

ARCTIC TECHNOLOGY CENTRE



ARCTIC TECHNOLOGY CENTRE - DTU

FIELDWORK REPORT

Wind Energy for Itilleq, Greenland

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Chapter 1

Introduction

Itilleq is a small settlement located 45 km south of Sisimiut, in the Qeqqata municipality, west Greenland. Nowadays it is possible to count about 110 inhabitants, the most of them hunters and fishers. As can be seen in Figure 1.1, the standard house is represented by a single-family house, provided by electricity and fresh water. The electricity is produced by a small power plant whereas the fresh water is obtained both from a desalination process and pumping the fresh water extracted from the ground. For the heating purposes, an oil burner is commonly used. In addition to the people houses, it is also present a small shop, a municipality office, a church, a school and a kindergarten.



Figure 1.1: Itilleq Settlement

Itilleq represents a perfect example of isolated system from an energy point of view. As in many other small settlements in Greenland, the power plant is mainly composed by three diesel generators. The diesel has to be transported by cargo ship or helicopter from the the main cities, namely Sisimiut or

Nuuk. In addition to this, the operator presence is constantly needed to ensure the correct functioning of the plant. These factors lead to a very high electricity price, one of the highest in the whole Greenland: 7.62 DKK/kWh¹.

The purpose of this report is to investigate the possibility of a reduction in the energy price by the installation of one or more wind turbines in order to supply the electricity needs of the settlement. The feasibility study will be conducted analysing the hourly consumption data from the electricity meters installed at the consumers. The total value will be compared with the estimated energy produced by the wind turbines, calculated from the measured wind speeds. Different types and brand of wind turbines will be considered.

Since the wind energy is variable, an auxiliary source will be needed when the production is too low. The diesel generators used nowadays to satisfy the electricity demand can be used. Moreover, a damp load has to absorb the superabundant power: two possibilities will be discussed. The water production plant, equipped with a larger tank, can work as a damp load storing an additional quantity of water that will be used afterwards. In addition to this, electric heaters can be installed in the private house in order to provide space heating.

An economic analysis will be conducted in order to estimate the effective savings and the new energy price.

¹http://www.nukissiorfiit.gl/fileadmin/user_upload/PDF_filer/AArsberetninger/Enhedsomkostninger_2009.pdf

Chapter 2

Consumption Analysis

In this chapter, the monthly electricity and water production and consumption are analysed. These data will provide a global overview of the present needs of the Itilleq inhabitants.

2.1 Electricity

The electricity is provided by the small power plant located in the middle of the town. The power plant was composed by three diesel generators:

- *Generator 1*
Brand: IVECO
Model: F4AE0685A
Power: ?
S/N: F101-00429679
- *Generator 2*
Brand: VDE-STIHOLT
Model: LHTG/HC244E
Power: 64 kW
Year 1986
- *Generator 3*
Brand: VDE-STIHOLT
Model: LHTG/HC244E
Power: 64 kW
Year 1986

The engines are controlled by a regulation system from Domex Electric (S/N 93-81134-1, Year 1993).

Recently, after the fieldwork activity, the generators have been substituted by three SISU 620 DSG 110 kW diesel generator coupled with a Stamford UCI274F generator. This represents the actual configuration for the electricity generation.

The plant is controlled and maintained by the local energy company, Nukissiorfiit. The office in Sisimiut has provided all the data related to the plant for the last 10 years. However, the available data are referred to the previous configuration.

The last year is considered, since it was not possible to verify that the equipment installed was the same along the whole data timespan. The energy production and the efficiency of the plant is plotted against the last year's months in Figure 2.1.

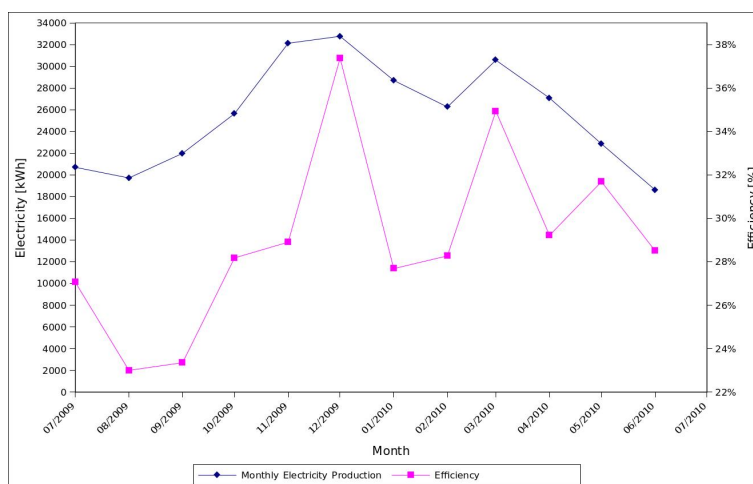


Figure 2.1: Power plant, production and efficiency

It is possible to observe that the plant was working with a relative high efficiency, between 20% and 38%. Furthermore the electricity production in this reference year was between 18000 kWh and 33000 kWh per month. The different trends between electricity production and efficiency can be explained considering that the power plant was composed by three different diesel generator, which are turned on in case of necessity. The use sequence of the generators was not always the same, since it is more convenient to maintain the same degree of utilization, and thus deterioration, among the three engines.

The consumption of the power plant is subtracted to the previous values: the net consumption of the settlement is then calculated. The results are reported in Table 2.1 and in Figure 2.2.

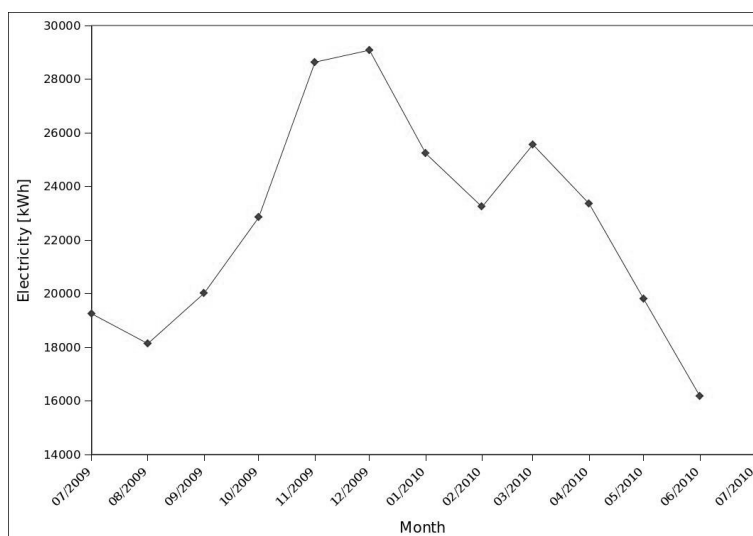


Figure 2.2: Monthly Electricity Consumption

Month	Electricity Consumption [kWh]
7/2009	19255
8/2009	18138
9/2009	20019
10/2009	22842
11/2009	28639
12/2009	29088
1/2010	25232
2/2010	23240
3/2010	25565
4/2010	23354
5/2010	19800
6/2010	16167

Table 2.1: Monthly Electricity Consumption

A deeper analysis of the consumption can be obtained considering the load composition. Due to communication problems related to the language, it was not possible to enter and analyse the private house loads. A possibility to conduct this analysis in the future relies on the student of the local school: the teacher has given his availability to start this project and provide the data to the Arctic Technology Centre (DTU). The loads in the public buildings have been mapped and reported in Appendix A.

2.2 Water

The city of Itilleq has a public fresh water distribution service. The scheme of the pipes (blue lines) and the sources are shown in Figure 2.3.

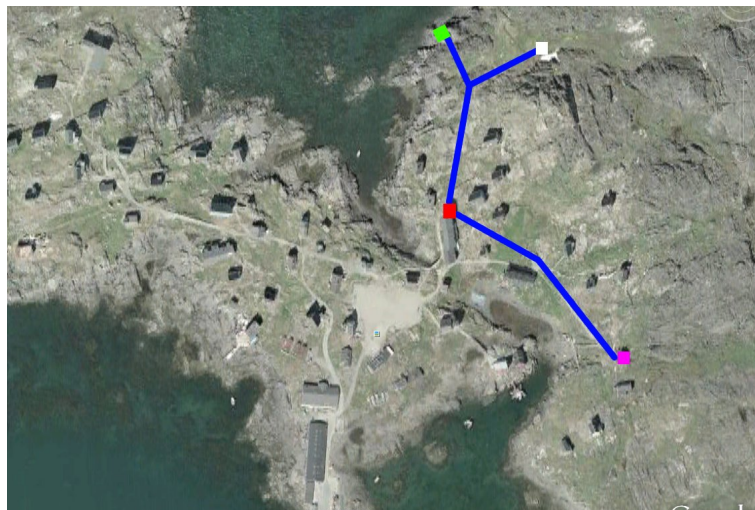


Figure 2.3: Fresh Water Facilities Map

The fresh water is collected from three main sources:

- *Reverse Osmosis System*

The desalination plant has been installed in Itilleq in 1994. The salt water is taken from a point in the sea far from the coast by an underground pipe. The pumping pressure is provided by two 4 kW pumps that are placed in a small house near the coast (green square). The salt water is sent to the plant (red square) in the middle of the town, where the desalination process is conducted by two reverse-osmosis systems. The water is then stored in three tanks (2x 3000 l and 1x 2000 l) for a total capacity of 8000 l. A scheme of the desalination plant, taken from a picture in loco, is shown in Figure 2.4.

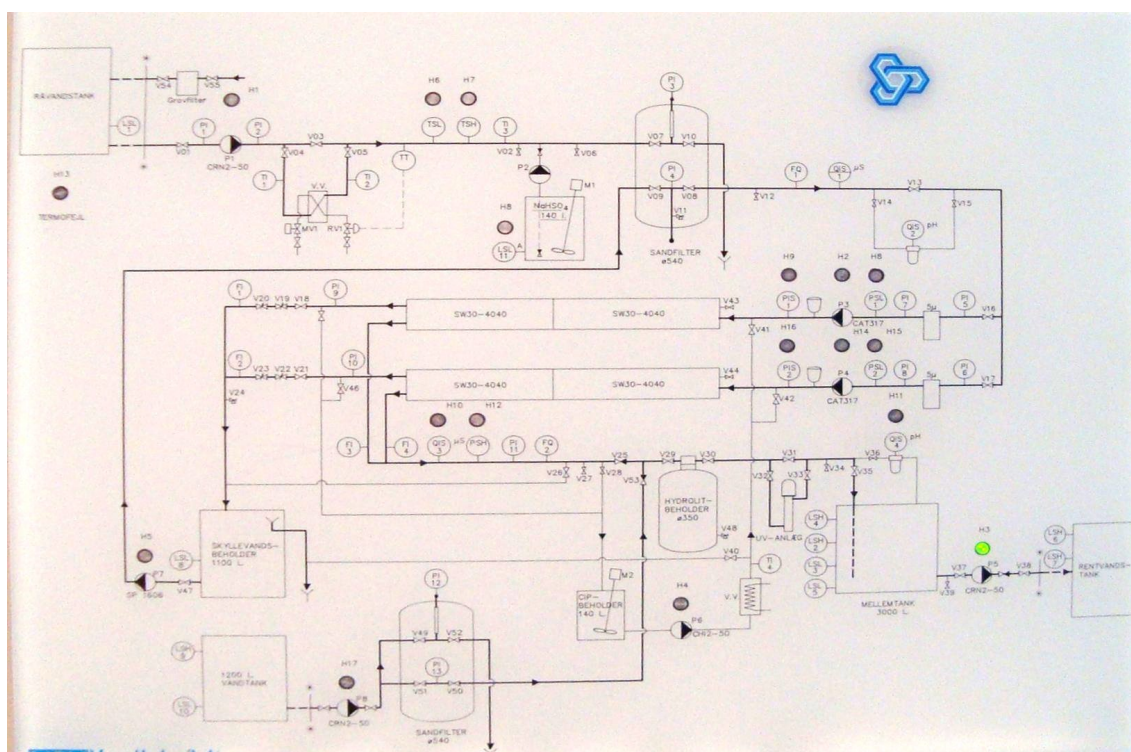


Figure 2.4: Desalination Plant Functioning Scheme

From the scheme it is possible to understand that the functioning of the desalination system is controlled by two level sensors placed inside the tanks. The system is supposedly changed since the panel installation because two other water sources were added.

- *Old Well*

The fresh water can be directly extracted from the ground through wells. In March 2004, a well in the town (purple square) has been equipped by pumps and two 1150 l tanks, in order to extract and store the fresh water. The fresh water is then sent to the fresh water tanks in the desalination plant.

- *New Well*

In December 2008, a new well just outside the town (white square) has been equipped with pumps in order to provide an additional amount of fresh water. The fresh water in this case is extracted and directly sent to the fresh water tanks in the desalination plant.

This system is controlled and maintained by Nukissiorfiit. The monthly data provided starts from November 1999. However, the system has experienced several changes until the connection of the newest well: only the data from December 2008 can be considered.

It is anyway possible to use the previous data to conduct some considerations. The maximum production of 350 m^3 of water per month before the installation of the first well in 2004 is increased up to 620 m^3 per month. Moreover, the electricity needed to obtain fresh water during summer and autumn, when the demand is higher, is halved with respect to the 2003 situation. During winter the energy efficiency is lower than 2003, but the demand is very low too.

Considering the period from December 2008 until July 2010, the monthly fresh water production from each source is shown in Figure 2.5

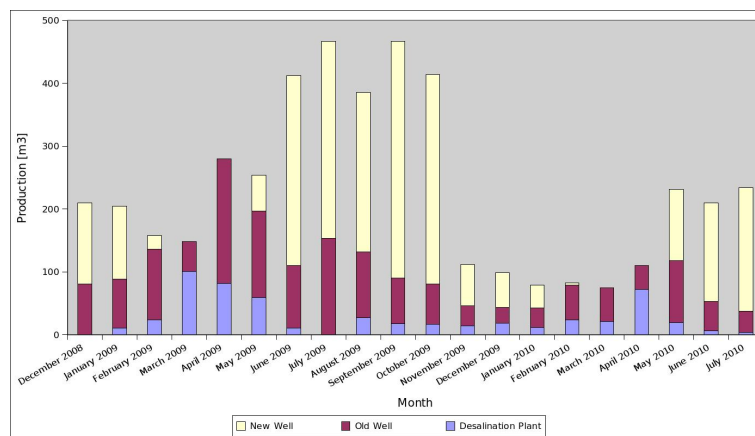


Figure 2.5: Water Production for each different source

It is possible to observe that the New Well provides considerable fraction of fresh water. However, in April and May the well is not providing any water: the Old Well and the Desalination Plant have to satisfy all the water demand. This is probably related to the fact that the aquifer is empty or frozen in that period. In the other periods the New Well production is very high, probably due to its cheap extraction.

The pipes need to be heated because of the negative temperatures during winter. Electric elements are then placed along the production and distribution pipes. The electricity consumption with respect to the different pipes are shown in Figure 2.6.

Their consumption is related only to the air temperature, since they are activated by a temperature sensor. It is interesting to notice that in April and May, even if the New Well is not extracting any water, its pipe continues to be heated. The temperature is kept positive in order to avoid the freezing of the water in the pipe. Emptying the pipe in these months would be a more efficient way to manage the system.

The water consumption is shown in Figure 2.7. The energy company data highlights the local fish factory consumption, that represents in some periods of the year a consistent percentage of the total.

It is possible to observe that the highest water consumption is related to the month from June to October.

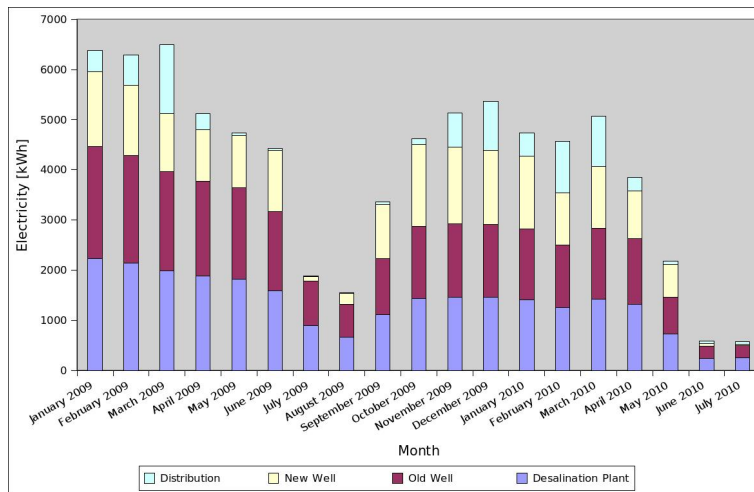


Figure 2.6: Pipe Heating Electricity Consumption

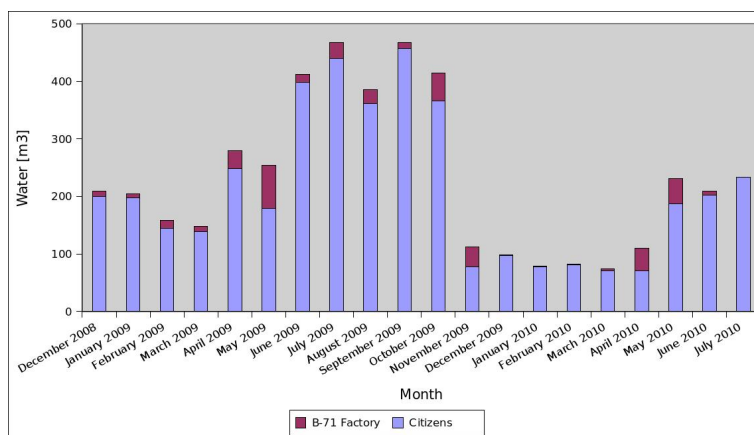


Figure 2.7: Water Consumption

Chapter 3

Wind Speed Analysis

A meteorological mast is present in Itilleq since August 2009. It is located on the top of a small hill outside the town. Its coordinates are **66°34.701' N, 53°29.191' W**. Even if the fieldwork activity has shown that the position of the mast is not the optimal, since the wind from some direction is shaded by the configuration of the surrounding hills, the data from this mast are the only ones available in the zone. The position of the mast is shown in Figure 3.1.



Figure 3.1: Position of the meteorological mast

The mast was equipped with an anemometer and a wind vane, installed at 10 meters high, and a temperature sensor, installed at more than 5 meters. During the fieldwork maintenance the wind anemometer (NRG #40C, S/N: 069165) and vane have been moved respectively to 11.1 m and 10.8 m whereas the temperature sensors has been placed at a more conventional height of 2.1 m. The mast scheme is shown in Figure 3.2.

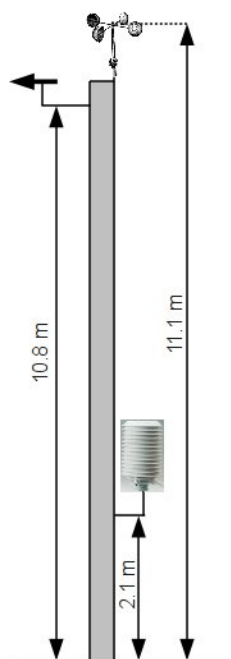


Figure 3.2: Mast Scheme

During the maintenance, the data stored in the data-logger were saved in order to be analysed. With these last measurements, a whole year of wind data for Itilleq is now available. Some measurements are missing due to technical problems: in these periods, the value for the wind speed is set to $0 \frac{m}{s}$. The data are elaborated in Matlab; the script is reported in Appendix B.1. The 10-minute average wind speeds are shown in Figure 3.3.

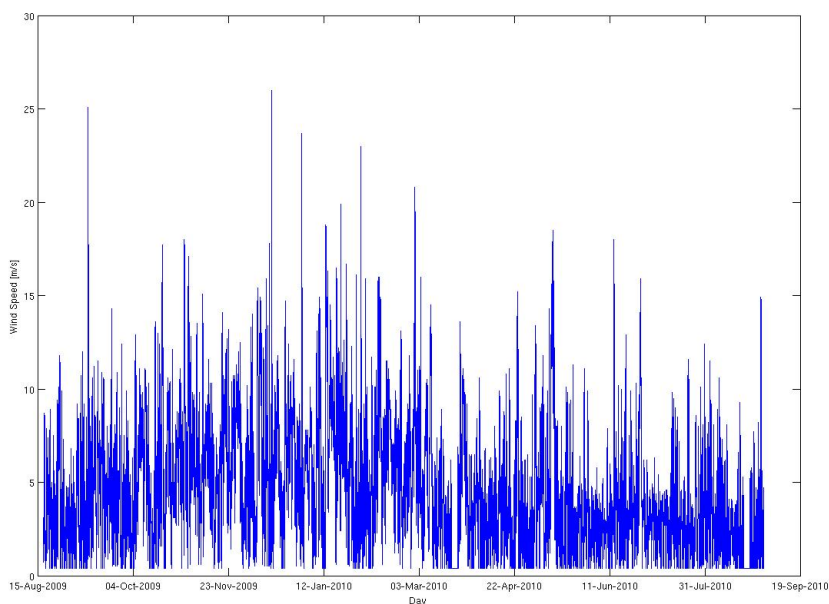


Figure 3.3: Wind Speeds

It is possible to observe that the wind speed presents some high peaks. The average wind during winter is higher than in summer. The frequency table of the wind speeds can provide informations about the wind distribution. The plot is shown in Figure 3.4.

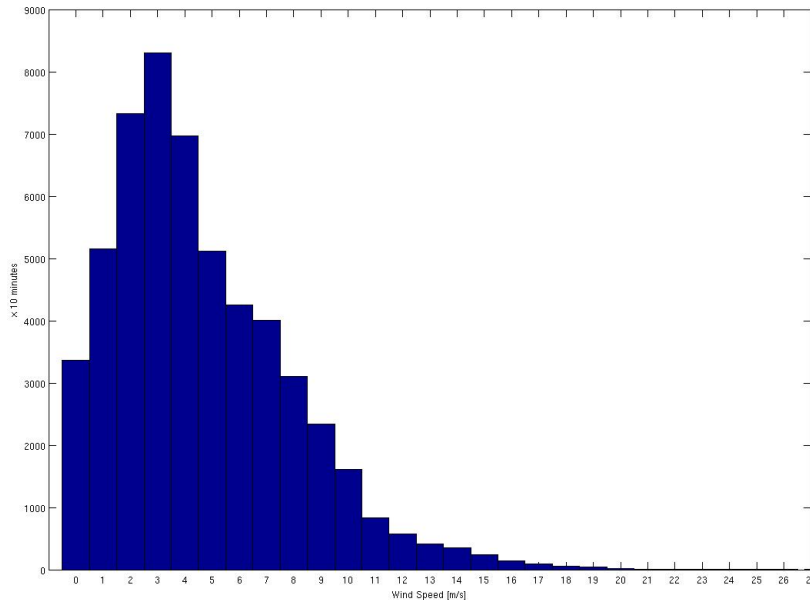


Figure 3.4: Wind Speed Frequency

The average wind speed estimated with all the available data is calculated to be **4.68 $\frac{m}{s}$** . This average speed is high enough to consider the installation of one or more wind turbines in the area. In addition to this, the average wind speeds measured by the meteorological masts installed in Sisimiut and Sarfannguaq in the period from August 2009 are lower than in the previous years: the Itilleq data may refers to a lower wind speed period. This can not be confirmed by other measurements, thus the data available are assumed to be representative. The maximum wind speed measured is under 40 $\frac{m}{s}$. A wind turbine in class IEC III (Low Wind) can be suitable¹.

¹<http://www.vestas.com/en/wind-power-plants/wind-project-planning/siting/wind-classes.aspx>

Chapter 4

Wind Energy Integration

The wind energy integration in the grid as the main source of electricity presents several challenges.

The first problem is related to the choice of the wind turbine. Its size has to be chosen in relation to the electricity consumption. A simulation conducted on a whole year is considered in order to choose the most suitable size.

The wind energy is a variable source as the most of the renewable energies. An auxiliary source and dump loads are necessary to produce or absorb the electricity when the production does not match the consumption. The first role can be played by the diesel generators that are actually installed in the village. Two possibilities for the dump load system will be discussed: the desalination plant and the electric heaters.

4.1 Turbine Choice

The comparison between the potential production of a wind turbine installation and the electricity demand is conducted using the wind turbine power curves. From the wind speed data analysed in the previous chapter, considering different wind turbine power curves, an estimation of the energy production can be calculated. The one hour consumption data are provided by Nukissiorfiit and elaborated in Matlab; the script is reported in Appendix B.2.

The one-hour production and consumption in the period from September 1st 2009 to August 30th 2010 are compared. The comparison Matlab script is reported in Appendix B.3. Three parameters have been considered to evaluate the wind turbine suitability:

1. The amount of electricity produced in one year, that has to be compared with the amount of electricity consumed (about 300 *MWh*);
2. The amount of electricity consumed exceeding the production, a measure of the necessary diesel generator operation, and its percentage relative to the total consumption;
3. The amount of electricity produced exceeding the consumption, a measure of the necessary dump load, and its percentage relative to the total energy consumption.

The objective of this analysis is to find a solution that is satisfying the first criteria and minimising the second one. The third criteria indicates how many changes have to be introduced in the system. It is not, in fact, depreciable to have an exceeding production of energy, if it can be used without damaging the

grid. The value of 200 kW is considered as an upper limit for the exceeding power that can be absorbed by the grid.

Even if the simulation is not perfect, since the comparison is not on one-second scale, it can be anyway considered reliable because the auxiliary energy from the diesel generator can be provided quickly.

The electricity consumption in the whole period considered (one year) is about 300 MWh. Considering the annual average wind speed, the size of the installed capacity for a wind turbine, estimated using the tables reported in the manufacturing companies sites, is $200 \div 300$ kW.

In addition to this, during winter the temperatures in Itilleq can reach -35 °C¹. They can affect the functioning of the wind turbine and have to be considered in the choice.

In the following, wind turbines with different size are considered. The simulation results will be discussed at the end, in order to identify the most suitable model for Itilleq.

4.1.1 Entegriety EW 50

The Entegriety EW 50 is a 50 kW wind turbine manufactured by the Canadian Company Entegriety².



Figure 4.1: Entegriety EW 50

It is a horizontal variable speed wind turbine. The power regulation is obtained by a passive stall. Its rated output is 50 kW with a wind speed of $11.3 \frac{m}{s}$. The rotor diameter is 15 m.

The power curve is reported in Figure 4.2. The cut-in speed is quite high: $4 \frac{m}{s}$.

Considering the dump load power absorption limit of 200 kW, the maximum number of wind turbine that can be installed is seven. Since the turbine control is passive, the output power from each turbine can not be controlled. A measure to limit the electricity overproduction is to disconnect some of the wind turbines from the grid in case of high wind speeds. This would lead to a decrease in the necessary dump load without a significant increase in the diesel generator production. In this simulation, if the

¹<http://www.sisimiut.gl/Municipality/About-the-municipality.aspx>

²<http://www.obliquedesign.com/entegrietywind/site/index.html>

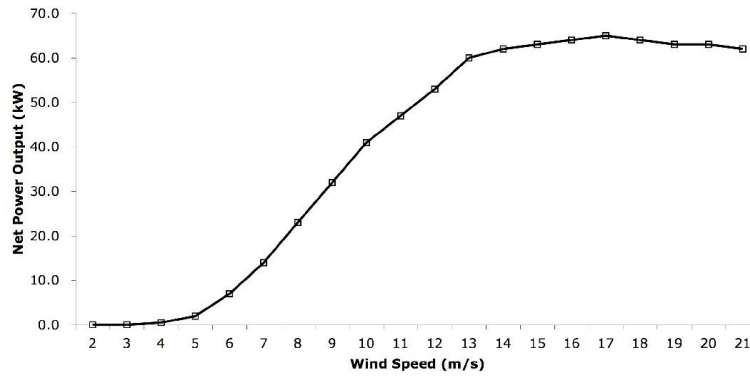


Figure 4.2: EW 50 Power Curve

energy produced from each turbine is higher than 30 kW, five turbines are disconnected. The results are reported in Table 4.1.

Number of WT	Energy Yearly Produced	Missing Electricity	Exceeding Electricity
7	328 MWh	135 MWh (52.0%)	203 MWh (78.6%)

Table 4.1: EW 50, simulation results

Despite the high number of wind turbines installed, the abatement in the diesel generator use is limited to 48%. This low value is related to the high cut-in speed that characterizes this wind turbine.

Entegrity provides a version of this model with special equipment suitable for the Arctic conditions. The stated temperature limit that can be reached is -40 °C.

4.1.2 WES 18

The WES 18 is a 80 kW wind turbine manufactured by the Dutch Company WES³.



Figure 4.3: WES 18

³http://wes18.com/index/3/wes18_home

It is a horizontal variable speed wind turbine. The power regulation is obtained by a passive pitch adjustment. Its rated output is 80 kW with a wind speed of 12.5 $\frac{m}{s}$. The rotor diameter is 18 m.

The power curve is shown in Figure 4.4. It is possible to observe that the cut-in speed is very low, 2.7 $\frac{m}{s}$.

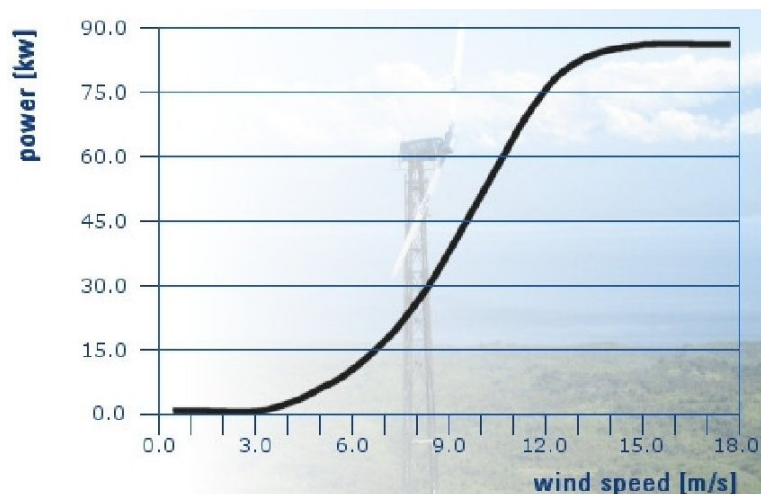


Figure 4.4: WES 18 Power Curve

The simulation is conducted with six wind turbines. The power regulation is passive so the maximum power production from each wind turbine is set to 40 kW. If the production is exceeding this value, all but one wind turbines are disconnected. The results are reported in Table 4.2.

Number of WT	Energy Yearly Produced	Missing Electricity	Exceeding Electricity
6	375 MWh	106 MWh (40.9%)	222 MWh (85.9%)

Table 4.2: WES 18, simulation results

The abatement of the diesel generator is use is higher than in the previous case: 58.1%. Moreover, the overproduction is not sensibly increased and can be used for non-continuous dump load proposal.

An estimation for the total project price is calculated by the WES Sales Office: the investment for one wind turbine is 225000 € \approx 1680000 DKK.

4.1.3 Northern Power Systems - Northwind 100 Arctic

The Northwind 100 Arctic produced by Northern Power Systems is based on the Northwind 100 and includes some technical equipments and design changes that makes it suitable for the Arctic weather conditions⁴.

It is a horizontal variable speed wind turbine, with a stall control system. Its rated output is 100 kW with a wind speed of 15 $\frac{m}{s}$. The rotor diameter is 14.5 m. The permanent magnet direct drive technology makes this turbine suitable for the harsh conditions in Itilleq during winter. Moreover, the blades are covered by an ice-block coating.

⁴<http://northernpower.com/wind-power-products/northern-power-arctic.php>



Figure 4.5: Northwind 100

The power curve is shown in Figure 4.6. The cut-in speed is stated to be $3.5 \frac{m}{s}$.



Figure 4.6: Northwind 100 Arctic Power Curve

The simulation is conducted as a first approach with three wind turbines. Since the turbine power regulation system is passive also in this case, the same measure to control the dump power as in the previous case is adopted: if the production from each wind turbine is exceeding 60 kW , all the wind turbines but one are disconnected from the grid. The results are reported in Table 4.3.

Number of WT	Energy Yearly Produced	Missing Electricity	Exceeding Electricity
3	328 MWh	117 MWh (45.3%)	187 MWh (72.25%)

Table 4.3: Northwind 100 Arctic, simulation results with three wind turbines

It is possible to observe that, despite the big number of wind turbine installed, the diesel generator use is still very high. If we increase the number of wind turbines by one, results do not improve sensibly, as can be seen in Table 4.4. Due to the presence of an additional wind turbine, in order to respect the

exceeding production power of 200 kW, the wind turbine maximum production in this simulation is set to 50 kW.

Number of WT	Energy Yearly Produced	Missing Electricity	Exceeding Electricity
4	373 MWh	109 MWh (42.3%)	223 MWh (86.3%)

Table 4.4: Northwind 100 Arctic, simulation results with four wind turbines

Adding one wind turbine does not lead to a consistent decrease of the diesel generator use. Moreover, it increases the necessary dump load.

4.1.4 WES 30

The WES 30 is the 250 kW wind turbine model produced by WES⁵.



Figure 4.7: WES 30

The characteristics are similar to the WES 18 model. The rated output is 250 kW and the rotor diameter is 30 m. The rated power is reached for a wind speed of 12.5 m/s. The same power regulation system as in the WES 18 is used.

The power curve is reported in Figure 4.8.

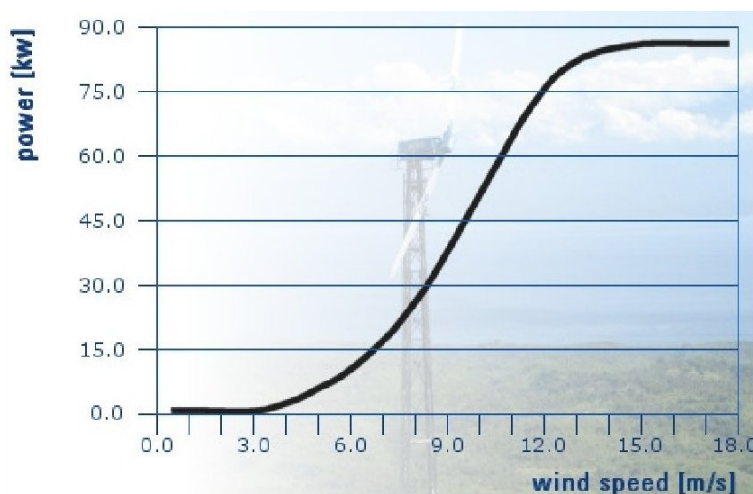


Figure 4.8: WES 30 Power Curve

⁵<http://www.wes30.com/>

The maximum production for each wind turbine is set to 70 kW . The simulation is conducted with three wind turbines and the results are reported in Table 4.5.

Number of WT	Energy Yearly Produced	Missing Electricity	Exceeding Electricity
3	424 MWh	112 MWh (43.3%)	277 MWh (107.2%)

Table 4.5: WES 30, simulation results

An estimation for the total project price is calculated by the WES Sales Office: the investment for one wind turbine is 450000 € \approx 3350000 DKK.

4.1.5 Enercon E-33

The E-33 is the smallest wind turbine produced by the German company Enercon⁶.



Figure 4.9: Enercon E-33

It is a horizontal variable speed wind turbine, with a variable pitch control system. Its rated output is 330 kW and the rotor diameter is 33.4 m . The rated power is reached for a wind speed of 13 $\frac{m}{s}$.

The power curve⁷ is shown in Figure 4.10. It is possible to observe that the cut-in speed is very low, 3 $\frac{m}{s}$.

The simulation results considering the installation of one wind turbine with the Enercon E-33 are reported in Table 4.6. Since this is a pitch controlled wind turbine, it is possible to control the output power adjusting the pitch angle. In the simulation it is considered that the Power Management System will send a signal to the turbine in order to limit the power output to 200 kW higher than the consumption, but this is an arbitrary value: the overproduction can be easily adjusted in relation to the non-continuous load that is installed and has to be fed.

Number of WT	Energy Yearly Produced	Missing Electricity	Exceeding Electricity
1	472 MWh	107 MWh (41.3%)	321 MWh (123.9%)

Table 4.6: Enercon E-33, simulation results

⁶<http://www.enercon.de/en/e33.htm>

⁷<http://zephyrschild.co.uk/commercial-wind-turbine-enercon-e33.shtml>

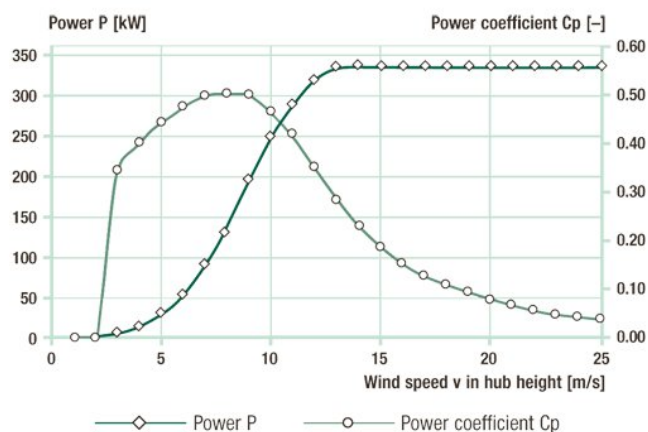


Figure 4.10: Enercon E-33 Power Curve

The diesel generator use abatement is considerable, 58.7%. In addition to this, the exceeding production can be adjusted by the Power Management System in relation to the citizen needs.

An estimation for the price for its production, assembly and transport is calculated by the Enercon Sale Office: $1600 \frac{\text{€}}{\text{kW}} \approx 11900 \frac{\text{DKK}}{\text{kW}}$.

4.1.6 Results and Discussion

The simulations are conducted with wind turbines of different size chosen among a big number of manufacturers. The diesel generator use abatement can not be considered as the only factor for the choice: the Arctic condition suitability, the project price and the provided technical equipment have to be considered. It was not possible to collect all the informations for each wind turbines from the manufacturers, so the choice will be conducted with the available data.

The Enercon E-33 wind turbine represents from the Author's point of view the most suitable wind turbine for Itilleq. The pitch controlled wind turbine can adapt its production in relation to the consumption needs very easily. Moreover Enercon is providing an Arctic version of this wind turbine, that can withstand temperatures of -40 °C. Finally, Enercon has a big experience in the stand-alone systems and can provide the Power Management System equipment and the temporary storages needed for a high wind energy penetration.

4.2 Dump Load

The configuration chosen is one Enercon E-33 330 kW. The production does not match the consumption on a hour scale: the power differences considering an allowed overproduction of 200 kW are reported in Figure 4.11.

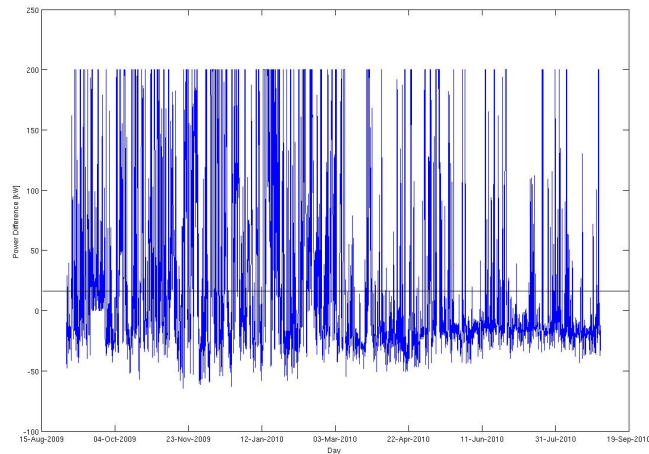


Figure 4.11: Production minus consumption power

The missing power (points under the line) can be produced by the diesel generators already present in Itilleq. This type of generator permits to adjust quickly the power output, providing electricity in case of low wind speeds.

The surplus power (points over the line) has to be considered carefully. Since the adopted turbine has a pitch control power regulation system, the power output can be regulated in relation to the demand. On the other hand, the pitch angle can not be adjusted instantaneously, so a very fast dump load has to be provided. Enercon developed this type of equipment to permit a high penetration of wind energy in the isolated system. An example of the production control scheme is reported in Figure 4.12.

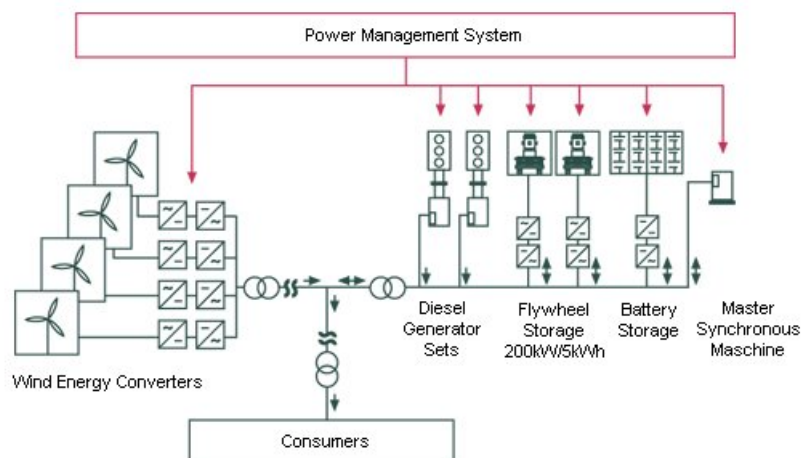


Figure 4.12: Enercon Stand Alone System

The stand-alone system equipment configuration should be adjusted considering the technical details for every single components. Enercon does not provide this kind of specific technical informations, but they can be estimated conducting some assumptions.

The flywheel storages are adopted in order to absorb the exceeding power production in the period needed for the dump load to be turned on. The 200 kW flywheel storage has a capacity of 5 kWh, enough for storing energy for a minimum of 1.5 minutes. It can be a good assumption to adopt 4 flywheel storages, in parallels lines of two. Thus the maximum absorbing capacity is 400 kW, enough for the Enercon E-33 wind turbine, for 3 minutes, enough to turn on the dump load and, in case of fault, to adapt the pitch angle of the wind turbine in order to produce a lower amount of electricity.

The battery storage is used, instead, to provide the electricity during the decreasing wind speed periods, when the diesel generators has to be turned on. The maximum power consumption in the period considered is 85 kW and the diesel generators or the pitch controller can take up to 2 minutes to be activated: a battery storage of 3 kWh can be considered a good choice.

The overproduction can be utilized to provide electricity to additional loads that do not need to operate continuously. Two possible applications are found and discussed.

4.2.1 Desalination Plant

The desalination plant can produce an additional quantity of fresh water during the periods of surplus energy availability. The fresh water can be stored as final energy form, with very low energy losses (small leakages), and it can be consumed whenever is needed. The additional water will be stored in additional tanks.

The reverse osmosis system installed can produce a maximum of 10 m³ of water per day⁸ absorbing 4.5 kW⁹. The daily water consumption within each month is estimated using the data reported in Chapter 2.2. The results are reported in Table 4.7.

Month	Daily Water Consumption [$\frac{m^3}{day}$]
September (2009)	15.57
October (2009)	13.35
November (2009)	3.73
December (2009)	3.19
January (2010)	2.56
February (2010)	2.96
March (2010)	2.40
April (2010)	3.67
May (2010)	7.46
June (2010)	6.98
July (2010)	7.55
August (2009)	12.45

Table 4.7: Daily Water Consumption

Hourly data are not available. During the fieldwork, measurements of the water tank levels in the

⁸<http://www.water-wastewater.com/pages/hoh.html>

⁹Estimation from the Nukissiorfiit energy consumption data

Desalination Plant and in the Old Well site were conducted. The results are reported in Appendix C. The measurements highlight a continuous water consumption. This allows to simplify the model, considering a hourly water consumption constant in the whole month.

The actual capacity installed is 8000 l in the Desalination Plant and 2300 l in the Old Well building. The water reserve that is nowadays maintained in the store, measured during the fieldwork, is 7900 l (6000 l + 1900 l). An additional capacity may need to be installed in order to store an additional quantity of water.

4.2.2 Electric Heaters

The overproduction is not absorbed completely by the desalination plant. The installation of electric heaters in the public buildings and private houses can satisfy part of the space heating demand and absorb the rest of the overproduction. The heat pump installation has been considered but, due to the very low ambient temperatures reached during winter (-35 °C), no suitable heat pump that can produce heating with such a low ambient temperature are found.

From the fieldwork activity and the satellite images provided by Google Earth, it is found that the heat customers in Itilleq are:

- 48 private houses, average size 8 x 6 m, 2 floors
- school, 27 x 7 m, 1 floor
- kindergarten, 13 x 15 m, 2 floors
- shop, 14 x 25 m, 1 floor
- factory, 41 x 12 m, 1 floor
- desalination plant & municipality office, 39 x 7 m, 1 floor

The most of the buildings in Itilleq are built several years ago and the insulation materials seem to be not very advanced. The specific energy demand for heating and ventilation is assumed to be the highest allowed by the Greenland building code, $230 \frac{kWh}{m^2 \text{ year}}$. On the other hand, the school and the kindergarten are recently built; the building design is improved with respect to the oldest buildings and the specific energy demand is supposed to be lower, $180 \frac{kWh}{m^2 \text{ year}}$. The shop is characterised instead by higher thermal losses, since the entrance doors are very often open: the specific energy demand is supposed to be higher, $300 \frac{kWh}{m^2 \text{ year}}$. The estimated heat demand is reported in Table 4.8.

The electric heaters efficiency for the conversion from electricity to heat is considered to be 100%.

Different types of electric heaters are available on the market. Since the power absorption has to be quick and immediate, a "fan-forced" electric heater has to be adopted. Without a forced convection equipment (fan), the heat body may become overheated: the electric consumption would be lowered in order to ensure the operation safety. A fan forced electric heater does not present this problem.

In addition to this, high installation costs should be avoided to decrease the profitability of the project. A wall electric heater would require excessive installation and maintenance costs. A portable heater would be easily installable in the most suitable position. It should be not possible to disconnect the heater, in order to avoid the reduction of the available dump load.

Customer	#	Size [m]		Floors	Specific Heat Demand [$\frac{kWh}{year \cdot m^2}$]	Heat Demand [$\frac{kWh}{year}$]
Private houses	48	8	6	2	230	1059840
School	1	27	7	1	180	34020
Kindergarten	1	13	15	2	180	70200
Shop	1	14	25	1	300	105000
Factory	1	41	12	1	230	113160
Desalination plant & municipality office	1	39	7	1	230	62790

Table 4.8: Estimated heat demand

The market offers different models of electric heaters corresponding to these characteristics. A 2 kW portable heater with a price of 40 € is considered¹⁰, reported in Figure 4.13. The choice can be easily reverted to a similar heater that is considered more suitable during the installation phases.



Figure 4.13: 2 kW Fan Forced Electric Heater

The electric heaters can be installed both in the public buildings and in the private houses.

4.2.3 Additional Load Configuration

The amount of surplus power provided during high wind speeds has to be split among the different dump loads. Moreover, if the desalination plant has to be used as a dump load, the amount of fresh water produced and stored has to be calculated in order to evaluate the water tank size needed. The simulations are conducted using the Matlab scripts reported in Appendix B.4.

The following configuration is found to be suitable for the grid. Three different dump load blocks have to be activated sequentially in case of surplus production:

1. 90 electric heaters, with a maximum load of 2 kW each;
2. desalination plant, with a maximum load of 4.5 kW;
3. 8 electric heaters, with a maximum load of 2 kW each.

The electric heater load is split in two blocks because of the limited absorption capacity of the desalination plant. In fact, if the desalination plant is put as first dump load, the amount of water to be stored would be bigger than 400 m³. Splitting the electric heaters load as above, the maximum amount is limited to 26 m³. The water stored as constantly maintained reserve is set to the present value, 7900 l.

¹⁰<http://www.airandwatercentre.com/2kw-convector-heater-turbo-fan-416-details/>

The tank store levels are reported in Figure 4.14. An additional capacity of at least **15700 l** need to be installed.

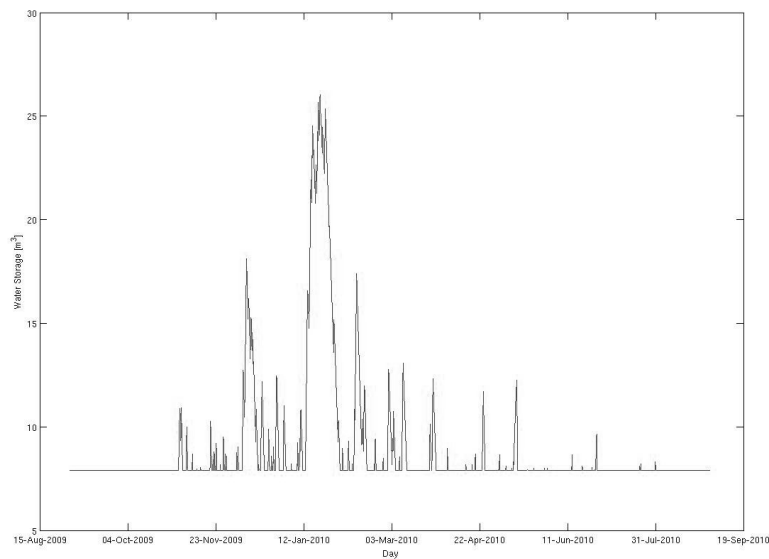


Figure 4.14: Amount of stored water

The amount of water produced using the electricity overproduction is **310 l**. This amount, compared with the yearly water production of 2500 l, covers only about 12.5% of the consumption. The limited amount produced is related to the low priority given to the desalination plant in the exploitation of the overproduction. Increasing its priority would lead to a bigger production but also would require a bigger tank size. A bigger tank would have a higher cost and positioning problems. Moreover the growth of bacterial cultures has to be considered.

The installation of electric heaters will produce **290 MWh** of heating. This is enough to cover the necessities of the School, the Kindergarten, the Shop and the Municipality Office. These buildings are public, so the installation will not involve private users' authorization. The heating is produced only when an overproduction is present, thus the oil burner heater is still necessary to supply heating during the low wind speed periods. A normal thermostat can be successfully adopted to switch on automatically the oil burner if the ambient temperature is below a comfort temperature. On the other hand, if the heating produced by the electrical units is too much, it can be easily dissipated by opening a door or a window.

Chapter 5

Economic Analysis

An economic analysis from the socio-economic point of view is conducted. This means that the costs and the savings vary the electricity price in order to obtain a net profit equal to zero. Moreover the interest rate adopted does not consider any revenue rate: it is set to the value of 3%.

5.1 Electricity Price

Investment

The investment cost comprehends several elements. Whereas the real cost informations are not available, an estimation is considered. The estimations are calculated using the indications of the National Renewable Energy Laboratory from the U.S. Department of Energy¹, applying a coefficient of 1.5 in order to consider the harsh condition of Greenland.

1. Wind Turbine

- Wind turbine: the Enercon Sale Office provided an estimation for the turbine manufacturing and transportation cost of 528000 € \approx 3940000 DKK.
- Grid control equipment: the Enercon Sale Office did not provide an estimation for the grid control equipment unit, since the cost is varying in relation to the particular installation specifications. An estimation of 50000 € \approx 373000 DKK is assumed.
- Foundation construction: it comprehends the ground digging and drilling and the concrete cast. The total cost is assumed to be 25000 € \approx 186000 DKK
- Electric Interface/Connection: it comprehends the cable posing and the specialised technician work. The total cost is assumed to be 24000 € \approx 176000 DKK.
- Roads and Civil work: it is needed to transport the turbine and the working facilities to the chosen location. The total cost is assumed to be 37000 € \approx 278000 DKK.

2. Heaters: 98 heaters are supposed to be installed. The 2-kW heater that is considered as example costs 40 € per unit². The total cost for the heaters is then 3920 € \approx 29200 DKK.

¹<http://www.nrel.gov/wind/pdfs/40566.pdf>

²<http://www.airandwatercentre.com/2kw-convactor-heater-turbo-fan-416-details/>

3. Water Tank: an additional capacity of at least 15700 l has to be installed to store the water overproduction. This type of tanks is not extremely expensive³ and a price of 5000 € \approx 37300 DKK including purchase and transportation is considered.
4. Commissioning: it comprehends all the operations in order to test, verify and put in operation the wind turbine, the electric heaters and the water tank. It is estimated to be 20000 € \approx 150000 DKK.

The total investment cost is **693000 € \approx 5160000 DKK**.

The annuity should be calculated considering the lifetime of each component. Since these data are not available for all of them and the biggest fraction of the investment is related to the wind turbine, the error committed considering all the components' lifetime equal to the wind turbine's lifetime is not big. The annuity, estimated considering a 20 years period, is **47000 $\frac{\text{€}}{\text{year}}$ \approx 350000 $\frac{\text{DKK}}{\text{year}}$** .

Diesel Generator

The diesel generator production is calculated subtracting the wind turbine production to the total consumption. Assuming an average auto-consumption of 12%, obtained considering the generator measures from the considered period, the total energy production is 120 $\frac{\text{MWh}}{\text{year}}$.

The actual electricity price, based only on the diesel generator production, is 7.62 DKK/kWh⁴. This price is considered as the marginal price for the generator use.

The total cost on a yearly basis for the generator use is, then, **122000 $\frac{\text{€}}{\text{year}}$ \approx 912000 $\frac{\text{DKK}}{\text{year}}$** .

Wind Energy Overproduction

The wind turbine production covers the 58.7% of the electricity consumption, equal to 151850 $\frac{\text{kWh}}{\text{year}}$.

Moreover, as discussed before, the overproduction can be used in order to provide electricity to the discontinuous loads. The amount of the electricity that is considered to be delivered to this type of load is approximately 320500 $\frac{\text{kWh}}{\text{year}}$. This energy is mainly addressed to heating purposes, so its price has to be comparable with the heating oil price.

The heating oil stock price in November 2010⁵ is 0.48 $\frac{\text{€}}{\text{l}}$ \approx 3.60 $\frac{\text{DKK}}{\text{l}}$. Considering a lower heating value⁶ of 10.61 $\frac{\text{kWh}}{\text{l}}$ and an average efficiency of the boiler of 85% (see Appendix A), the heating price is 0.054 $\frac{\text{€}}{\text{kWh}}$ \approx 0.40 $\frac{\text{DKK}}{\text{kWh}}$. This estimation does not consider that the stock price is not the price for the heating oil delivered in Itilleq. There are some additional costs here not considered because difficult to estimate that would increase sensibly the price. Thus the price for overproduction electricity is set to **0.054 $\frac{\text{€}}{\text{kWh}}$ \approx 0.40 $\frac{\text{DKK}}{\text{kWh}}$** .

³<http://www.enviro-friendly.com/tankmasta-water-tanks.shtml#20000T>

⁴http://www.nukissiorfiit.gl/fileadmin/user_upload/PDF_filer/AArsberetninger/Enhedsomkostninger_2009.pdf

⁵<http://money.cnn.com/data/commodities/>

⁶http://en.wikipedia.org/wiki/Heating_oil

Electricity Price

The electricity price is calculated considering no revenues over the 20 years period. A maintenance cost for the wind turbine is assumed: $15000 \frac{\text{€}}{\text{year}} \approx 112000 \frac{\text{DKK}}{\text{year}}$. The following expression is considered:

$$\text{Elec. Price} = \frac{\text{WT Annuity} + \text{WT Maint.} + \text{Diesel Gen. Cost} - \text{Overprod.} \cdot \text{Overprod. Price}}{\text{Total Consumption}} \quad (5.1)$$

The electricity price after the installation of the wind turbine is $0.645 \frac{\text{€}}{\text{kWh}} \approx 4.804 \frac{\text{DKK}}{\text{kWh}}$. Comparing this price with the actual electricity price, the reduction is estimated to be 37%.

5.2 Sensibility Analysis

A sensibility analysis is conducted on a number of parameters in order to estimate the possible variation of the electricity price.

Consumption

The number of inhabitants in Itilleq has decreased in the last years⁷. Therefore it can be interesting to analyse the electricity price variation if the consumption is increased or decreased.

Considering the same technical configuration (wind turbine, control equipment, overproduction load, etc.), a price estimation is conducted adopting the procedure described before. The different prices are reported in Table 5.1.

Consumption Variation	Electricity Price
-30%	$0.668 \frac{\text{€}}{\text{kWh}} \approx 4.978 \frac{\text{DKK}}{\text{kWh}}$
-20%	$0.645 \frac{\text{€}}{\text{kWh}} \approx 4.805 \frac{\text{DKK}}{\text{kWh}}$
-10%	$0.643 \frac{\text{€}}{\text{kWh}} \approx 4.795 \frac{\text{DKK}}{\text{kWh}}$
0%	$0.645 \frac{\text{€}}{\text{kWh}} \approx 4.804 \frac{\text{DKK}}{\text{kWh}}$
+10%	$0.647 \frac{\text{€}}{\text{kWh}} \approx 4.822 \frac{\text{DKK}}{\text{kWh}}$
+20%	$0.651 \frac{\text{€}}{\text{kWh}} \approx 4.848 \frac{\text{DKK}}{\text{kWh}}$
+30%	$0.655 \frac{\text{€}}{\text{kWh}} \approx 4.880 \frac{\text{DKK}}{\text{kWh}}$

Table 5.1: Electricity Prices for Consumption Variations

The electricity price trend is parabolic for a price variation. This means that the actual consumption is near to the minimum price one. An increase or a consistent decrease in the consumption would lead to a small price increase, that remains however lower than the actual electricity price.

Wind Resource

The wind speed data available at the moment cover only one year. This timespan is very small considering the lifetime of the wind turbine: a sensibility analysis on the wind speed is conducted. The wind speed is decreased using a correction factor, increasing or decreasing every wind speed measured. The different electricity prices are reported in Table 5.2.

⁷<http://en.wikipedia.org/wiki/Itilleq#Population>

Wind Resource Variation	Electricity Price
-30%	$0.907 \frac{\text{€}}{\text{kWh}} \approx 6.761 \frac{\text{DKK}}{\text{kWh}}$
-20%	$0.809 \frac{\text{€}}{\text{kWh}} \approx 6.026 \frac{\text{DKK}}{\text{kWh}}$
-10%	$0.722 \frac{\text{€}}{\text{kWh}} \approx 5.382 \frac{\text{DKK}}{\text{kWh}}$
0%	$0.645 \frac{\text{€}}{\text{kWh}} \approx 4.804 \frac{\text{DKK}}{\text{kWh}}$
+10%	$0.574 \frac{\text{€}}{\text{kWh}} \approx 4.280 \frac{\text{DKK}}{\text{kWh}}$
+20%	$0.511 \frac{\text{€}}{\text{kWh}} \approx 3.810 \frac{\text{DKK}}{\text{kWh}}$
+30%	$0.455 \frac{\text{€}}{\text{kWh}} \approx 3.390 \frac{\text{DKK}}{\text{kWh}}$

Table 5.2: Electricity Prices for Wind Resource Variations

The electricity price trend is obviously positive. It is possible to observe that a wind resource decrease would lead to a consistent electricity price increase but still lower than the actual one. On the other hand, the wind turbine has been chosen considering a wind potential. If the real potential, with future measurements, results to be higher or lower, another turbine may need to be considered.

Investment

The investment needed has been calculated estimating different costs. A sensibility analysis on the investment cost can be useful to evaluate the profitability of the investment in case of deviation from the assumptions. The different electricity prices are reported in Table 5.3

Investment Variation	Electricity Price
-40%	$0.573 \frac{\text{€}}{\text{kWh}} \approx 4.267 \frac{\text{DKK}}{\text{kWh}}$
-20%	$0.609 \frac{\text{€}}{\text{kWh}} \approx 4.535 \frac{\text{DKK}}{\text{kWh}}$
0%	$0.645 \frac{\text{€}}{\text{kWh}} \approx 4.804 \frac{\text{DKK}}{\text{kWh}}$
+20%	$0.681 \frac{\text{€}}{\text{kWh}} \approx 5.072 \frac{\text{DKK}}{\text{kWh}}$
+40%	$0.717 \frac{\text{€}}{\text{kWh}} \approx 5.340 \frac{\text{DKK}}{\text{kWh}}$

Table 5.3: Electricity Prices for Investment Variations

The electricity price trend is obviously positive. It is possible to observe, anyway, that even a consistent investment variation leads to an electricity price lower than the actual one. This is related to the high electricity price that is nowadays paid by the consumers.

Chapter 6

Conclusions

The settlement of Itilleq is an energy isolated system. The electricity grid presents the typical island system difficulties related to the grid stabilization and overproduction control. The installation of one Enercon E-33 wind turbine is proven to be an optimal choice with respect to the consumption pattern and the wind availability. Enercon provides also a control equipment suitable and necessary for this type of isolated systems. The economical analysis showed that the electricity price would be decreased from such an installation, considering also the consumption variation that characterises the small settlements. Moreover, the overproduction from the wind turbine can be successfully exploited in order to produce fresh water and heating for the public buildings, substituting the heating oil nowadays utilised. This would lead to an additional oil-purchase savings.

The project realization requires nevertheless a consistent investment. This investment would be not easily undertaken by a private company. On the other hand, the municipality may be interested to decrease the electricity price, contributing to the wind turbine purchase and installation. Furthermore, the wind turbine would work alongside the diesel generator, but it will require a different maintenance and control. If the Itilleq wind turbine installation is followed by installations in the other settlements, this will lead to the need for specialised supervisors and technicians, creating new job opportunities in the local energy company.

Finally, the emissions from the energy production would be sensibly cut off. In addition to this, the emissions from the heating boilers and the cargo-ships transporting the fuel have to be considered, because they do not represent a negligible contribute to the energy production emissions.

Thus, the wind turbine installation represents a big opportunity for Itilleq, leading the settlement to a greater and greener energy independence, decreasing the consumer price and creating new job opportunities.

Appendix A

Load Map for the Public Buildings

In this chapter the main loads founded in the public accessible buildings are reported. The informations reported are not always complete due to the difficulties to found and identify the characteristics of each load. The data reported are mainly found in the little metallic panels present in many electric components.

Power Plant

Production, Meter no.: 12239175

Internal Consumption, Meter no.: 14230323

Road Light, Meter no.: 14230324

Desalination Plant

Meter no.: 14228634 & 14230326

The desalination plant is provided with several pumps. Some of them are needed to distribute the water in the grid. Other are related to the desalination process and are used to pump the sea water to high pressures. The remaining ones are related to other processes such cleaning and maintenance and are manually switched on. The desalination plant scheme with reference of the pump number is shown in Figure 2.4.

- *Supply Grid Pump:* (P5) 1x 1.5 kW; 1x 1.1 kW
- *High Pressure Pumps:* (P3 & P4) 2x 2.5 kW
- *Additional Pumps:* (P8) 1x 0.55 kW;
(P1) 1x 0.75 kW;
(P2) 1x 12 W + Mixer 0.18 kW;
(P6) 1x 800 W + Mixer 0.18 kW;
(P7) 1x 0.55 kW

Old Drilling Point

Meter no.: 14228604

- *Electric Heater*: 2x 600 W
- *Water Pump Meter S/N*: 2958365 & 2958366

Sea Water Pump Point

Meter no.:

- *Pump*: 2x VEM, 4 kW

Shop

Meter no.: 12239176

- *Light*: 48x 36 W; 28x 35 W
- *Freezer*:
2x Novum Model 805 L, Class N, 700 W;
1x Intercold Costan E526, 2100 W;
1x Vibrocold;
1x 315 W;
1x U3655G/SGG AHT, 210 W, 2.5 kWh daily
- *Cooling Room*: 1x 1480 W
- *Refrigeration Room*: 1x 4.6 kW
- *Pre-heater*: 1x small, GRAM; 1x big, GRAM
- *Oven*: 2x Unox XF090P, 66 kW
- *Boiler*: 1x Tasso 20 MS, 27.3 kW, electricity 0.29 kW
Loss 13.8 %, CO₂ 10.2%
Chimney Temp 25 °C, Set Point 60 °C
- *Ventilator*: 1x 70 W

School

Meter no.: 14228598

- *Light*: 46x 28 W; 2x 18 W, 3x 30 W
- *Dish Washer*: 1x 2.2 kW
- *Computer*: 1x

-
- *Fridge*: 1x Sorenje; 1x Bosch, Class A, 343 kWh/year
 - *Refrigerator*: 1x Electrolux, 0.685 kWh/day
 - *Boiler*: 1x Fer GGNN70, 51 kW, electricity 290 W

Kindergarten

Meter no.: 14228619

- *Light*: 22x 18 W; 18x 36 W; 9x 18 W
- *Oven*: 1x 19.6 kW
- *Dish Washer*: 1x 10.5 kW
- *Fridges*: 2x 125 W
- *Microwave Oven*: 1x 1.2 kW
- *Refrigerator*: 1x 320 W
- *Boiler*: 1x SIME (2002), efficiency 88%, 33.4 kW, electricity 0.7 kW

Church

Meter no.: 14228093

- *Light*: 32x 9 W; 12x ?W (old lamps)
- *Boiler*: 1x Sime SOLO 20 (2003), 21.5 kW

Metropolitan Office

Meter no.: 14228630 & 14228631

- *Light*: 8x 36 W; 6x 20 W; 11x neon 36 W
- *Computer*: 3x
- *Fridge*: 2x small; 1x big
- *Boiler*: 1x Tasso (1994); Loss 8.5%
- *Pumps*: 1x 70 W; 1x 44 W; 1x 40 W; 1x 149 W; 1x 45 W
- *Washing Machine*: 2x 7.5 kW; 1x 12.5 kW
- *Drying Machine*: 1x 330 W

Appendix B

Matlab Scripts

B.1 Wind Speed Analysis

WindFile.m

This script creates a Matlab compatible data file from the .dat file available on <http://www.winddata.com/greenland/>.

```
%%
close all;
clear all;
clc;

%% Load Data
load ItilleqSpeed.dat;
load ItilleqDirection.dat;
mI = numel(ItilleqSpeed(:,1));

%% Memory Allocation
ItilleqSpeed = [ItilleqSpeed zeros(mI,1)];

%% Analysis
if ItilleqSpeed(:,2)~=ItilleqDirection(:,2);
    error('Mismatching data');
end
for p=1:mI
    str=num2str(ItilleqSpeed(p,2));
    C={str(1:4) str(5:6), str(7:8), str(9:10), str(11:12)};
    ItilleqSpeed(p,3)=datenum([str2double(C) 0]);
end
Itilleq=(ItilleqSpeed(:,3));
Itilleq(:,2)=ItilleqSpeed(:,2);
Itilleq(:,3)=ItilleqSpeed(:,1);
```

```
Itilleq(:,4)=ItilleqDirection(:,1);  
Itilleq=sortrows(Itilleq);  
save ('Itilleq','Itilleq');
```

Plot.m

This script creates the plots reported in the report.

```
%%  
close all;  
clear all;  
clc;  
  
%%  
load Itilleq;  
figure(1);  
plot(Itilleq(:,1),Itilleq(:,3));  
datetick('x',1,'kepticks','keeplimits');  
xlabel('Day');  
ylabel('Wind Speed [m/s]');  
figure(2);  
hist(Itilleq(:,3),(0:1:27));  
set(gca,'XTick',(0:1:27));  
xlabel('Wind Speed [m/s]');  
ylabel('x 10 minutes');  
axis([-1 27 0 9000]);  
avg = sum(Itilleq(:,3))/numel(Itilleq(:,3));
```

B.2 Electricity Consumption

ElecFile.m

```
%%  
close all;  
clear all;  
clc;  
  
%% Load Data  
load consumption.dat;  
mI = numel(consumption(:,1));  
  
%% Memory Allocation  
ElecCons = zeros(mI,3);
```

```

%% Analysis
ElecCons(:,3)=consumption(:,2);
ElecCons(:,2)=consumption(:,1);
for p=1:mI
    str=num2str(consumption(p,1));
    C={str(1:4) str(5:6), str(7:8), str(9:10), str(11:12)};
    ElecCons(p,1)=datenum([str2double(C) 0]);
end
plot(ElecCons(:,1),ElecCons(:,3));
datetick('x',1,'kepticks','keeplimits');
save('ElecCons','ElecCons');

```

B.3 Production/Consumption Year Simulation

Comparison.m

```

%%
close all;
clear all;
clc;

%% Load Wind & Turbines
load Itilleq;
load ew_50;
load wes_18;
load northern_100;
load wes_30;
load enercon_e33;

%% Load Consumption
load ElecCons;
ElecCons = ElecCons(1:8736,:);
nC = numel(ElecCons(:,1));

%% Sensibility Analysis
%ElecCons(:,3) = 1.3*ElecCons(:,3);
%Itilleq(:,3) = 1.3*Itilleq(:,3);

%% Memory Allocation
ElecProd = zeros(nC,3);
ElecDiff = zeros(nC,2);
numTur = zeros(nC,1);
pitchMode = zeros(nC,1);

```

```
%% Parameters
n=1;
pitchControl = true;
dumpLoad = 200;
discProd = 70;

%% Comparison
MinProd(:,1:2)=Itilleq(2018:end,1:2);
MinProd(:,3)=interp1(enercon_e33(:,1),enercon_e33(:,2),
    Itilleq(2018:end,3))/6;
nP = numel(MinProd(:,1));
if nP/6~=nC; error('Mismatching data'); end
for p=1:nC
    ElecProd(p,1:2)=MinProd(6*p,1:2);
    %ElecProd(p,3)=n*sum(MinProd(6*p-5:6*p,3));
    hourProd = sum(MinProd(6*p-5:6*p,3));
    if pitchControl
        numTur(p) = n;
        diff = hourProd - ElecCons(p,3);
        if diff > dumpLoad
            hourProd = ElecCons(p,3)+dumpLoad;
            pitchMode(p) = true;
        end
    else
        if hourProd > discProd && n~=1
            numTur(p) = 1;
        else
            numTur(p) = n;
        end
    end
    ElecProd(p,3)=numTur(p)*hourProd;
end
if ElecProd(:,1)~=ElecCons(:,1); error('Mismatching data'); end

TotProd=sum(ElecProd(:,3));
TotCons=sum(ElecCons(:,3));

ElecDiff(:,1)=ElecCons(:,1);
ElecDiff(:,2)=ElecProd(:,3)-ElecCons(:,3);

Minus=sum((ElecDiff(:,2)<0)'*ElecDiff(:,2));
Plus=sum((ElecDiff(:,2)>0)'*ElecDiff(:,2));
```

```

PercMinus=-Minus/TotCons;
PercPlus=Plus/TotCons;

%% Plot and Save
figure(1);
plot(ElecDiff(:,1),ElecDiff(:,2));
datetick('x',1,'kepticks','keeplimits');
xlabel('Day');
ylabel('Energy Difference [kWh]');

figure(2);
plot(ElecDiff(:,1),ElecDiff(:,2));
datetick('x',1,'kepticks','keeplimits');
xlabel('Day');
ylabel('Power Difference [kW]');

save('ElecDiff','ElecDiff');

```

B.4 Dump Load Estimation

Dump.m

```

%%
clear all;
close all;
clc;

%% Memory Allocation
% Consumption
load ElecDiff;
dumpElec = zeros(numel(ElecDiff(:,1)),8);
tot = zeros(numel(ElecDiff(:,1)),1);
n = numel(ElecDiff(:,2));
% Tank
load WaterCons;
tank = zeros(n+1,1);
totWater = 0;

%% Parameters
% Consumption
Load(1) = 90*2;
Load(2) = 4.5;

```

```
Load(3) = 8*2;
Load(4) = 0;
% Tank
base = 6+1.9;
desaLoad = find(Load == 4.5);
maxProd = 10;
preLoad = sum(Load(1:desaLoad-1));

%% Consecutive hour sum and split load
plus = (ElecDiff(:,2)>0);
iDump = 0;
indexStop = 0;
stop = false;

while (stop == false)
    indexStart = find(plus(indexStop+1:end)==1,1)+indexStop;
    if isempty(indexStart);
        stop = true;
    else
        indexStop = find(plus(indexStart:end)==0,1)+(indexStart-2);
        iDump = iDump + 1;
        dumpElec(iDump,1) = indexStop - indexStart + 1;
        dumpElec(iDump,2) = ElecDiff(indexStart,1);
        dumpElec(iDump,3) = max(ElecDiff(indexStart:indexStop,2));
        tot(iDump) = sum(ElecDiff(indexStart:indexStop,2));

        for p=indexStart:indexStop
            remain(1)=ElecDiff(p,2)-Load(1);
            if remain(1) >= 0;
                dumpElec(iDump,4)=dumpElec(iDump,4)+Load(1);
                next = true;
            else
                dumpElec(iDump,4)=dumpElec(iDump,4)+ElecDiff(p,2);
                next = false;
            end

            remain(2)=remain(1)-Load(2);
            if remain(2) >= 0 && next;
                dumpElec(iDump,5)=dumpElec(iDump,5)+Load(2);
                next = true;
            elseif next;
                dumpElec(iDump,5)=dumpElec(iDump,5)+remain(1);
                next = false;
            end
        end
    end
end
```

```

end

remain(3)=remain(2)-Load(3);
if remain(3) >= 0 && next;
    dumpElec(iDump,6)=dumpElec(iDump,6)+Load(3);
    next = true;
elseif next;
    dumpElec(iDump,6)=dumpElec(iDump,6)+remain(2);
    next = false;
end

remain(4)=remain(3)-Load(4);
if remain(4) >= 0 && next;
    dumpElec(iDump,7)=dumpElec(iDump,7)+Load(4);
    dumpElec(iDump,8)=dumpElec(iDump,8)+remain(4);
    next = true;
elseif next;
    dumpElec(iDump,7)=dumpElec(iDump,7)+remain(3);
    next = false;
end
end

end

end

dumpElec = dumpElec(1:iDump,:);
dumpOrd = sortrows(dumpElec);

totLoad1 = sum(dumpOrd(1:end-2,4));
totLoad2 = sum(dumpOrd(1:end-2,5));
totLoad3 = sum(dumpOrd(1:end-2,6));
totLoad4 = sum(dumpOrd(1:end-2,7));
totRemainEn = sum(dumpOrd(1:end-2,8));
totRemainPw = max(dumpOrd(1:end-2,3))-sum(Load);

%% Tank Size
tank(1) = base;
for p=1:n
    if ElecDiff(p,2)>Load(desaload)+preLoad
        totWater = totWater + maxProd/24;
        tank(p+1) = tank(p) + (maxProd-WaterCons(p,2))/24;
    elseif ElecDiff(p,2)>preLoad
        totWater = totWater+(ElecDiff(p,2)-preLoad)/Load(desaload)*
            maxProd/24;
    end
end

```

```
        tank(p+1) = tank(p) + (ElecDiff(p,2) - preLoad) / Load(desLoad) *  
            (maxProd - WaterCons(p,2)) / 24;  
    else  
        tank(p+1) = tank(p) - WaterCons(p,2) / 24;  
    end  
    if tank(p+1) < base  
        tank(p+1) = base;  
    end  
end  
figure(1);  
plot(ElecDiff(:,1), tank(2:end));  
datetick('x', 1, 'kepticks', 'keplimits');  
xlabel('Day');  
ylabel('Water Storage [m^3]');
```

Appendix C

Water Tank Level Measurements

During the fieldwork in Itilleq, measurements with minute resolution of the water levels in the storage tanks installed in the Desalination Plant and Old Well Building are conducted. The measurements are made inserting pressure sensors in the tanks and subtracting the atmospheric value measured outside. Considering the base area of the tanks, the water volume stored can be estimated. The results are shown in Figure C.1 and Figure C.2.

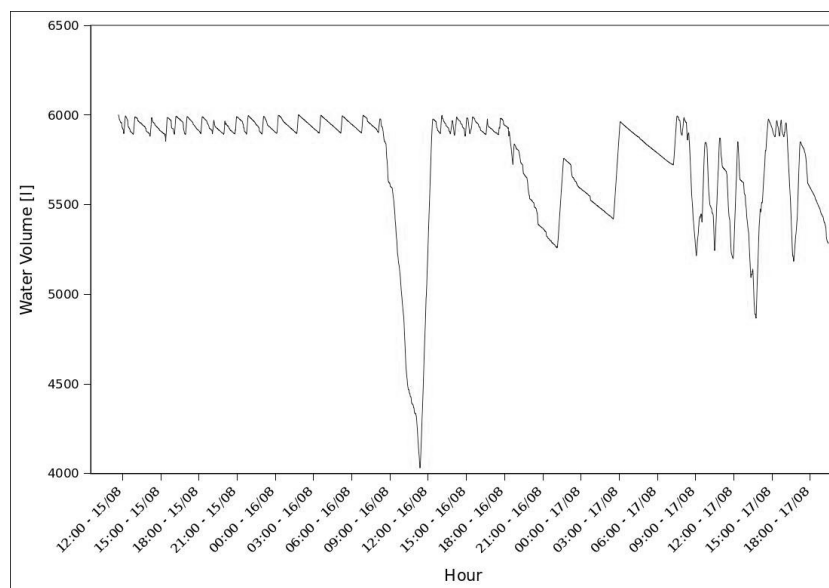


Figure C.1: Desalination Tank, Stored Water Volume

It is possible to observe that the water level in the Desalination Plant tank is slowly decreasing due to the consumption. Suddenly the level increases: this is related to a tank sensors that enables the reverse osmosis water production. Moreover, during the high consumption periods, the water stored in the Old Well tank is transferred to the Desalination Plant tanks in order to give a contribute to the water distribution: this is highlighted by a decrease of the water level in the Old Well tank.

The water stored in the tanks as reserve is 6000 l in the Desalination Plant and 1900 l in the Old Well site.

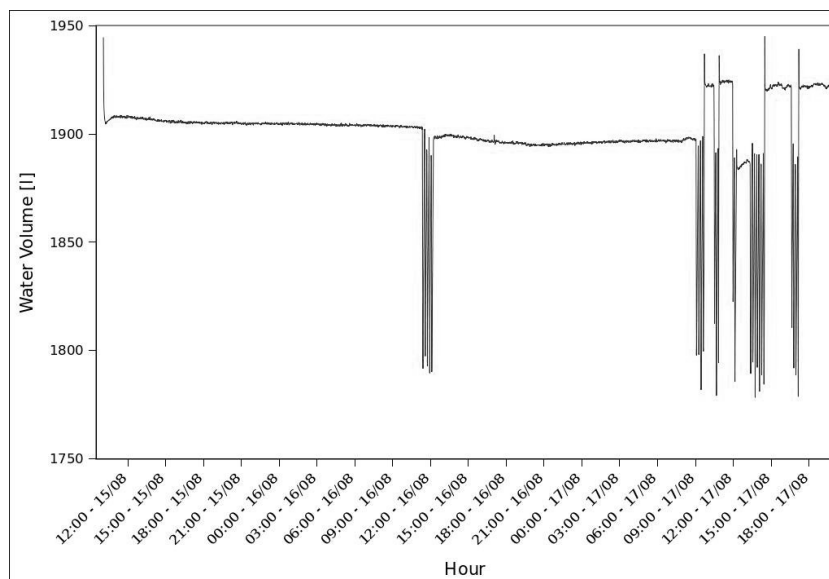


Figure C.2: Old Well, Stored Water Volume