turbine and for DHS central plants were identified. The biomass based DHS alternative is highly dependent on future grant schemes of the Scottish government.

[55] Emissions from biomass transportation were not taken into account.

The study team would like to suggest:

- **Wind data:** To more accurately assess the wind potential at the possible wind turbine sites, actual wind velocity needs to be measured. The team suggests the installation of a wind data measuring station.
- **Development of control system:** The Wind2heat technology is highly feasible in many similar small islands in Scotland. An innovative control system which works to maximize the use of wind energy and minimize the grid energy can be developed. There are various market opportunities that encourage the development of such a new control system. The study team strongly believes that such a new control system can be developed with collaboration of electronics and electrical research institutions and experts' collaborations. The community is encouraged to take the initiative of seeking funding in possible form of grants for R & D of such a technology.
- **Look into public acceptance:** Vatersay has been considered as environmentally sensitive area (Western Isles Islands Council, Barra and Vatersay Local Plan - Map). Therefore, the acceptance from public and other authorities need to be deeply assessed before the planning of wind mill installations.

4 Wind Electricity supply to fish factory

4.1 Introduction to the Project

The project aimed at assessing the possibility of meeting part of the energy demand of "Barratlantic Fish and Shell Fish Processing Company limited" using wind energy. This is in line with the desire of the Barra & Vatersay community limited to explore this potential as a possible business opportunity for their organization. The factory is supplied by grid connection. Cooling equipments consumes higher energy than other equipments. The energy consumption varies with seasons.

4.2 General Information about Fish Factory

Barratlantic is built on croft land within Ardveenish area. The factory started back in 1974 mainly to process fish meal. In 1990's, the management of the factory changed hands and the same was expanded to process more fish and transport it to the mainland. The factory is currently under the management of West Coast Sea foods, Southern Scotland where most of the administrative functions are conducted.

The factory has a workforce of between 30-40 people. This includes those who work in the processing, administration, maintenance, drivers as well as those who manage the fishing boats. The workforce is divided into a regular and a back-up shift. The regular shift runs from 8:30 am to 5:00 pm from Monday to Friday. The Back-up shift starts from 3:00pm to a round 9:00Pm. The main duty of this shift is to receive fish from the fishing boats. Therefore the stop time for the back-up shift depends on when the fishing boats dock.

The factory has two cold stores. During winter season when the production is low, one cold store is always shut down due to lack of enough capacity to process. The cold store(s) run for 24 hours. The factory also owns a range of equipments such as Blast freezer, chiller plant, and cabin plant, skinning & strapping machines. Their consumption varies with seasons, cold months being lower than warm months.

4.3 Methodology

The first level of the survey involved face to face interview with the maintenance engineer (Mr. Don McNeil) so as to understand the general information about the fish factory. The main target was to gain ideas about their current energy consumption & supply and the main production processes. This level was mainly guided by structured questions and involved the collection of crucial support documents like electricity bill.

The second level involved the audit of the whole plant where all the equipments were examined and their power rating and working hours noted. This helped in estimating the energy demand of the various equipments. This also involved a whole day monitoring of the electricity meter so as to establish the load profile of the factory. The information from the survey was then analyzed to guide on the proposal of suitable technical designs of electricity supply.

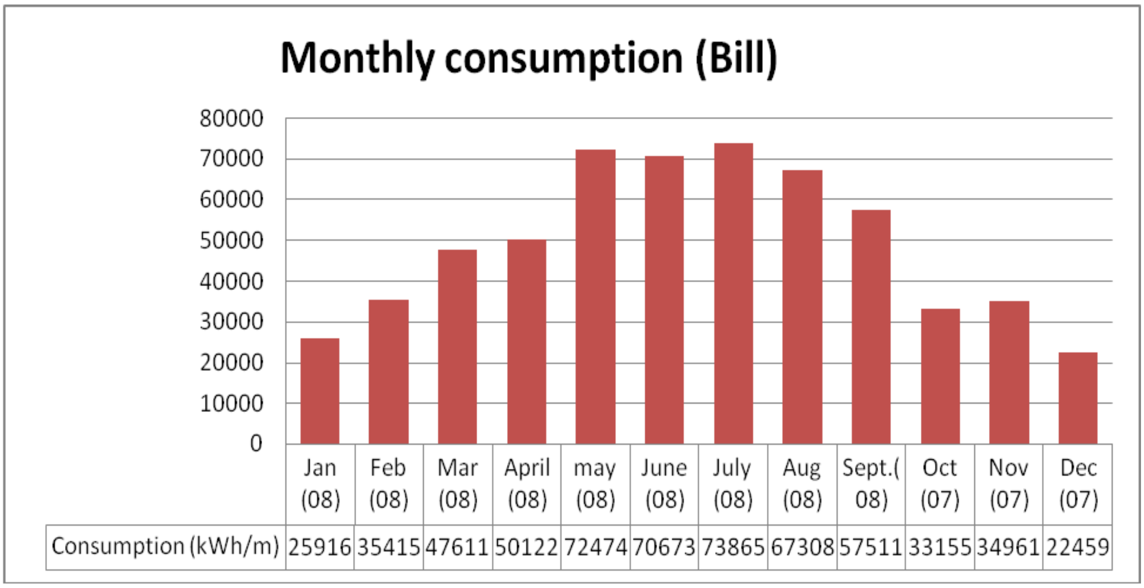
4.4 Energy Demand

The fish factory draws its power from the grid which is operated by the Scottish and Southern Energy. In addition, the electricity company has installed a standby Diesel generator which is switched on whenever there is no grid connection. The company uses electricity mainly for cooling, production of ice to chill the fish, for the processing of the fish and to smaller extent running the workshop equipment. Other uses involve office and canteen, space and water heating.

4.4.1 Electricity Bill and Audit

Energy bills were available for the period from October 2007 to the month of September 2008. The bills give an annual electricity consumption of about 591.47MWh. The analysis reveals that the high season starts from the month of May running through to September giving an average daily demand of 2232.92 kWh. The demand then goes down from the month of October through to the month of April giving an average daily demand of 1306.64 kWh for the low season. Simple comparison of these two averages yields a factor of 1.70. This higher trend during the high season can be attributed to the fact that more fish is delivered to the factory hence more capacity is required for processing in comparison to the low season.

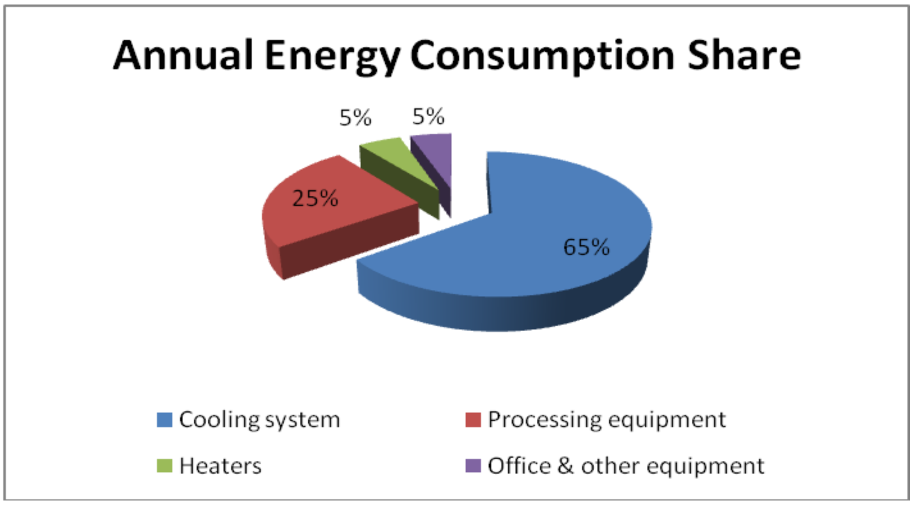
Figure 26: Monthly Consumption (Bill)



Source: Authors

The plant audit revealed that amongst the four categories of energy consumers, the cooling plant takes 65% (406.55MWh/y) of the total energy followed by processing equipment with a share of 25% (155.40MWh/y). Heating, office and other equipments takes about 5% (33MWh/y) of the total energy consumption each. The category of other equipments includes the workshop & kitchen equipment as well as other miscellaneous consumer appliances .The pie chart below shows the percentage share contribution of each category.

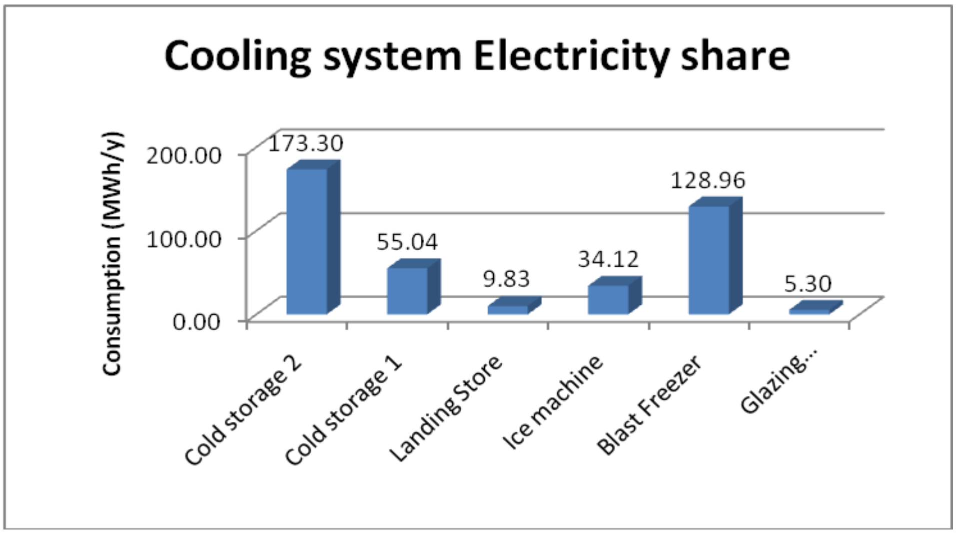
*Figure 27***:** *Annual Energy Consumption Share*



Source: Authors

The cold storage and the blast freezer are the main electricity consumers as shown in the graph below.

Figure 28. Cooling System Electricity Share



Source: Authors

4.4.2 Energy Demand Based on Future Development(s)

According to the management, the factory will maintain its operations without any expansion but considers the implementation of variable frequency drive (VFD) systems. Additionally the team has assumed energy management measures, which are described below.

The Blast freezer is a high power consumer. The blast freezer rarely runs at its design load, the chiller part load performance is therefore very critical to the plant performance[56]. By installing VFD, this improves both part and full load efficiencies for the chiller which can lead to energy savings of between 30-40% of its power consumption. Taking a conservative value of 30%, the consumption of the blast freezer can remarkably fall to about 89.6 MWh/y reducing the total annual plant consumption to 552.6 MWh/y.

Other energy efficiency management measures such as switching off the Circuit Breaker (CB) for heaters after the office hours, replacing the plastic door curtains at the landing area, store the excess electricity from the wind turbine through thermal storage so as to provide energy for the heat demand. This can yield an energy saving of 5-10% of the total energy consumption.

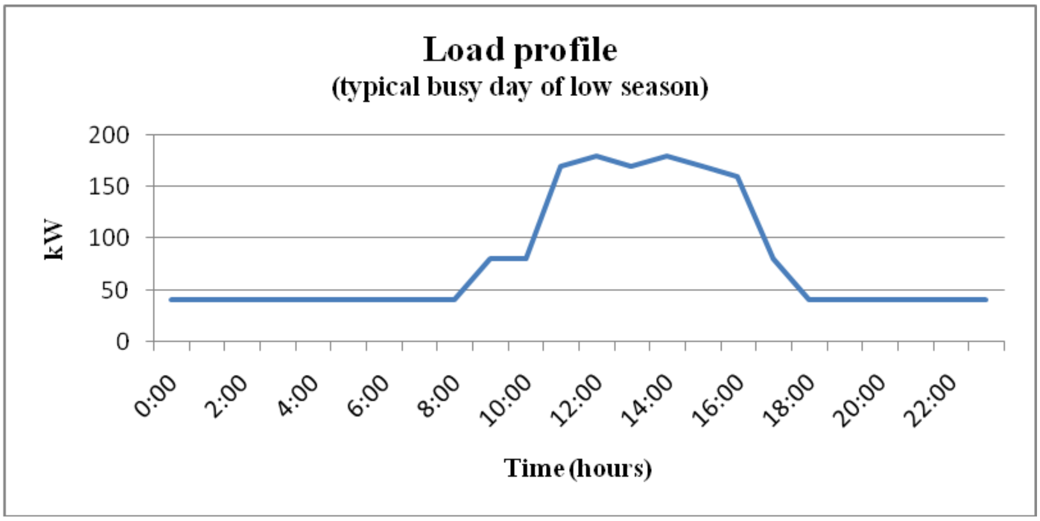
[56] McQuay air conditioning; Application Guide AG31-003-1: Chiller plant design.

4.4.3 Load Profile Based On Electricity Meter Monitoring

From the meter monitoring and recording carried out for one typical working day in winter (24th February), it is revealed that, the base hourly load demand is 40kWwith a peak load demand of about 180kW. The total energy consumed for the day stood at 1870kWh/day. The figure 30 shows the typical load curve as monitored.

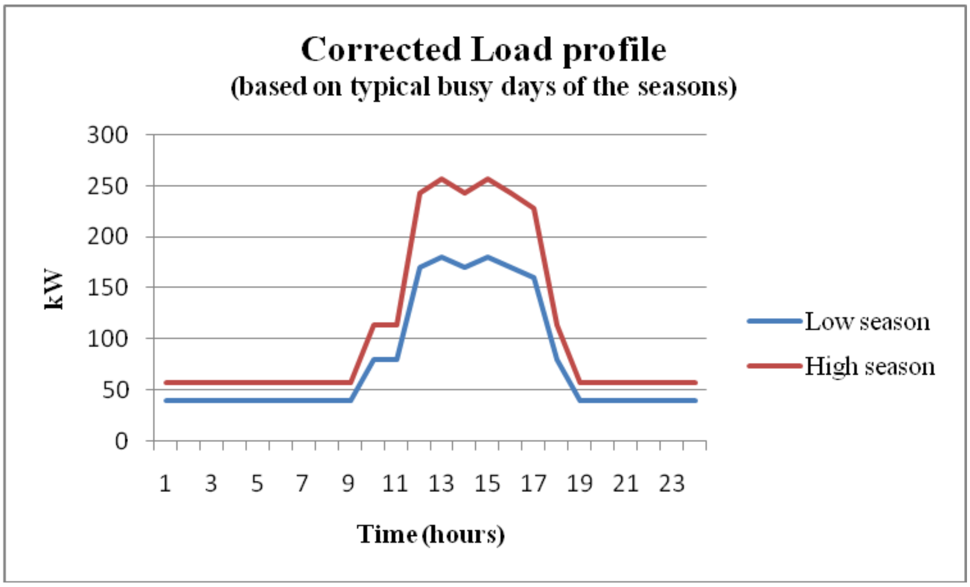
According to the energy consumption bills, the month of July has the highest consumption with a daily average of 2382.74 kWh/d in high season while the month of April has the highest consumption with a daily average of 1670.73kWh/d in low season. This means that in the month of July which is the peak for high season, the plant consumes 1.42 times of what it consumes in the month of April which is the peak for the low season. This value was then used as a multiplication factor to the recorded values from the meter reading so as to project the load profile for a typical busy day in high season. By applying this assumption, the baseload for the high season shifts to 57kW (40kW*1.42) and peak load shifts to 256kW (180kW*1.42). Figure 30 shows a typical load profile for a busy day in both high and low seasons as deduced from the one-day meter recording (figure 29).

Figure 29 : Measured Load Profile



Source: Authors

Figure 30: Corrected Load Profile



Source: Authors

The base load of the factory is mainly due to the cold store(s) energy demand. When the load profile is corrected by the factor of 1.42, the new base load covers the demand of the two cold stores. The demand rises between 11hrs and 17hrs when most of the processing as well as cooling equipment like blast freezer run. So this period marks the peak load time.

4.5 Supply Options

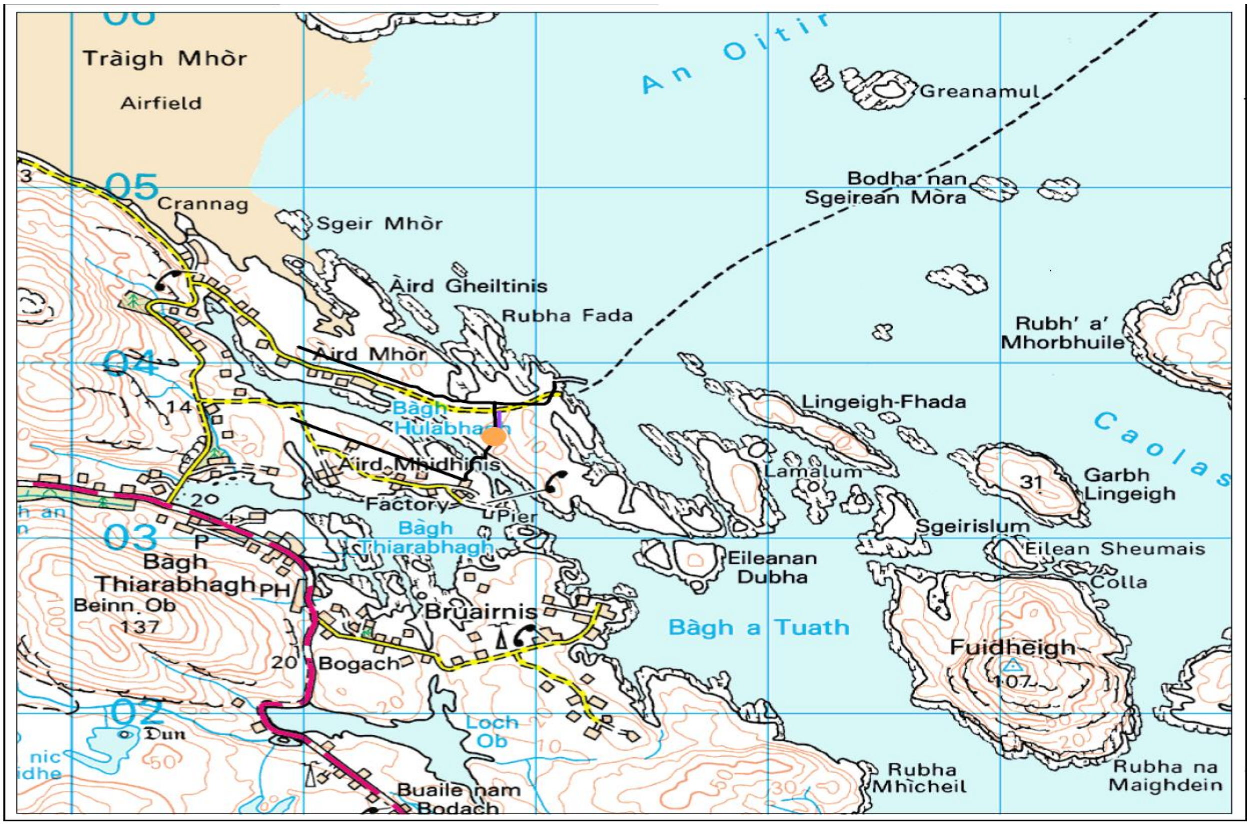
Based on the energy demand and load profile, this report explores two possible system designs to meet the base load demand for the factory. This is due to the intermittent nature of wind resource which makes it both technically and economically non-feasible to provide the whole energy demand for the factory. Therefore electricity from the grid shall be required to meet any additional energy requirement. Both scenarios use wind resource to generate electricity with the first option considering the business as usual. The second scenario is based on shifting the energy demand of the chiller plant from the normal working hours of the day to 24 hours by applying storage technologies.

4.5.1 Wind Turbine Site Selection

The factory is about 10 meters above the sea level with an open space. The possible site could be the eastern side of the factory (about 200 m far from the power station). A detailed study on the topography of the site (in the wind feasibility study) conducted by the West Coast Energy ltd confirms that this is one of the candidate sites for wind turbine installation in Barra. The Average Wind Speed at 40 m AGL is 10.2 m/s according to the same study report. A different study by Western Isle Islands Council indicates that the site is free of birds, clear from buildings up to a radius of 100 meters, or any public service center and it is close to the fish factory. See the topographical attached in the figure 31[57].

The topographic map below, showing the approximate area within orange circle (east part of the factory site) is the suitable demarcation for a wind turbine around the fish factory according to the west coast energy report[58].

Figure 31: Topographic Map of Barra showing Potential site around fish factory[59] site (marked in orange colour)



Source: West Coast Energy, 2006.

4.5.2 Scenario1: Wind Turbine (80 kW)

This design option considers supplying for the base load under the business as usual scenario with no storage system. Therefore the additional energy requirement will be supplied from the grid. It also considers that the consumption of the cold stores have the highest

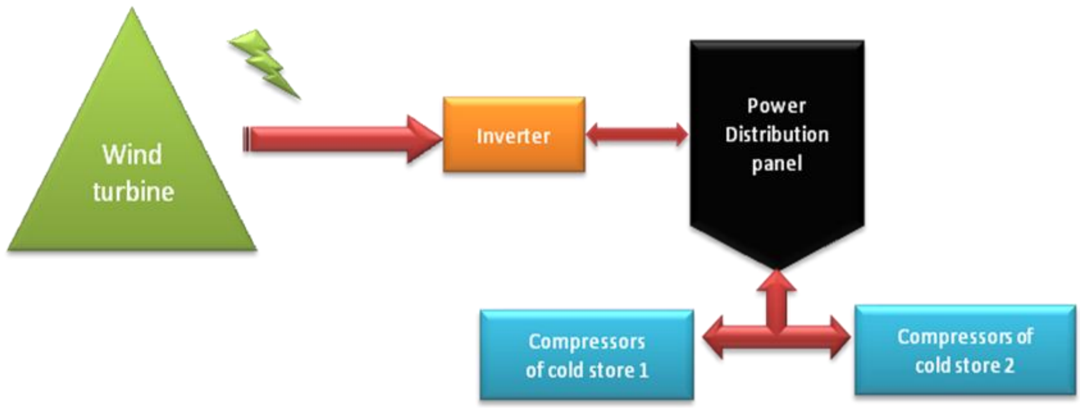
57 Western Isle Islands Council

58 WEST COAST ENERGY LTD. 2006

59 WEST COAST ENERGY LTD. 2006

contribution to the base load. So by supplying for the base load, the system will basically be providing for the energy demand of the cold stores. According to the corrected load profile (shown under the demand scenario above), the considered base load is about 60kW. This gives an average annual base load energy demand of about 293.72MWh/y. The system involves generating electricity through a wind turbine. This is then fed to the power distribution board and distributed to power the compressors which run the cold stores. The schematic diagram of the supply system is as shown below.

Figure 32: Schematic Diagram



Source: Authors

A wind turbine, model WES80[60] of rated power 80kW, hub height of 30 meters and a rotor diameter of 18 meters was selected. It has a capacity factor of 35.2%, considering the fact that not all capacity can be used, considering an average wind speed of 10.2m/s[61]. This turbine can generate an average annual energy of 308.6 MWh/y. Considering that the useful energy will be 80% of the annual energy produced, this results into an actual energy deficit of 46.84MWh/y. Therefore the turbine can only supply 84% (246.88MWh/y) of the annual base load requirement (293.72MWh/y). The energy deficit can then be supplied directly from the grid. A detailed calculation is attached in annex 4.3

[60] Wind energy solutions Canada

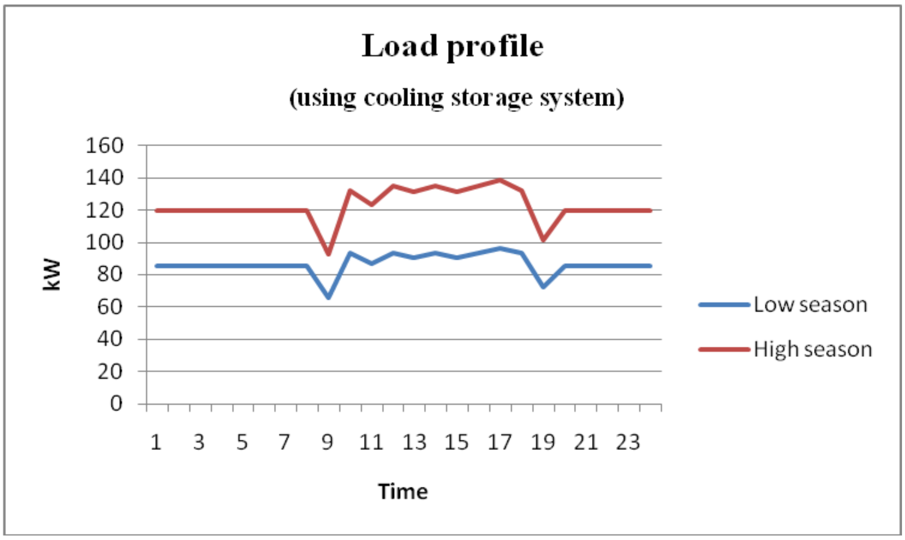
[61] West Coast report, 2006

4.5.3 Scenario2: Wind Turbine (160 kW)

The system is designed based on the need to supply energy for the cold stores plus part of the additional energy demand of the whole factory. The design considered shifting the energy consumption of the chiller plant outside the normal processing hours by using an energy storage tank which contains heat exchange fluid and nodules. The normal operating mode for the chiller changes to nightime and to some extent at a lower mode (about 10-15% of the chiller capacity) during the normal processing hours. The chiller runs to cool the refregirant and to crystallize the nodule[62] [63]. During the normal processing hours, when the energy demand is high, the stored charge is then pumped to serve the blast freezer.This reduces the overall peak load demand.

The shift of the chiller plant energy consumption is characterized by an upward shift of the base load to 120kW. (See the load profile after shifting the chiller energy demand).

Figure 33: Load Profile after Shifting the Chiller Operation Hours

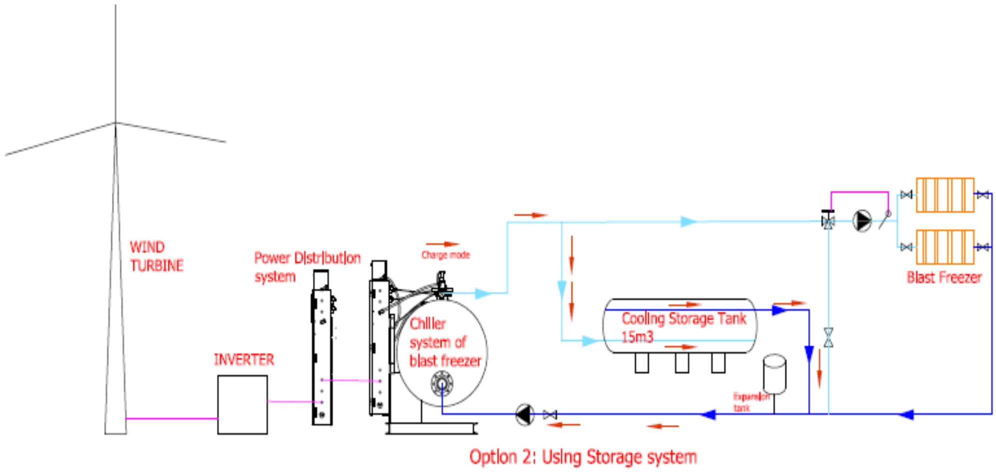


Source: Authors

[62] Nodule contains a range of phase change materials which enables it to store thermal energy at a temperature of between -33^0 C to 27^0 C

[63] Cristopia energy systems: thermal storage http://www.cristopia.com/english/products/indproducts.html

Figure 34: Schematic Diagram



Source: Authors

A wind turbine, model NORWIN29-Stall of rated power 160 kW and hub height of 40m with a rotor diameter of 29 meters was selected. This turbine can generate an average annual energy of 612 MWh/y. Considering that useful energy will be 80% of the total annual production, this results into an actual energy deficit of 101.4MWh/y so as to meet the annual energy demand (591MWh/y). The selected wind turbine can therefore effectively supply about 82% of the total energy demand. However, the turbine generates an annual excess of about 66.95 MWh/y which can directly be used in a thermal storage tank for space heating. The design considered that the factory will maintain electricity grid as a back-up. A detailed energy calculation is attached in annex 4.3.

4.6 Economic analysis

The Economic Analysis of the two possible wind turbines was assessed. The analysis for both scenarios the following major assumptions considered;

- Inflation rate of 2.5%.
- Economic lifetime of 20 years for a turbine;
- Operation and maintenance costs at 2.5% of capital cost;
- Capital costs estimates based on industry standard costs(2000£ per kW for 80 kW and of 1500£ per kW for 160 kW);

- 95% availability all facilities for installation and for Maintenance;
- Annual Running Cost 2.5%
- ROC is 46 £ per MWh

Option -1

The economic analysis revealed that the 80 kW wind turbine system would require a total investment of £98,178 with grant, a payback period of –3 years and the internal rate of return of 24%. This is assumed if the community company to operate wind turbine for the electricity supply to fish factory with electricity price of £0.07/kwh. The selected Turbine capacity of 80kw is an environmentally attractive option with a CO_2 emission offset of 126.07 tons per year [64]which is equivalent of around 2521.37 tons over the lifetime.

Option -2

The economic analysis for 160 kW turbine revealed that the system would require about £ 379,487 with grant, a payback period of 7 -years. The selected Turbine is an environmentally attractive option with an offset CO_2 emission of 260.98 tons per year [65]which is equivalent of around 5219.6 tons over the lifetime. The economic indicators for the two options are summarized in the table below.

[64] (0.43KG OF CO2/kwh) (Scottish standard).

[65] (0.43KG OF CO2/kwh) (Scottish standard).

Table 23: Economic parameters for wind turbine options for fishery.

Description	**Option 1**	**Option 2**
Wind turbine capacity	80 kW	160 kW
Investment wind turbine (£)	160,000	240,000
Investment for distribution) (Cables +Transfer) (£)	32,500	32,500
Investment storage *		200,000
Planning Cost	4936	6987
O &M	6100	9600
Total Investment without grant (£)	197,436	479,487
Investment with grant (£)	98,718	379,487
Annuity of Investment at 8% interest rate	10,566	478
Electricity from wind (kWh/a)	247,000	490,000
Annual maintenance costs as a percentage of the total investments	2.5%	2.5%
Electricity tariff (£/kWh)	0.07	0.07
Simple payback period with grant (years)	3	7
Net Present Value (NPV) at 8% discount rate	103,745	4,694
Internal Rate of Return (IRR) with grant.	24 %	11%

Source: Authors

**) the investment in the storage is a very rough estimation. According to Cristopia energy systems the required storage type is no longer produced, but the company is extremely interested in assessing the potential and making a qualified offer*

The electricity tariff for two options was taken at £0.07/kwh. The tariff could go up closer to the present average (day and night tariff) electricity tariff of 8.6 p/kWh trying to maximize the revenues for the community. ROCs are considered for the NPV, IRR payback calculations.

4.7 Summary of the findings

Cold stores consume about 39% (228MWh/year) of the total energy demand (591.47MWh/year) of the factory. Although the blast freezer contributes to the high peak load, its annual energy demand is less than that of the cold stores since it only operates for few hours/day as compared to the cold stores which run for 24 hours/day.

While both supply options considered were found to be technically feasible, the first (80Kw) option of wind turbine was found to be more financially viable. With an estimated total investment cost of £98,718 (Grant and ROCs factored), this option would generate an annual profit of £10,566 to the community with a payback period of 3 years.

However, this section of the report recommends the following further considerations;

a) Further specific wind resource measurements should be done at the proposed site since wind data used to calculate the given results was extracted from the measurements taken from a different site. Furthermore, the wind data was only available for a period of ten months. So the data for the two missing months (February and March) were assumed to be the same as those for the month of January.
b) A one year monitoring of the load profile of the factory should be measured to provide data for a more precise assessment of storage and turbine size.
c) A detailed assessment should be conducted so as to establish the specifications of the cooling storage tank and exact costs. The same would be necessary for the additional investment in the thermal storage.

5 Overall recommendations and conclusions

The concept of wind based district heating systems for Castlebay and Vatersay can be viable from a financial and environmental perspective.

For Castlebay the option of a water bound heating system combining a 266 kW oil boiler and a 600 kW wind turbine was found to be the most attractive with an IRR of 16.4%. This project would have the largest social impact due to the high number of beneficiaries.

In Vatersay, the alternative of a Wind2heat option using a 50 kW wind turbine was found to be the most feasible. This technology enables the users to continue making use of the current electricity based heating systems which yields a lower investment than the wet bound heating systems. Interesting financing opportunities could arise for this project due to it replicable nature.

For the Barratlantic Fish and Shelfish Company Ltd the most attractive option is investment in a 80 kW wind turbine. It would yield an IRR of 24%. This would be a profitable alternative for both the community and the fish company.

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Annexes

Annex 1. General

Annex 1. 1. Heating degree day

2006 (15.5 degrees centigrade base):

	1 London (Thames Valley)	2 South Eastern	3 Southern	4 South Western	5 Severn Valley	6 Midland	7 West Pennines	8 North Western	9 Borders	10 North Eastern	11 East Pennines	12 East Anglia	13 West Scotland	14 East Scotland	15 North East Scotland	16 Wales	17 Northern Ireland	18 North West Scotland
Jan	306	335	339	288	334	350	360	351	338	358	345	350	342	343	336	324	325	291
Feb	299	334	333	295	325	331	318	310	300	306	319	325	298	312	318	303	306	272
Mar	291	321	319	292	300	337	341	344	352	353	336	343	350	356	381	308	322	340
Apr	166	191	197	185	188	206	202	227	235	221	213	222	244	248	252	221	237	256
May	75	96	110	115	95	113	100	146	177	147	113	109	165	185	203	143	154	198
Jun	24	39	46	39	32	35	32	59	85	58	44	54	71	70	80	56	62	99
Jul	4	7	13	10	9	11	6	25	35	26	12	11	30	32	34	18	27	43
Aug	17	27	29	19	20	29	23	45	40	37	27	31	53	51	49	32	45	59
Sep	9	22	24	15	27	27	23	30	43	34	23	19	48	53	57	25	44	49
Oct	59	82	72	54	67	104	91	109	114	102	86	75	129	132	132	83	109	123
Nov	177	207	219	166	197	218	182	231	228	225	221	217	242	257	240	202	251	233
Dec	252	268	276	213	245	283	262	303	302	306	284	290	294	328	343	251	297	265

*highlighted figures corrected 05.10.06

Annex 2 Castlebay Project

Annex 2. 1. The heat demand calculation (refered more detail calculation in the CD)

Heating project	Unit		Building clusters									
Base case heating system	Multiple buildings - space heating											
See technical note on heating network design			1	2	3	4	5	6	7	8	9	10
Heated floor area per building cluster	m²	14,968	3,075	306	260	867	2,774	860	722	180	2,850	3,075
Number of buildings in building cluster	building	87	80	1	1	1	1	1	1	1		
Fuel type			Electricity	Oil (#6) - L	Electricity	Oil (#6) - L	Oil (#6) - L	Oil (#6) - L	Oil (#6) - L	Oil (#6) - L	Electricity	Electricity
Seasonal efficiency	%	-	70%	70%	70%	100%	100%	100%	100%	70%	70%	70%
Heating load calculation												
Heating load for building cluster	W/m²	-	35.2	27	30	76	64	85	76	850	27	27
Domestic hot water heating base demand	%	70%										
Total heating	MWh	5,177	693	53	50	422	1,136	468	351	979	493	532
Total peak heating load	kW	809	108	8	8	66	178	73	55	153	77	83
Fuel consumption - unit		-	MWh	L	MWh	L	L	L	L	L	MWh	MWh
Fuel consumption - annual		-	990	7,022	71	39,250	105,736	43,544	32,686	130,197	704	759
Fuel rate - unit		-	£/kWh	£/L	£/kWh	£/L	£/L	£/L	£/L	£/L	£/kWh	£/kWh
Fuel rate		-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fuel cost		£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -	£ -
Proposed case energy efficiency measures												
End-use energy efficiency measures	%	6%	0%	0%	0%	10%	10%	10%	10%	10%		
Net peak heating load	kW	756	108	8	8	59	160	66	49	138	77	83
Net heating	MWh	4,841	693	53	50	380	1,023	421	316	882	493	532

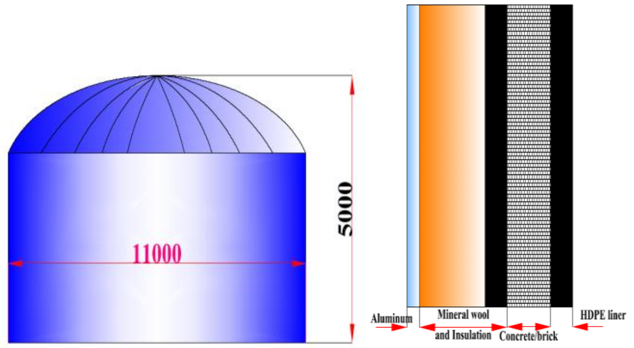
Source: Author – Retscreen softwares

Annex 2. 2. Heating pipe design criteria

Heating pipe design criteria			
Design supply temperature	°C	90	
Design return temperature	°C	60	
Differential temperature	°C	30	
Main heating distribution line			
Main pipe network oversizing	%	0	
Pipe sections	**Load**	**Length**	**Pipe size**
	kW	**m**	**mm**
Section 1	756.2	1,500	DN 100
Section 2	124.3	55	DN 40
Section 3	483.1	105	DN 80
Section 4	148.8	145	DN 50

Annex 2. 3 Storage tank

Figure 35. On-ground storage tank



The specification of the tank:

- Volume: 390 m^3
- Dimension: beside figure (in meter).
- Estimated Price: 80 Euro/m^3
- Materials:
  - 2,5 mm HDPE liner.

Annex 2. 4 ***Emissions from Transporting Wood by Truck***

Description	Amount	Unit
Pay-Load	27	tonnes
Emission Factor	1.046	Kg CO_2/km
Distance	205	km
Emissions per trip	214.43	Kg CO_2/trip
Number of Trips	48	trips/year
Total Emissions	9832.407	Kg CO_2/year

Annex 2. 5 Pipeline Network following Water line

Source: Google map, Author 2009

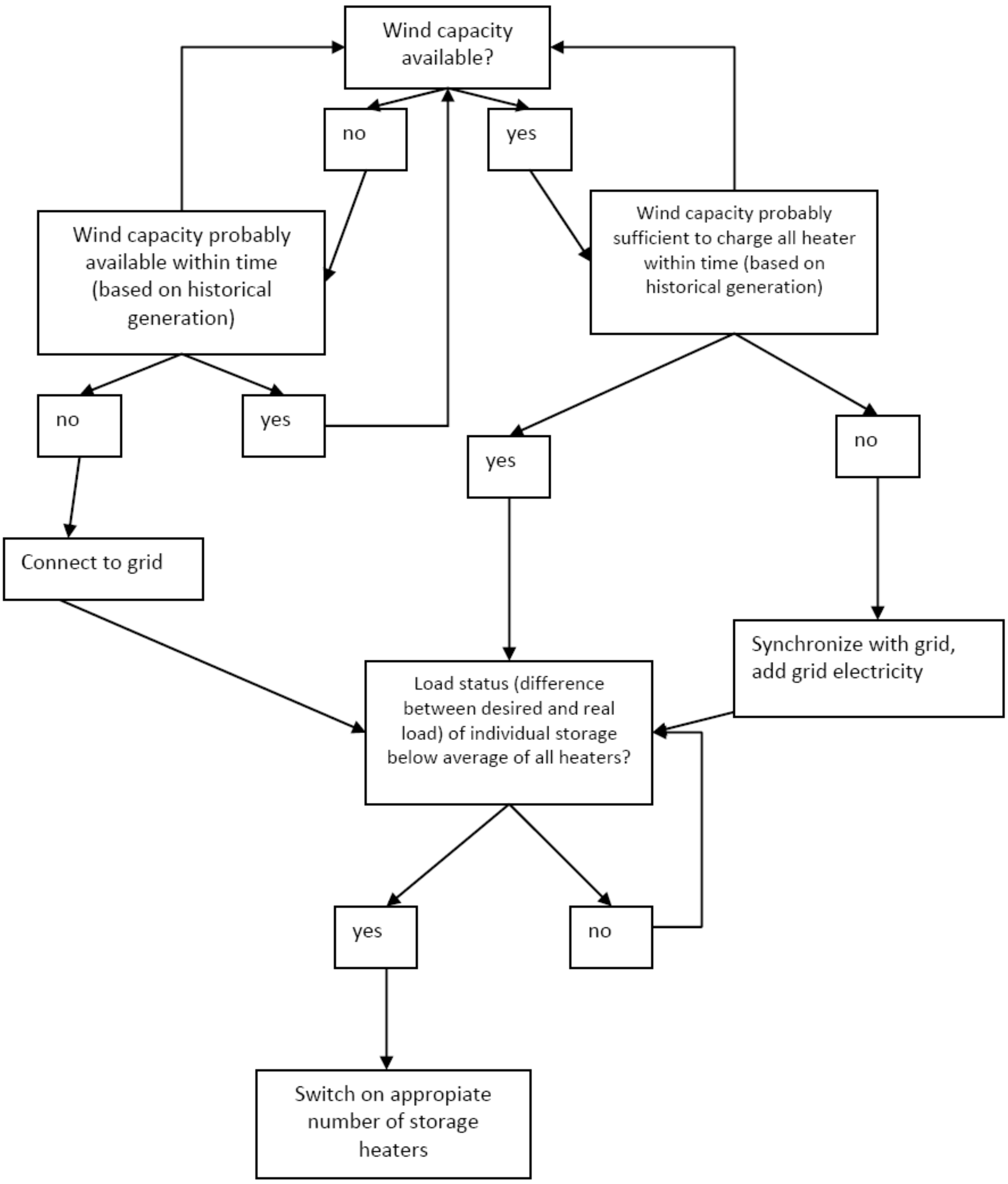
Annex 2. 6. The wind turbine power curve for DHS in Horve, Castlebay

Nodex , SÜDWIND S.46/600 - 51.5m, hub height 51.5m	600kW		NEG Micon, NM 52/900. Contact NEG Micon, salesinfo@negmicon-usa.com .	900kW	
	0	0		4	27
	1	0		5	65
	2	0		6	118
	3	4		7	199
	4	17		8	304
	5	44		9	421
	6	87		10	541
	7	145		11	640
	8	227		12	725
	9	327		13	791
	10	454		14	839
	11	588		15	872
	12	600		16	891
	13	600		17	900
	14	600		18	898
	15	600		19	892
	16	600		20	882
	17	600		21	872
	18	600		22	860
	19	600		23	852
	20	600		24	846
	21	600		25	843
	22	600		26	0
	23	600		27	0
	24	600		28	0
	25 - 30	600		29	0

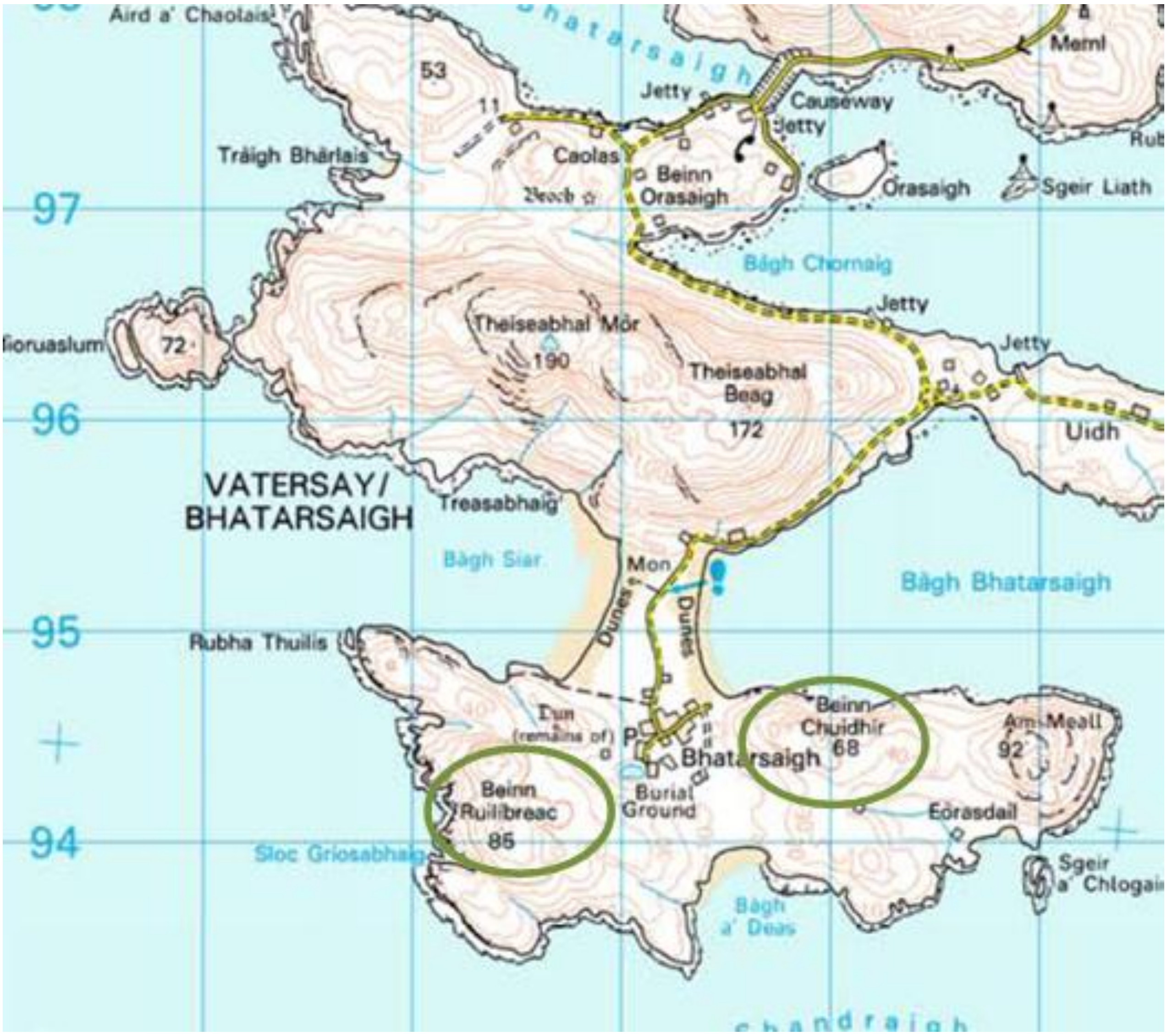
Database of Retscreen Software and Nodmad Desktop

Annex 3. Vatersay project

Annex 3. 1. ***Logical flow diagram for the Wind2heat control system***



Annex 3. 2 ***Location of proposed wind turbine sites.***



Proposed Sites: Source: (WEST COAST ENERGY LTD, 2006 p. Fig 6)

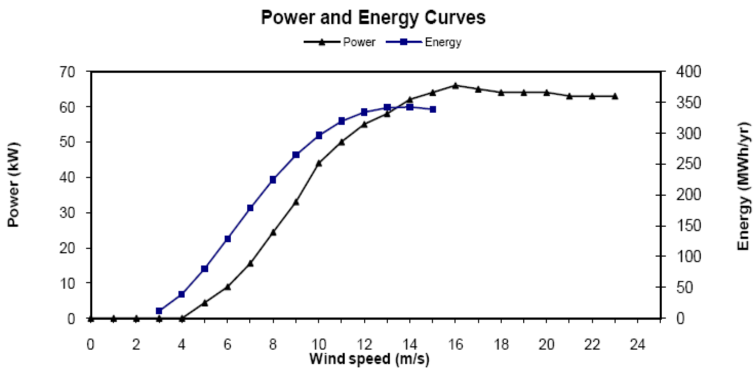
Annex 3. 3. ***Power curve for possible wind turbines***

RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	50	See Product Database
Hub height	m	25.0	6.0 to 100.0 m
Rotor diameter	m	15	7 to 80 m
Swept area	m²	177	35 to 5,027 m²
Wind turbine manufacturer		Entegrity Wind Systems	
Wind turbine model		AOC 15/50	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	11.6
4	0.0	39.1
5	4.4	80.5
6	8.9	129.1
7	15.6	178.6
8	24.4	224.6
9	33.0	264.4
10	44.0	296.1
11	50.0	319.2
12	55.0	333.9
13	58.0	341.1
14	62.0	342.3
15	64.0	338.7
16	66.0	-
17	65.0	-
18	64.0	-
19	64.0	-
20	64.0	-
21	63.0	-
22	63.0	-
23	63.0	-
24	-	-
25	-	-



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15/03/2009; WIND3

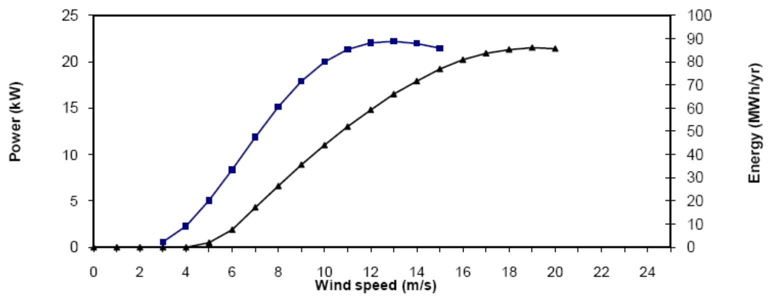
RETScreen® Equipment Data - Wind Energy Project

Wind Turbine Characteristics		Estimate	Notes/Range
Wind turbine rated power	kW	20	See Product Database
Hub height	m	18.0	6.0 to 100.0 m
Rotor diameter	m	10	7 to 80 m
Swept area	m²	79	35 to 5,027 m²
Wind turbine manufacturer		Vergnet	
Wind turbine model		VERGNET GEV 10/20	
Energy curve data source	-	Standard	Rayleigh wind distribution
Shape factor	-	2.0	

Wind Turbine Production Data

Wind speed (m/s)	Power curve data (kW)	Energy curve data (MWh/yr)
0	0.0	-
1	0.0	-
2	0.0	-
3	0.0	2.3
4	0.0	9.2
5	0.5	20.2
6	1.9	33.5
7	4.3	47.5
8	6.6	60.6
9	8.9	71.6
10	11.0	79.9
11	13.0	85.3
12	14.8	88.1
13	16.5	88.8
14	17.9	87.8
15	19.2	85.8
16	20.2	-
17	20.9	-
18	21.3	-
19	21.5	-
20	21.4	-
21	-	-
22	-	-
23	-	-
24	-	-
25	-	-

Power and Energy Curves



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Annex 4. Barratlantic Fishery Project

*Annex 4. 1*Data Collected and analyzed of energy audit Barratlantic

Analyzing the data collected from Barraatlantic fish factory

Place: Barraatlantic fish factory
Date: 23-Feb-09
Anzlyzer: Charles,Dereje,Truc
Code: IC09_B_FC_Analysis

No.	Equipment	End Use	Unit	Rated Power		Operation Time			Use	Energy
				kilo-Watt		h/d	d/w	h/y	Factor	MWh/y
A	**Processing equipment**									
1	Electricity water heater	heating	1	18.0		24.0	7	8736	60%	94.35
			1					0		0.00
2	Packing Machine 1	mechanical	1	11.3	3hrs/week	9.00	5	2340	70%	18.43
3	Packing Machine 2	mechanical	1	6.0		9.0	5	2340	70%	9.83
			1					0		
4	Pressure Washer	mechanical	1	0.37	6hr/5days/week	9.0	5	2340	70%	0.61
			1					0		0.00
5	Strapping machine(95kVA)	mechanical	2	1.2	2hrs/day	9.0	5	2340	60%	1.67
			1					0		
6	Skinning machine	mechanical	1	5.0	2hrs/5day/week	9.0	5	2340	60%	7.02
7	main conveyor	mechanical	3	0.4	4hrs/5day/week	9.0	5	2340	60%	0.52
10	Hot water compressor	heating/mech	1	3	6hrs/day	9.0	5	2340	70%	4.91
11	Cabin plant	mechanical	1	1.1	5hrs/5day/week	9.0	5	2340	60%	1.47
12	Skinning machine 2		1	0.7		9.0	5	2340	70%	1.15
13	Air Compressor	phuenmatic f	1	11.0		9.0	5	2340	60%	15.44
	Subtotal A									**155.40**
B	**Cooling equipment**									
1	**Cold storage 2**	Cooling								
	compressor, a		1	18.2		24.0	7	8736	70%	111.05
	Evaporating temperature			(neg)34 oC				0		
	Floor Area (7.37Wx 14.961Lx3.91H)		1					0		0.00
	Working temperature		1	neg 20 oC				0		
			1					0		0.00
	compressor, b, pluss 2 fans(0.49)		1	10.2		24.0	7	8736	70%	62.25
	Floor Area (7.715Wx9.514Lx5H)							0		0.00
			1					0		0.00
2	**Cold storage 1**	Cooling	1					0		0.00
	compressor		1	12.0		24.0	7	6552	70%	55.04
			1					0		0.00
3	**Landing Store**	Cooling	1					0		0.00
	Working temperature			0 oC				0		
	compressor pluss 2fans (100w)		1	4.2		12.0	5	3120	75%	9.83
	Floor area (5.806Wx11.77Lx4.25H)									0.00
4	**Ice machine**	Cooling	1					0		0.00
	compressor system		1	13.7		12.0	5	3120	80%	34.12
										0.00
5	Blast Freezer	cooling	1	124.0	5hrs/day	5.0	5	1300	80%	128.96
6	Glazing Compressor	Cooling	1	5.1	5hrs/day	5.0	5	1300	80%	5.30
			1					0		0.00
	Subtotal B									**406.55**
C	**Office equipment**									
1	Computers(Pc)		5	1.104	9.0	9.0	5	2340	40%	1.03
	Computers(Lap-Top)		2	0.36	9.0	9.0	5	2340	40%	0.34
								0		0.00
2	Lights(Office)		34	0.025	9.0	9.0	5	2340	100%	0.06
	Lights(Process Room)		1	0.225	9.0	9.0	5	2340	100%	0.53
	Lights(Others)		6	0.250	9.0	9.0	5	2340	100%	0.59
								0		0.00
3	Printers		3	0.95	9.0	9.0	5	2340	30%	0.67
	Copier		1	0.35	9.0	9.0	5	2340	30%	0.25
	Subtotal C									**3.45**
D	**Other Equipment**									
1	Freezer		1	0.5	24.0	24.0	7	8736	70%	3.06
2	Fridge		2	0.25	24.0	24.0	7	8736	70%	1.53
	Fridge		1	0.75	24.0	24.0	7	8736	70%	4.59
3	Micro-wave(1)		1	0.75	4.0	4.0	5	1040	40%	0.31
	Micro-wave(2)		1	0.5	4.0	4.0	5	1040	40%	0.21
4	Dispenser (Snack)		1	1.0	24.0	24.0	7	8736	60%	5.24
5	Dispenser (Drink)		1	0.75	24.0	24.0	7	8736	60%	3.93
6	Dispenser(Warm Water)		2	1.5	6	6	5	1560	40%	0.94
7	coocker(1)		1	2.5	9	9	5	2340	70%	4.10
	coocker(2)		1	2.5	4	4	5	1040	30%	0.78
8	Light Packing Machine		1	0.55	3 days in a week	2	3	312	30%	0.05
9	Hand Drier		2	2.6		5	5	1300	10%	0.34
10	Soap Dispenser		1					0		0.00
11	Washing Machine		1	2.5	per week	1.2	5	312	70%	0.55
12	Radio Phone		1	0.3		3	5	780	30%	0.07
13	Welding Machine		1	7.47	per week	1.2	5	312	60%	1.40
14	Pressure Washing Machine		1	2.5	per week	1.2	5	312	80%	0.62
15	Small Air Compressor 1		1	7.5	per week	1.2	5	312	40%	0.94
	Small Air Compressor 2		1	7.5				0		0.00
16	**Heaters**							0		0.00
	Winter		1	3	9	5	5	325	80%	0.78
	Throughout		1	7.5	24	24	7	2184	80%	13.10
	Office time		1	10.5	9	9	5	2340	80%	19.66
	Never used		1	3	0			0	80%	0.00
	Subtotal D									**62.18**
				314.4215						
	Total									**627.58**

Annex 4. 2. Power Consumption Profile Per day in Winter Time (Meter Reading)

Measure the power consumption profile

Place: Barraatlantic fish factory
Date: Feb 25,2009
Monitored By: Charles,Dereje,Truc
Code: IC09_B_FC_Monitoring

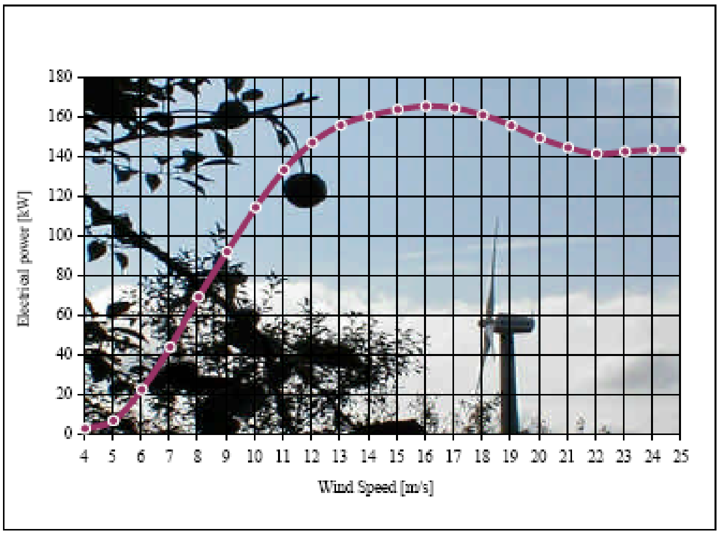
	Time	Power	Remark
	every 15mins	kWh	
	9:00		
	9:15		
	9:30		
	9:45	x10	
1	10:00	600322	Start Recording
2	10:15	600325	
3	10:30	600330	
4	10:45	600334	
5	11:00	600339	
6	11:15	600343	
7	11:30	600348	
8	11:45	600352	
9	12:00	600357	
10	12:15	600361	
11	12:30	600366	
12	12:45	600370	
13	13:00	600374	
14	13:15	600379	
15	13:30	600383	
16	13:45	600388	
17	14:00	600392	
18	14:15	600396	
19	14:30	600401	
20	14:45	600405	
21	15:00	600409	
22	15:15	600413	
23	15:30	600418	
24	15:45	600422	
25	16:00	600425	
26	16:15	600429	freezer
27	16:30	600431	
28	16:45	600432	
29	17:00	600433	End of working time
30	17:15	600434	
31	17:30	600435	
32	17:45	600436	0.91
33	18:00		

Annex 4. 3. Power Curve for NORWIN 29-STALL-160 Kw

NORWIN 29-STALL-160 kW
Power Curve and Energy Production (AD=1.000)

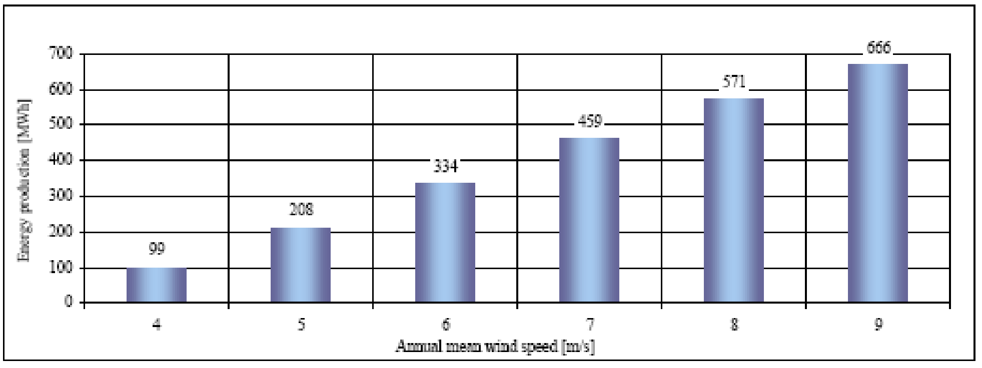
The power curve is for our 160 kW turbine, with a rotor diameter of 29 m, single generator and featuring Stall Regulation.
The power curve is valid for an air density equal to 1.000 kg/m3, clean blades and undisturbed horizontal inflow.
(In the stall range, at wind speeds above 16 m/s, the power curve may deviate some from the one stated below).

Important! The 160 kW turbine is only applicable for air densities in the range of 1.150 kg/m3 down to 0.900 kg/m3.



Wind speed [m/s]	Elect. power [kW]
4	0
5	4
6	20
7	41
8	67
9	89
10	112
11	131
12	145
13	153
14	158
15	161
16	163
17	162
18	159
19	153
20	147
21	142
22	139
23	140
24	141
25	141

The annual energy production is calculated for different annual mean wind speed in hub height.
A Rayleigh wind speed distribution and 100 % availability is assumed



N-NW29-160-1000-01.xls

Annex 4. 4 Cooling Storage Tank[66]

CHARACTERISTICS FOR 1 m^3 STL

Nodule type	Phase change temperature °C	Latent heat Ql kWh/m^3	Sensible heat solid Qss $kWh/°C.m^3$	Sensible heat liquid Qsl $kWh/°C.m^3$	Heat transfer crystallisation Kvcr $kW/°C.m^3$	Heat transfer PCM fusion Kvfu $kW/°C.m^3$	Nodule weight Kg	Toxicity LD50 value in mg/kg a	Operating temperature limits (°C)
SN.33	- 33.0	44.6	0.70	1.08	1.6	2.2	724	2,600	
SN.29	- 28.9	39.3	0.80	1.15	1.6	2.2	681	1,200	-40°C
SN.26	- 26.2	47.6	0.85	1.20	1.6	2.2	704	1,200	to
SN.21	- 21.3	39.4	0.70	1.09	1.6	2.2	653	1,300	+60°C
SN.18	- 18.3	47.5	0.90	1.24	1.6	2.2	706	2,700	
IN.15	- 15.4	46.4	0.70	1.12	1.6	2.2	602	8,400	
IN.12	- 11.7	47.7	0.75	1.09	1.6	2.2	620	5,000	-25°C
IN.10	- 10.4	49.9	0.70	1.07	1.6	2.2	617	11,000	
IN.06	- 5.5	44.6	0.75	1.10	1.6	2.2	625	18,000	to
IN.03	- 2.6	48.3	0.80	1.20	1.6	2.2	592	58,000	
IC.00	0	48.4	0.70	1.10	1.6	2.2	558	85,000	
AC.00	0	48.4	0.70	1.10	1.15	1.85	560	85,000	+60°C
AC.27	+27.0	44.5	0.86	1.04	1.15	1.85	867	2,500	

EXAMPLE OF TANK CHARACTERISTICS

Consult us for alternative dimensions.

Volume in m^3	External diameter D mm	Total length without flanges L mm	External surface to be insulated m^2	Inlet and outlet flanges ES mm	Number of cradles	Empty weight PE 4.5 bars kg	Heat transfer fluid volume m^3
2	950	2,980	10	40	2	660	0.77
5	1,250	4,280	18	50	2	1,050	1.94
10	1,600	5,240	29	80	2	1,890	3.88
15	1,900	5,610	37	100	2	2,540	5.82
20	1,900	7,400	47	125	3	3,200	7.77
30	2,200	8,285	61	150	3	4,580	11.64
50	2,500	10,640	89	175	4	6,860	19.40
70	3,000	10,425	106	200	4	8,400	27.16
100	3,000	14,770	147	250	6	11,700	38.80

Standard pressure drop 2.5 mWG at nominal flow rate - See our technical manual

[66] Cristopia energy systems: thermal storage http://www.cristopia.com/english/products/indproducts.html