ARCHITECTURAL ENGINEERING GRADUATION STUDIO
AR3AE015

SOLAR AND WIND ENERGY
FOR
PARK GRAVENRODE IN KERKRADE

AUTHOR:
KEREN YANG
4401859

TUTOR:
LEO GOMMANS
ANNEBREGJE SNIJDERS
01-10-2016
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Abstract and Introduction

ABSTRACT

This paper aims to study solar and wind energy generation technologies and apply them in Park Gravenrode in Kerkrade. In order to provide more renewable clean energy to Kerkrade to support its energy neutral goal in 2040.

INTRODUCTION

Problem Statement

As a solution of global climate change and resource crisis, sustainability has become the trend of human civilization development. Since the architecture industry occupies 40% of world’s total resource consumption, the world calls for better research and appliance of sustainable architecture and urban planning.

The south Limburg area used to be an important mining and industry area of the Netherlands. With population aging and industry infrastructures closing down, the area is shrinking now. In October 2013, the Parkstad municipalities and the Province of Limburg decided to launch an IBA, which collects innovative, future-proof projects to revive a town, city or region, economically, culturally and socially. According to the planning of Parkstad Limburg, this region is working on sustainable renovation approaches that focus on renewable and local resources with a zero-impact on environment, and to be energy neutral in 2040.

In order to achieve the energy neutral goal, Parkstad Limburg has drafted many “PALETs”, as guiding reports, to analysis the energy profile for each municipality, energy saving potentials, and locally sustainable energy production possibilities for towns of IBA Parkstad Limburg.

As a part of IBA Parkstad Limburg, Kerkrade has relatively complete town structures and natural landscapes, which makes it contain a rich potential of improvement. According to the “PALET 2.0” for Kerkrade, the total energy consumption of the town was 6302TJ in 2011 and aimed to be 4246TJ in 2040. However, the estimated renewable energy production of Kerkrade in 2040, mainly comes from solar and wind, is only 3795TJ. Thus, there will be an renewable energy gap of 451TJ in Kerkrade, 2040. It means the energy neutral goal for Kerkrade is hard to achieve, unless more renewable and clean energy is generated on site.

Gravenrode park is a tourist-recreational area in Parkstad Limburg, cross Landgraaf and Kerkrade. In its Kerkrade part, it contains large undeveloped open ground, which has rich potential to provide solar and wind energy, in order to support the energy neutral goal of Kerkrade. Meanwhile, the combination of solar and wind energy in architecture provides a possibility to establish a sustainable landmark, to attract more visitors to the park and the town.

Research Question

Is the nature condition of Park Gravenrode in Kerkrade support solar and wind energy generation?

What kinds of solar and wind energy generation technology can be applied in Park Gravenrode in Kerkrade?

How to integrate solar and wind energy generation technology with architecture design?

Structure of the Paper

1. Using climate data, terrain information, and public function, to analysis the appliance potential and requirement of solar and wind technology for Park Gravenrode in Kerkrade.

2. A brief introduction of solar and wind energy generation technology and studies of most suitable ones for Park Gravenrode in Kerkrade.

3. A architectural concept design applied with selected solar and wind energy generation technology as a sustainable landmark for Park Gravenrode in Kerkrade.
RESEARCH METHOD

Literature

Search and analysis relevant articles / books / essays / conference documents through Internet and library.

Purpose: Basic means to receive the relevant knowledge about sustainable energy generation technologies from previous researchers.

Limits: Some books and articles were published many years ago, which results in out of date data and information. For example, some energy generation technologies introduced in the old books were designed and tested in 1980s and 1990s, but now they are proved to be not practical nor secure.

Case Study

Search and analysis relevant built energy maximized architecture design, and projects with the landmark feature that can be applied on this site.

Purpose: Study cases to understand how sustainable energy generation technologies are applied in reality. For instance, how they operate, what are their advantages, and what factors need to be improved. Meanwhile, in order to realise sustainable energy generation technologies with architectural values, as an attractive landmark on the site, projects with the landmark features and sustainable spirits can be considered as proper reference.

Limits: Both kinds of the cases are all realised under the requirement of certain context and purpose, which might not be the same as the site of this paper. Such differences restrict the reference value of cases.

Field Trip

Visit the site and catch its characteristics. Moreover, to observe the daily activities of local people on the site.

Purpose: To have a more realistic understanding and collect first-hand information of the site. To have a better understanding of what kind of landmark is needed to the site.

Limits: To have a fully understanding of the site and its meaning to local people requires multi times of site visit, in different seasons and different weathers. Restricted by time and finance status, it is not available to have many times of site visit for the author.

Research by Design

Use sketching, diagrams, 3d models to analysis, test and present the research progress and results.

Purpose: To organize and convert suitable sustainable energy generation technologies into a practical orientated planning, in order to provide an architectural solution to contribute the sustainable clean energy requirement of Kerkrade.

Limits: Due to the time and information limitation, the site planning in this paper is general, and leaves many details to be discussed in the future. The actual construction cost, energy production, and economic benefit cannot be calculated accurately in this paper.
Site Analysis

SITE ANALYSIS

Park Gravenrode in Kerkrade

Crossing the border of Landgraaf and Kerkrade, Gravenrode park is a tourist-recreational area in Parkstad Limburg. In its Kerkrade part, it contains large open ground, a north-south-going lake called Crane Weyer, and an area of thick woods, which provides recreational nature landscape, and rich potential to collect solar and wind energy.

According to the general sustainable planning of Parkstad Limburg. It has been planned as a more developed park in the future but the function and design has not been determined yet.

Terrain Features

Open Ground:
The west side of the lake Crane Weyer is a large open ground with an area about 0.8 square kilometre. The west side of open ground is higher than its east side, which results in a gentle slope. There are several dirt roads across the open ground, to connect its boundaries as well as two brick cottages on it. The open ground provides sufficient area for solar and wind energy collection and landmark architecture construction. (See Appendix 1.1)

Vegetation:
The open ground area is now consisted of grass land and low crops. Tall trees are mostly growing along the shore of Crane Weyer. Several of them are distributed randomly on the open ground. The east side of the lake Crane Weyer is occupied by leafy trees and bushes, which provides natural scenery but not suitable for energy collectors and buildings.

Surrounding:
The west of the site is adjacent to busy traffic road and a well organised and developing industrial area. The south of the site is the GaiaZOO of Kerkrade, which is a 25 hectare park with 100 species of animals, and about 450,000 visitors a year. The east and north of the site is surrounded by high rail way tracks behind trees. On the east-south of the site there locates a traditional hotel, Kasteel Erenstein, surrounded by trees. In the north part of the lake shore there is a water cleaning plant.

Lake Crane Weyer:
The site is separated by the north-south-going lake, Crane Weyer, which is connected with several small streams. The flow of the streams are weak and not capable to be used as hydro power source. The natural environment of the lake is well preserved. Many ducks and water-fowls can be seen in and near the lake. (See Appendix 1.2)

Public Function

Leisure:
The site preserves a relatively complete natural environment, which consist of a large area of meadow, a lake and thick woods. Thus, it is an attractive site to provide natural experience to visitors and remind them to cherish the beauty of nature as well as to protect the environment. The development of the site should respect and express its rare natural landscape qualities. (See Appendix 1.3)

Exercise:
Unlike the GaiaZOO to its south, which has many visitors coming from outside the town by car, the atmosphere of the site is relatively quiet. Many local people come to the site jogging, biking, and walking dogs, which indicates the fact that the site has important meaning to local people’s daily exercise activities. Thus, a sport park might be a suitable development theme of the site which meets local people’s need. (See Appendix 1.4)
In order to apply solar and wind energy generation technologies properly and efficiently, as well as to calculate the anticipate production of solar and wind energy, the collection of information about the site's solar and wind conditions is necessary.

**Solar Condition**

**Average day sums by month (Mega Joule m\(^{-2}\)) [KNMI, (1989), P54]**

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.51</td>
<td>5.20</td>
<td>8.31</td>
<td>12.98</td>
<td>16.59</td>
<td>17.14</td>
<td>17.16</td>
<td>14.87</td>
<td>10.73</td>
<td>6.55</td>
<td>3.14</td>
<td>2.00</td>
</tr>
</tbody>
</table>

**Average day sums by season and year (Mega Joule m\(^{-2}\)) [KNMI, (1989), P54]**

<table>
<thead>
<tr>
<th>Season</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.17</td>
<td>12.62</td>
<td>16.38</td>
<td>6.80</td>
<td>9.79</td>
</tr>
</tbody>
</table>

According to the table above, the annual sum of global radiation and sunshine duration in South Limburg is:

\[9.79 \times 365 = 3,573.35 \text{ (Mega Joule m}^{-2}\) = 992.6 \text{ (kWh m}^{-2}\)\]

**Sunshine duration in hours, South Limburg, 1951-1980**

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>43.4</td>
<td>64.9</td>
<td>103.1</td>
<td>147.0</td>
<td>192.0</td>
<td>191.5</td>
<td>178.1</td>
<td>175.0</td>
<td>141.1</td>
<td>108.4</td>
<td>54.4</td>
<td>40.1</td>
</tr>
</tbody>
</table>

**Sunshine duration in hours by season and year (hour) [KNMI, (1989), P84]**

<table>
<thead>
<tr>
<th>Season</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>148.4</td>
<td>442.1</td>
<td>544.6</td>
<td>303.9</td>
<td>1,439.0</td>
</tr>
</tbody>
</table>

**Wind Condition**

From the Prevailing Winds Frequency Diagram of Beek, Netherlands, it is clear that although the wind directions are quite scattered, the prevailing but not dominant wind direction is from south west. Moreover, the wind speed of the prevailing winds could be up to 50 km/h, which is 14 m/s. Mostly, the wind speed maintains within the range from 4.2 m/s to 8 m/s. However, how high is the wind speed detected is unknown from the diagram. (See Appendix 1.7)

According to the PALET 2.0 for Kerkrade, in the town of Kerkrade wind speed ranges from 6.0 to 7.0 m/s, 100m from the ground. However, the direction of the prevailing wind direction is not clear. (See Appendix 1.8)

By combining the information from the Prevailing Winds Frequency Diagram of Beek and the wind energy potential map integral scenario from PALET 2.0 for Kerkrade, in the site wind speed mostly ranges from 6.0 to 6.5 m/s 100m from the ground, and the wind mostly comes from the west, especially southwest.
Solar Energy

There are many solar and wind energy generation technologies under development and into the market. Due to limited space, only the technologies those are possible to be applied on the site would be introduced in this paper. The selection of technologies is based on the consideration of following criteria:
1) Size and Efficiency
2) Investment and Energy Payback Time
3) Expected Life Span
4) Site Weather Condition

SOLAR ENERGY

Photovoltaic - Turns Sunshine into Electricity

Factors that effect the photovoltaic performance:
1). Solar radiation available at the site;
2). Peak sunshine hours;
3). Orientation (azimuth);
4). Tilt angle of the modules from the horizontal plane (for a fixed mounting);
5). Energy conversion efficiency of the modules;
6). Temperature affection;
7). Clarity of the atmosphere and the path of the sun;
8). Shadows projected on the modules;
9). System efficiencies
10). Type of mounting structure - fixed or tracking

[David Thorpe, (2011), Page.137]

Cell-Module-Array: The minimum unit of solar-electricity transformation is the silicon solar cell. One silicon solar cell could approximately create a voltage of 0.5V at the contacts when bath under the sun. [Dieter Seifried, Walter Witzel, (2010), Page.52] To reach voltage levels commonly used (such as 12V of direct current), multiple solar cells are connected in rows into modules (commonly known as solar panels), with electrical outputs varying from a few watts to over 10W of DC electricity. [David Thorpe, (2011), Page.127] The modules can be connected together into Photovoltaic arrays for powering a wide variety of electrical equipment. The most common types of solar cell are crystalline silicon and thin films, but there are also several other types. (See Appendix 2.1)

Material of solar cells: Normally, with a efficiency generally around 15% [Dieter Seifried, Walter Witzel, (2010), Page.52], crystalline solar cells are reliable, cost effective and lasts many years, but the efficiency of crystalline solar module drops shapely when only partly shaded, or under high temperatures. Meanwhile, low weight thin film solar cells not only costs less than crystalline cells, preform better in indirect light and high heat, but also more flexible in module size, shape, and the backing material requirements. Although the efficiency of thin film solar cells is relatively lower, it has been improved considerably. According to TSMC Solar’s manual, the efficiency of its CIGS solar module could be up to 14.7%. (See Appendix 2.2)

Systems: The most common use of photovoltaic is to generate power to be consumed locally, or fed into the electrical grid when there is superfluous power. These systems are called grid-connected, and come in all sizes, from the domestic scale right up to large power stations. Also, the system use the grid as a backup when insufficient power is being generated by solar modules. A typical photovoltaic system includes: modules, a DC- AC grid-inverter, controllers, disconnects, meters and fuses. (See Appendix 2.3)

The approximate energy produced per photovoltaic module in a year: [David Thorpe, (2011), Page.137]

Module rated output (peak watts) × Peak sunshine hours (per year) × Performance ratio = Energy generated (kilowatt-hours/year)

The performance ratio is to cover higher module operating temperatures, system losses and other factors - in a well installed grid-connected system it is usually between 0.7-0.8.
Solar Energy

Building-integrated photovoltaic instead of photovoltaic on buildings: [David Thorpe, (2011), Page.144]
Modules can be integrated with roof, cladding, overhanging shading or windows elements of a building, dependent upon the building's location and orientation. The design and installation of building-integrated photovoltaic should be integrated with the whole building design to minimize the total energy consumption and extra cost of the building. (See Appendix 2.4)

In a successful building-integrated photovoltaic case, the architecture would be more energy efficient with the help of photovoltaic, meanwhile the photovoltaic technology would obtain more aesthetic values by being an organic part of the architecture. Thus, building-integrated photovoltaic could be considered as an architectural integration of technology and aesthetic, with a brighter future. And it should be an important topic for sustainable renovation planning of Kerkrade.

Solar Water Heating

Heat is an important form of solar energy, which could be collected and generally used to provide heated service water. Moreover, the hot water can be used in heating systems, and the solar thermal system is then combined with the heating system. Generally, the solar heat suffices to cover all heating demand in the warm season and part of heating demand in the cold season.

Solar heating collector types: [David Thorpe, (2011), Page.68],
1) Flat collectors, which are dark coloured solar absorbers through which water flows in pipes. The pipework could be glazed or unglazed. (See Appendix 2.5, 2.6)
2) Batch solar water heater, as know as the breadbox, which includes one or more black or TISS painted tanks in an insulated glazed box. (See Appendix 2.7, 2.8)
3) Evacuated tube collectors, which consist rows of vacuum tubes with copper heat pipes within. (See Appendix 2.9, 2.10)

Systems: (See Appendix 2.11)
Solar water heating systems can be either active with pump, or passive by thermosiphon effect. Also, there are indirect heating systems, also known as the dual circuit systems, which use a closed loop of fluid to collect and transfer heat to water in the tank, while direct heating systems that water heated is water used. [David Thorpe, (2011), Page.76]

As for the Netherlands, the closed loop active water heating system is a reliable choice. The system consists two main parts. The first part is the solar circuit, which includes a closed loop between solar collector, bottom heat exchanger, and pump. And the second part is the water tank and backup heating source. Basically, any liquid passed through solar collector, which are narrow black pipes beneath glass pointed at the sun will be quickly heat up. In order to against the cold weather, the liquid in solar circuit is usually a mixture fluid of water and glycol. The frost-proof fluid which retains most of its heat is pumped through well insulated pipes leading from the collector to the bottom heat exchanger in the lower part water storage tank, where the heat is transferred to the water in the tank. As the water heated with solar energy rises to the top of the tank where the hot water drawing point locates, the heat given frost-proof fluid is pumped back to the solar collector to receive solar heat again. [Dieter Seifried, Walter Witzel, (2010), Page.42]

System sizing: [David Thorpe, (2011), Page.83]
The higher latitude or cloudier the climate, the more surface area is needed to collect the same amount of heat. At the latitude of 50°, where Kerkrade locates, 2.5 square meter of collector area is required to provide 75 litres of hot water per person per day.

Before the hot water being used by the user, it need to be stored in well insulated storage tanks. The volume of the storage tank could be calculated from the solar area, which also depends on the solar resource at the location. Approximately, 2.5 square meter of collector area requires a tank capable of storing around 200-250 litres of water.
Solar Space Heating and District Seasonal Storage

Solar space heating:[Dieter Seifried, Walter Witzel, (2010), Page.44]
Far more heat is required for space heating, which is only required in cold months, compared with that for hot service water, which is needed all the year round. Even in well insulated buildings, 2-3 times as much energy is needed for space heating than for hot service water. Thus, in order to cover space heating with solar power, far more surface area-as for collectors are needed besides water heating.

Another fact is that in cold months, when most space heating is needed, the least solar energy could be gained. For example, according to the KNMI report, in January, the sun only provides a seventh of the energy it supplies in July in South Limburg. [P.C.T. van der Hoeven, J.M. Koopstra, W.R. Raaff, W.H. Slob, (1989), Page. 54]

District solar seasonal storage:
Based on the fact mentioned above, it is an efficient way to use long-term heat storage tanks to store excess heat from summer, in order to support space heating requirements in winter. Generally speaking, the larger size of these heat storage tanks, the less heat losses and costs are. Therefore, underground heat storage is the best option, especially for district heating networks, which require a large amount of heat storage. If there are not natural underground caves or reservoirs to be used as storage tanks, specially excavated, highly insulated chambers are needed. Storage could be centralized or decentralized.

District heating systems using solar energy cannot supply all of a district’s heating needs throughout the year, but they can make a significant contribution to the heating supply. Although their operational costs are fixed and predictable, the efficient system requires an accurate estimate of hot water needs. Generally, in central Europe, every 1000kWh of annual heat demand requires 1.5 - 2.5 square meters of collector area and up to 5 cubic meter of storage volume. [David Thorpe, (2011), Page.108]

Currently, four main systems are often used for solar heat district seasonal storage: (See Appendix 2.12)
1) Hot water heat storage
2) Pit thermal energy storage
3) Duct heat storage
4) Aquifer Heat storage.

Among these systems, hot water and Pit thermal energy storage systems require large underground thermal tanks, which have strict water and steam tightness demands and cost a lot for construction if the site does not have natural underground caves or reservoirs. Aquifer Heat storage is cheaper but requires certain ground properties such as low hydraulic and geochemical gradients, which the site might fail to meet.[Bettine Gommer, Pieter van Hall, Gabrielle de Leo, (2015), Page.9] Thus, duct heat storage system is the most suitable choice for the Park Gravenrode in Kerkrade.

Case study: The Drake Landing Solar Community

As a settlement in Okotoks, Canada, the Drake Landing Solar Community was equipped with the duct heat storage system in 2006. There are 144 30-meters-deep bore holes with a total volume of 34,000 cubic meter under the ground as the seasonal storage; 2293 square meters of solar collectors on the roofs of four rows of garages; and a central heating plant which contains two buffer tanks of 120 cubic meter each. After four years of starting heat up, the system has reached a intended steady behaviour, which is to cover 90% of its heating needs.

According to the heat flow scheme of the year 2008-2009, 1219.7 MWh/a of solar energy was collected; 753.7 MWh/a of heat was charged to the bore holes and 394.2 MWh/a was directed delivered to the heat exchanger; only a quarter of the energy charged into the bore holes, 156 MWh/a was extracted to the heat exchanger in winter. In the final energy, 823.6 MWh/a, delivered to heat up the 52 homes with 7280 square meters, 60% came from solar energy and the rest was generated by gas. (See Appendix 2.13)
Wind energy, one of the first natural sources of energy to be exploited by human civilisation, has been used for thousands of years. Traditionally, windmills have been used to provide mechanical power, for milling grain, pumping water and other mechanical productive activities. Modern wind energy convert mechanisms are mainly wind turbines, which are mainly used to convert the pollution-free wind energy into electricity.

Sorted by the number of blades, there are two kinds of Horizontal Axis Wind Turbines (HAWTs). High-solidity HAWTs have many cambered sheet metal blades. With a relatively small and solid swept area, High-solidity HAWTs are mostly used for water pumping on farms. Another kind of HAWTs have either three or two blades, which have largely void swept areas and high rotation speed. Low-solidity HAWTs are by far the most common and effective form of wind turbines manufactured today for converting wind energy into electricity. [Godfrey Boyle, (2004), Page.253]

Modern wind turbines come in two basic types. The first type is the horizontal axis wind turbine. Most horizontal axis wind turbines are “axial flow” type. The other type is the vertical axis wind turbine, generally built as the “cross flow” type. (See Appendix 3.2)

The idea of using wind to generate electricity was first proposed by British physicist and electrician William Thomson, in 1881. However, the attempts to use windmills to generate electricity was eventually failed. The main problem was not the irregularity of wind, nor the cost of windmill tower. It was the wind rotor of traditional windmill only produced high torque at low speed, which was in favour of mechanical power generation but not suitable to generate sufficient electricity. Only after modern wind turbines with high speed and low torque generators were invented, the wind energy has been converted into electricity maturely. [Richard L. Hills, (1994), Page. 269] (See Appendix 3.1)

Vertical Axis Wind Turbines (VAWTs)

The advantage of the principle of modern VAWTs is that they accept wind from any direction without the need to reposition the rotor when the wind direction changes. VAWTs are sorted into two major groups. The first group is consist of those that use aerodynamic drag to obtain power from the wind; the other group of VAWTs, also know as helix wind turbines, use lift force from wind to generate electricity. In large sizes, VAWTs are not economically and productively competitive with HAWTs at present.

From 1920s to 1980s, the mostly researched kind of VAWTs were arch-like Darrieus turbines. With a more natural appearance, they were lighter and rotated faster than straight blades VAWTs. However, the work on Darrieus turbines has already been stopped, due to the poor performance and poor reliability of their blades. Their aluminium blades are difficult to manufacture, transport and install. They sag due to their own weight and stress the connection of the rotor torque tube when the rotor is at rest. Besides, they cannot drive the rotor up to operation speed from the rest, unless they are parked in just the right position relative to the wind. [Paul Gipe, (2004), Page.87]
General Calculation of Wind Energy

Estimating how much electricity could be generated from wind turbines and knowing what are most relevant factors to the estimation is crucial to the choice of wind turbines and the arrangement of them.

The equation of wind power can be defined as: [Paul Gipe, (2004), Page.30]
\[ P = 0.5 \rho A V^3 \]
where (P) stands for power in the wind, (\(\rho\)) is the air density, normally 1.225 kg/m\(^3\), (A) is the sweep area, (V) is the wind speed.

The following equation is how to use the power law method to calculate the increase in wind speed with height in the easiest way, [Paul Gipe, (2004), Page.40]
\[ V = \frac{\ln(H/z_0)}{\ln(H_0/z_0)} V_0 \]
where (\(V_0\)) is the wind speed at the original height, (\(V\)) is the speed at the new height, (\(H_0\)) is the original height, (\(H\)) is the new height, and (\(z_0\)) is the surface roughness length. (See Appendix 3.3)

The annual energy output (AEO) of a wind turbine is: [Paul Gipe, (2004), Page.61]
\[ AEO = P \times EPF \times \eta \times (8,760 \text{ h/year}) \]
where (P) stands for power in the wind, (EPF) stands for the energy density factor which is 1.91 according to the Rayleigh distribution, (\(\eta\)) is the wind turbine efficiency which is related to wind speed, the data could be found in the table in appendix. (See Appendix 3.4)

For example, if there is HAWT with a tower height and sweep diameter of 30 meter on the open ground of Park Gravenrode in Kerkrade. Surface roughness length would be 0.007 meter, and wind speed is 6.5 m/s at the height of 100 meter.

According to the equation above, at the height of 30 meter, the wind speed would be:
\[ V = \frac{\ln(30/0.007)}{\ln(100/0.007)} 6.5 = 5.63 \text{ (m/s)} \]
The wind power would be captured by HAWT is:
\[ P = 0.5 \times 1.225 \times \pi \times (30/2)^2 \times 5.63^3 = 77.3 \text{ (kW)} \]
The annual energy output of the HAWT is:
\[ AEO = 77.3 \times 1.91 \times 33\% \times 8,760 = 426,806 \text{ (kWh)} \]

From the calculation, the annual energy output of the 30 meter HAWT on the open ground of Park Gravenrode in Kerkrade is equal to the annual energy output of the Wind Technik Nord turbine which has a nominal output of 250 kW. (See Appendix 3.5)

Requirements and Impacts

Compared with static solar panels, dynamic wind turbines have more design requirements and environmental impacts. Applying wind turbines without considering these requirements and impacts would lead to poor electricity production and negative influences on site.

Requirements:
1) Sufficient wind velocity. According to the equations above, wind speed is the most influential factor in wind energy generation. Double the wind speed would result in eight times wind energy production. To overcome the terrain restriction to achieve stable proper-speed wind, higher towers and enough distance to any obstructions (to avoid turbulent wind flow) are usually required. (See Appendix 3.6)
2) Sufficient sweep area of the rotor. The more sweep area of the rotor, the more wind could be obtained and transformed into electricity. To increase the rotor sweep area, the rotor diameter should be enlarged, which results in more complicate tasks to aerodynamic and structural design of blades and towers.
3) Wind-electricity convert efficiency. Generally, larger wind turbines are more efficient than smaller ones. To one specific wind turbine, the higher annual average wind speed, the less overall conversion efficiency, but this efficiency decline is negligible compared to the wind energy production increase resulted in higher wind velocity. [Paul Gipe, (2004), Page.58]
Kite and Balloon for Wind Energy

According to the introduction above, in order to maximize the electricity generated from wind, conventional wind turbines are growing taller, heavier, more expensive, and more landscape visually interfering. The mega wind turbines over 100 meters are so noticeable that they can be seen from high-flying aircraft. [Paul Gipe, (2004), Page.148]

In order to reach stable proper-speed wind higher in the sky without constructing complex and expensive ground-based structures, new wind energy technologies, for example, wind kite and wind balloon, are currently under research. These newly developing technologies have inspiring prospects of energy production and visual aesthetic, which make them considerable choices for the sustainable green energy production of Kerkrade in the coming future.

Wind energy kite (Makani):
The Makani energy kite system consists of four parts: composite material kite with rotors on the wings; a conductive tether which connects the kite to the ground station; the ground station which is much smaller than conventional wind turbines and used for resting the energy kite; and the control system which controls the flight path of the kite for maximum energy production. The developing prototype of Makani kite has a rated power of 600 kW, a circling radius of 145 meters, a first power point of 4 m/s, and operates with the altitude range from 140 meters to 310 meters.

Wind energy balloon (The Buoyant Airborne Turbine):
Altaeros Energies is exploring the deployment of individual 100 kilowatt Aerostat Mounted Wind Turbine units, with an operation radius of 300 meters and a maximum operation height of 600 meters, at a variety of off-grid and remote land sites, like Alaska. The system consists of an inflatable hollow cylinder shell filled with helium, light weight horizontal-axis wind turbines mounted in the shell, a ground station that contains a docking platform and winches, and multiple tethers to connect the shell to the ground station. The scale of this system is currently structurally restricted, which results in small rotor sweep area and less energy production.

Impacts:
1) Vibration. Under the force of wind and the rotating blades, an operating wind turbine is actually vibrating. The vibration is finally transmitted to the structure on which the turbine is mounted, which could be very dangerous if the wind turbine is installed directly on the roof of a building. [Paul Gipe, (2004), Page.157]
2) Safety. General public has concerns about hazards like falling blades and falling ice from large wind turbines. However, the possibility of a safety qualified wind turbine to fall off its blade is very low, and the medium-size wind turbines designed for cold climates are usually constructed with heated blades to shed ice as it forms. Thus, if the large wind turbine is constructed under good quality and kept a certain distance from people and houses, nothing dangerous would take place. [Paul Gipe, (2004), Page.278]
3) Noise. All operating wind turbines do make sounds and it is audible to people nearby. Sounds come from air sweeping rotors, transmission wires, and the hum of generator. Although these sounds are not physically harmful, they could be annoying sometimes. (See Appendix 3.7) Improving turbine gears and keeping their distance to public would lower the sound. [Paul Gipe, (2004), Page.253]
4) Visual Effect. Although large wind turbines have unique appearances, as icons of sustainability, they are not being considered as aesthetic, and even being disliked by general public. The main reason of this phenomena is not because wind turbines themselves are visually dislikeable, but the changes in the natural landscape scenery caused by construction of large wind turbines. The image of wind turbines should be tide, and friendly to their neighbour landscape. It is foreseeable that the new view of large wind turbines will be gradually accepted by people.
Concept Design of a Sustainable Landmark

CONCEPT DESIGN

Solar Appliance

Technology Appliance and Requirements

Main appliance:
Mainly photovoltaic panel, to generate electricity for pavilions and the nearby neighbourhood. Connect to the grid and no batteries.

Requirement:
Large open area or roof surfaces to install solar collectors.

Supporting appliance:
District solar heating, associated with wasted heat from nearby industrial zone.
Summer: Use solar heat for domestic water heating and seasonal thermal storage charging.
Winter: Use solar heat and heat discharged from seasonal thermal storage for heating water and space heating.

Requirements:
1). Large open ground for duct heat storage.
2). A central heating plant with buffer tanks and heat exchangers.
3). Enough roof areas for solar heating collectors.

Architectural Form Requirements

1). The more solar collectors installed directly on the ground, the less utilization of the ground. Roofs make solar panels floating in the air, free the ground space for all kinds of leisure activities, and provide effective wind and rain shelter spaces for visitors.

2). Large areas of roofs require minimized structure to make it investment efficient. Large areas of roofs require free and dynamic form to make it more related to nature spirit and leisure mood.

3). The solar roof should contain various appearances of transparency. By using the different patterns of solar cells, the roofs are able to provide delightful natural lighting and colour for its visitors.

4). Roofs should consider best solar orientation and appropriate slope angles to reduce snow load.

5). Solar roofs should be designed and constructed under the variations of one formative typology, to provide rich visual effect without being too disordered, as an attractive landmark for local public and visitors.

Tensile Structure for Solar Technology

1). The dynamic and natural shapes create various spaces, also cope with the site atmosphere of leisure and nature.

2). Tent is one of the most original architecture typology in human history. Its spirit of lightness and adaptation echoes with the ideology of sustainability.

3). Cover large areas with efficient structure and express its component honestly.

4). The scale of the tensile structure could be various, which provides great potential for designing many different tensile structure systems under one formative typology, with rich appearances and functions, for different scales.

Tensile Structure System for Olympic Park, Munich
http://www.arcaro.org/tension/album/munich09.jpg
Concept Design of a Sustainable Landmark

Wind Appliance

Technology Appliance and Requirements

Main appliance:
Mostly medium sized Horizontal Axis Wind Turbines, with a tower height and diameter of 30 meters, to generate electricity.

Requirements:
1) Sufficient distance from trees, buildings, and other wind turbines to avoid wind turbulence.
2) Certain distance from people for safety protection.

Main supporting appliance:
Mostly Vertical Axis Wind Turbines, with a height of 15 meters, to generate electricity.

Requirement:
Sufficient distance from trees and buildings to avoid wind turbulence.

Secondary supporting appliance:
Horizontal Axis Wind Turbines with multi-blades to convert wind energy to mechanic force for water pumping.

Requirement:
Certain distance from people for safety protection.

Future supporting appliance:
With one Makani wind energy kites and several aerostat mounted balloons in the future, flying about 300 meters above the ground, as visual icons and electricity providers.

Requirement:
Large open ground to provide sufficient space for tender swinging and kite/balloon rest.

Architectural Form Requirements

1). With iconic visual effect, wind turbines and wind kites/balloons should have attractive but not disarranged appearances. In order to fit in the leisure and natural mood of the site, they should not be over-sized, even though it restricts the energy harvest from wind.

2). Main wind harvest turbines are relatively large and noisy, should be placed near the main traffic road to the west of the site. Considering the visual effect, main turbines should be arranged linear.

3). Smaller Vertical Axis Wind Turbines can be arranged along the road in the site, also function as road light.

4). Small horizontal Axis Wind Turbines with multi-blades can be placed in the middle of plaza or in the middle of landscape gardens, as visual attractions. Its mechanic power from wind can be used to pump water from the lake to the water landscape of the site.

Wind Technology as Landscape Embellishments

There are mainly two typologies for wind technology structures: the tower and the kite. Because of the consideration for public safety and energy conversion efficiency, wind technology structures are not suitable to be integrated with architecture. However, they could be planted in the natural landscape and among the pavilions, as lively landscape embellishments. With organic arrangement, different kinds of wind turbines and kites would be dynamic attractions of sustainability on the site.
Introduction:

The project will be an organic combination of sports park and multi-functional pavilions. The propose of the project is to provide clean energy to make a contribution to the energy neutral planning of Kerkrade in the future, as well as natural recreation to local residents of Kerkrade, and visitors coming here especially.

The project follows the spirit of Munich Olympic Park. Meanwhile, the scale of the project needs to be further studied, to make it more financially affordable for Kerkrade.

The project can be established for more than one phases. The first phase could be arranged as the host pavilion for IBA Parkstad Limburg exhibition in 2020.

Under the structural principle of tensile structure and the formative typology of tent, there are many variations of tensile systems. They can be sorted mainly as permanent and temporary structures. Permanent structures, like panel-cable net system, are for solar roofs and pavilions. Temporary structures, like membrane systems, are for mobile small collectors, landscape embellishments, playground facilities, and so on.

Nature, technology, and life, are three main themes of the project. The project would be a landmark of natural lives, a medium of sustainability education, and an inception of an energetic future for everyone.
## Solar Roof Structure

Follow the roof structure of Munich Olympic Park, thin film solar cells are arranged on $3 \times 3$ meter transparent panels and installed on steel cable nets with a mesh width of 0.75 meter. [Irene Meissner, Eberhard Möller, Mirjana Grdanjski, Winfried Nerdinger, (2005), Page.269]

## Energy Output Estimation

Available solar collector roof area (approximately): 30000 square meter.

Solar energy production in a year: (electricity)

\[
160w \times 1439\text{hour} \times 0.8 \times 30,000m^2 = 5,530\text{MWh}
\]

(See equation in page 6, and Appendix 2.2)

Wind energy from 30M Darrieus Wind Turbine $\times 6$:

\[
426,806\text{kWh} \times 6 = 2,570\text{MWh}
\]

(See calculation in page 10)

Wind energy from Makani wind kite:

Power = 2,337kW

AEO = 12,900MWh

(See calculation in page 10, and data from page 11)

Currently, solar heating and seasonal storage are not available for the consumption demand is not yet clear. Wind energy from wind balloon and street VAWTs are not available for the lack of solid data.

Sum of sustainable clean energy production:

\[
5,530\text{MWh} + 2,570\text{MWh} + 12,900\text{MWh} = 21,000\text{MWh} = 75.6\text{TeraJoule}
\]

(1 MWh = $3.6 \times 10^9$ Joule)

(1 TeraJoule = $1 \times 10^{12}$ Joule)
CONCLUSION

Research Answers

According to the content above, it is clear that:
1). Although the solar and wind natural power of Park Gravenrode in Kerkrade is not abundant, they meet the requirements to support solar and wind energy generation technologies.
2). Photovoltaic, solar heating and district seasonal thermal storage systems could be applied as solar energy generation technologies on the site; Medium and small HWATs, small VWATs, and wind kites/balloons could be used as wind energy generation technologies in Park Gravenrode in Kerkrade.
3). By applying tensile structures to provide large roof areas for solar collectors, and setting wind turbines and wind kites/balloons as multi landscape embellishments, solar and wind energy generation technologies are able to be integrated with architectural design and site planning.

Problems and Limits

1). Energy Efficiency:
The actual effectiveness of solar roof is hard to make sure.
The actual production of wind energy is hard to make sure.
2). Construction and cost.
Cost of solar panels and structure is unknown
Foundation of construction is unknown.
3). Energy production.
The energy generation of this project is approximately 75.6 Tera Joule, which is only one sixth of the Sustainable energy shortage of Kerkrade, 451 Tera Joule.

The analysis and planning only focus on aesthetic forms without considering technological practicability is not realistic and eventually lead to unnecessary waste; on the contrary, those analysis and planning only pays attention to how to maximize sustainable energy production without considering the natural landscape and public expectation would be nothing but undesirable machines.
Taking the balance between natural landscape with public satisfaction requirement, and sustainable clean energy generation is difficult, but necessary.

Social and Technological Contribution

The analysis and planning in this paper is a valuable attempt, showing a positive gesture toward a sustainable and energetic future which is full of natural beauty.

As for this project in Kerkrade, socially, attract more visitors to boost local economy, as well as to integrate natural environment with recreation and sport activities for local people.; technologically, the project will provide a possibility to increase the sustainable clean energy production. It can be the host pavilion for IBA Parkstad Limburg exhibition. It is not only an exhibition of technology, nor a landmark architecture of nature and recreation, but a combination of both. Moreover, the framework of social improvements and technical systems are generically applicable for other shrinking industrial areas like IBA Parkstad.

An Education of Sustainability

As an organic part and a representative landmark of the district, the new sustainable architecture design should not only use building technologies to establish energy based sustainable systems for itself and the district planning, but also use architectural factors to express the sustainable system, as an education of sustainability, to general public.
Because the implementation of sustainable renovation requires lifestyle and idea changes, from the unawareness of sustainability into a common understanding of greener and healthier living possibilities, of general public. People deserve to receive better education about how their lives are supported by natural resources and what kinds of sustainable ideologies and technologies are available to improve their lives, so that they can play more active parts in the sustainable renovation of their living environment. And this kind of education should be provided in the new sustainable architecture design of this project.
Appendix

APPENDIX

Site Analysis

Appendix 1.1 - Page 4
The view of west side of the lake Crane Weyer, open ground and vegetation.
Source of the picture: Took by author.

Appendix 1.2 - Page 4
The view of the lake Crane Weyer, surrounded by trees and with many ducks living in.
Source of the picture: Took by author.

Appendix 1.3 - Page 4
The view of the lake Crane Weyer, with old bench near the lake
Source of the picture: Took by author.

Appendix 1.4 - Page 4
The jogging path near lake Crane Weyer
Source of the picture: Took by author.
Appendix 1.5 - Page 5
Daily course of global radiation per month for South Limburg

Source of the data:

Appendix 1.6 - Page 5
Stereographic Diagram of Beek, Netherlands

Source of the data:
Weather Data - U.S. Department of Energy
Diagrammed by:
Weather Tool of Autodesk Ecotect 2010

Appendix 1.7 - Page 5
Prevailing Winds Frequency Diagram of Beek, Netherlands

Source of the data:
Weather Data - U.S. Department of Energy
Diagrammed by:
Weather Tool of Autodesk Ecotect 2010
Appendix 1.8 - Page 5
The Wind Speed Distribution in Kerkrade
Source of the data: IBA PALET 2.0 for Kerkrade.

Appendix 1.9
The Solar Energy Distribution in Kerkrade
Source of the data: IBA PALET 2.0 for Kerkrade.
Appendix 2.1 - Page 6
Efficiency and Development Stages of Different PV Cell Types
Source of the table: [David Thorpe, (2011), P132]

<table>
<thead>
<tr>
<th>Type of cell</th>
<th>Construction</th>
<th>Cell efficiency (%)</th>
<th>Module efficiency (%)</th>
<th>Current stage of development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monocrystalline silicon</td>
<td>uniform crystalline structure - single crystal</td>
<td>24</td>
<td>14-20</td>
<td>industrial production</td>
</tr>
<tr>
<td>Polycrystalline (multi-crystalline)</td>
<td>multi-crystalline structure - different crystals visible</td>
<td>18</td>
<td>13-15</td>
<td>industrial production</td>
</tr>
<tr>
<td>Amorphous silicon</td>
<td>atoms irregularly arranged thin-film technology</td>
<td>11-12</td>
<td>5-9</td>
<td>industrial production</td>
</tr>
<tr>
<td>Cadmium-telluride</td>
<td>thin-film technology</td>
<td>17</td>
<td>9-11</td>
<td>industrial production</td>
</tr>
<tr>
<td>Copper-indium-selenide</td>
<td>thin film, various deep position methods</td>
<td>18</td>
<td>10-12</td>
<td>industrial production</td>
</tr>
<tr>
<td>Gallium-arsenide</td>
<td>crystalline cells</td>
<td>25</td>
<td>-</td>
<td>produced exclusively for special applications (e.g. spacecraft)</td>
</tr>
<tr>
<td>Gallium-arsenide, gallium-antimony and others</td>
<td>tandem (multi-junction) cells, different layers sensitive-different light wave-lengths</td>
<td>25-31</td>
<td>-</td>
<td>research and development stage</td>
</tr>
<tr>
<td>Organic solar cells</td>
<td>electric-chemical principle based</td>
<td>5-8</td>
<td>-</td>
<td>research and development stage</td>
</tr>
</tbody>
</table>

Appendix 2.2 - Page 6
Electrical Characteristics, Standard Test Conditions (STC), (area: 1.09m²)
Source of the table: [TSMC Company, (2014), P2]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power (P&lt;sub&gt;max&lt;/sub&gt;)</td>
<td>145</td>
<td>150</td>
<td>155</td>
<td>160</td>
</tr>
<tr>
<td>Factory binning</td>
<td>+5/-0</td>
<td>+5/-0</td>
<td>+5/-0</td>
<td>+5/-0</td>
</tr>
<tr>
<td>Open-circuit voltage (V&lt;sub&gt;oc&lt;/sub&gt;)</td>
<td>86.0</td>
<td>86.6</td>
<td>86.7</td>
<td>86.8</td>
</tr>
<tr>
<td>Short-circuit current (I&lt;sub&gt;sc&lt;/sub&gt;)</td>
<td>2.62</td>
<td>2.62</td>
<td>2.62</td>
<td>2.62</td>
</tr>
<tr>
<td>Maximum power voltage (V&lt;sub&gt;mp&lt;/sub&gt;)</td>
<td>63.6</td>
<td>65.5</td>
<td>67.1</td>
<td>68.7</td>
</tr>
<tr>
<td>Maximum power current (I&lt;sub&gt;mp&lt;/sub&gt;)</td>
<td>2.28</td>
<td>2.29</td>
<td>2.37</td>
<td>2.33</td>
</tr>
<tr>
<td>Module efficiency (Eff %)</td>
<td>13.3</td>
<td>13.8</td>
<td>14.3</td>
<td>14.7</td>
</tr>
<tr>
<td>Power tolerance</td>
<td>+/-5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum reverse current (I&lt;sub&gt;r&lt;/sub&gt;)</td>
<td>6.5 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-40°C to 85°C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix 2.3 - Page 6
The Components of a grid-connected system
A: Solar modules
B: Grid inverter
C: Grid-feed electricity meter
D: House connection point
E: Public electricity network
F: Consumption electricity meter
G: Electrical load

The modules feed power to the home's appliance through the grid inverter, which produces grid-quality AC electricity. Any surplus not used is sent to the local electricity network through the grid feed electricity meter. When the home's demand is greater than can be satisfied by the PV array, such as at night time, power is drawn instead from the local network through the consumption electricity meter. The utility company would bill the home for the balance of the amount of power used and supplied, according to the tariffs agreed for the electricity bought and sold. [David Thorpe, (2011), Page.136]

Source of the picture: http://www.solar-energy-systems.eu/NL/images/consumer/1a.jpg
Appendix 2.4 - Page 7

Cases of Building-integrated photovoltaic.

Lehrter Bahnhof Central Railway Station in Berlin (June 2006)
Location: Berlin, Germany
Architect: Van Gerkan, Marg und Partner
Glass-glass Modules Manufacture: HSG Flabeg
Selected from [Deutsche Gesellschaft Für Sonnenenergie (Dgs), (2001), Page.300]

GreenPix - Zero Energy Media Wall (June, 2008)
Location: Beijing, China
Architect: Simone Giostra & Partners Architects
Solar technology R&D: Schuco International KG, Sunways AG

The Earth Centre Canopy (August 2001)
Location: South Yorkshire, England
Architect: Feilden Clegg Bradley Architects
Structure Engineers: Atelier One, Carpenter Oak
Selected from [Randall Thomas, Max Fordham and Partners, (2001), Page.102]

Steel-glass construction: cable-tensioned arched trusses and a cable-tensioned grid of cross and longitudinal beams provide the glass support.
All modules have different sizes (depending on their position). They lie on silicone gaskets and their corners are screwed with clamping plates to the grid intersection points.

GreenPix is a large-scale display comprising of 2,292 color (RGB) LED’s light points comparable to a 24,000 sq. ft. (2.200 m2) monitor screen for dynamic content display.
LED powered by PV cells embedded in a glass wall, that produce digital art at night time and are powered by solar energy stored from the day time.

The canopy is roofed with photovoltaic cells embedded in glass. The cells are spaced 4mm apart with a 60 mm space round the edge.
The installation is of monocrystalline silicon cells with a minimum collection efficiency of 15.5% set between 2 panes of glass.
The output of the 1000 m² of collector array is just over 107kW peak yielding a total potential of 77000 kWh of generated electricity per year.
Appendix 2.5 - Page 7
Flat Collectors

Appendix 2.6
Flat Collectors on the Roof

Appendix 2.7 - Page 7
Batch Solar Water Heater
Source of the picture: http://www.solar-energy-at-home.com/images/batch_heater.gif

Appendix 2.8
Batch Solar Water Heater on the Roof

Appendix 2.9 - Page 7
Evacuated Tube Collectors
Source of the picture: http://www.daviddarling.info/images/evacuated-tube_collector.gif

Appendix 2.10
Evacuated Tube Collectors on the Roof
Source of the picture: https://alternativepowerdistribution.files.wordpress.com/2011/03/apd-classic-from-other-side.jpg
Passive solar water heating system

Advantages:
- does not require a pump;
- more reliable as there is less to break down.

Disadvantages:
- the storage tank must be situated above the top of the collector(s) or thermosiphoning will now work;
- the thermosiphon effect only works consistently well in warm climates.

Direct solar water heating system

Advantages:
- easiest to install;
- used in tropical settings where it never freezes;
- also useful for swimming pools;
- low maintenance.

Disadvantages:
- unsuitable in areas where it freezes unless the system is drained;
- if the tank is outside then thermal losses will be high;
- the water heated is the water used.

Indirect solar water heating system

Advantages:
- can be used in areas where the temperature drops below freezing;
- the water being heated indirectly can be in an insulated tank indoors so thermal losses will be lower than for the direct system.

Disadvantages:
- more complex and requires a heat exchanger;
- this negatively affects the efficiency of the system;
- the heat-transmitting fluid (which contains anti-freeze) must either be non-toxic or there must be no chance of it leaking into the water.

Active solar water heating system

Advantages:
- the tank can be located anywhere.

Disadvantages:
- requires a pump and electricity source;
- requires a valve or thermostat controller so that the pump only comes on when the collector is hotter than the tank.
Appendix 2.12 - Page 8
The Four Sensible Seasonal Thermal Energy Storage Technologies.
Source of the picture: Selected from [AGFW, Solites, (2012), Page.7]

Tank thermal energy storage (TTES)
(60 to 80 kWh/m²)

Pit thermal energy storage (PTES)
(30 to 80 kWh/m²)

Borehole thermal energy storage
(BTES)
(15 to 30 kWh/m²)

Aquifer thermal energy storage
(ATES)
(30 to 40 kWh/m³)

Appendix 2.13 - Page 8
Working Flow and Energy Flow Diagrams of The Drake Landing Solar Community,
Source of the picture: Selected from [Bettine Gommer, Pieter van Hall, Gabrielle de Leo, (2015), Page. 44-47]

During spring and summer, a lot of heat is available from the solar collectors. In order to supply domestic hot water, the solar collectors placed on the roof top are directly connected to the housing units. The heat collectors on the garage however, transfer the heat to energy centre, where buffer tanks are charged. Once the short term tanks are fully charged, the excess heat is transferred to the ground, charging the BT ES system.

During winter, the heat demand raise significantly, being the space heating demand added to the domestic hot water demand. Also, the heat that is provided by the solar panels drops. During this period, the BTES is discharged, providing the heat needed to face the heat demand.
Wind Energy

Appendix 3.1 - Page 9
Effect of the Number of Blades

Source of the text and equations: Selected from [Godfrey Boyle, (2004), Page.254]

The speed of rotation of a wind turbine is usually measured in either revolutions per minute (rpm) or radians per second (rad s\(^{-1}\)). The rotation speed in revolutions per minute (rpm) is usually symbolized by \(N\) and the angular velocity in radians per second is usually symbolized by \(\Omega\) (and sometimes by \(\omega\)). The relationship between the two is given by:

\[
1 \text{ rpm} = \frac{2\pi}{60} \text{ rad s}^{-1} = 0.10472 \text{ rad s}^{-1}
\]

Another measure of a wind turbine's speed is its tip speed, \(U\), which is the tangential velocity of the rotor at the tip of the blades, measured in metres per second. It is the product of the angular velocity, \(\Omega\), of the rotor and the tip radius, \(R\) (in meters)

\[
\text{i.e. } U = \Omega R
\]

Alternatively, \(U\) can be defined as:

\[
U = \frac{2\pi RN}{60}
\]

By dividing the tip speed, \(U\), by the undisturbed wind velocity, \(V_o\), upstream of the rotor, we obtain a non-dimensional ratio known as the tip speed ratio, which is usually symbolized by \((\lambda)\). This ratio provides us with a useful measure with which to compare wind turbines of different characteristics.

\[
\lambda = \frac{U}{V} = \frac{\Omega R}{V}
\]

A wind turbine of a particular design can operate over a range of tip speed ratios, but will usually operate with its best efficiency at a particular tip speed ratio, i.e., when the velocity of its blade tips is a particular multiple of the wind velocity.

The optimum tip speed ratio for a given wind turbine rotor will depend upon both the number of blades and the width of each blade.

In order to extract energy as efficiently as possible, the blades have to interact with as much as possible of the wind passing through the rotor’s swept area. The blades of a high-solidity, multi-blade wind turbine interact with all the wind at very low tip speed ratios, whereas the blades of a low-solidity turbine have to travel much faster to “virtually fill up” the swept area, in order to interact with all the wind passing through. If the tip speed ratio is too low, some of the wind travels through the rotor swept area without interacting with the blades; whereas if the tip speed ratio is too high, the turbine offers too much resistance to the wind, so that some of the wind goes around it. A two-bladed wind turbine rotor with each blade the same width as those of a three-bladed rotor will have an optimum tip speed ratio one-third higher than that of a three-bladed rotor. A one-bladed rotor with a blade width the same as that of a two-bladed rotor will have twice the optimum tip speed ratio of the two-bladed rotor. Optimum tip speed ratios for modern low-solidity wind turbines range between about 6 and 20.

In theory, the more blades a wind turbine rotor has, the more efficient it is. However, large numbers of blades can interfere with each other, so high-solidity wind turbines tend to be less efficient overall than low-solidity turbines. Of low-solidity machines, three bladed rotors tend to be the most energy efficient; two-bladed rotors are slightly less efficient and one-bladed rotors slightly less efficient still. Wind turbines with more blades can be generally expected to generate less aerodynamic noise than wind turbines with fewer blades.

The mechanical power that a wind turbine extracts from the wind is the product of its angular velocity and the torque imparted by the wind. Torque is the moment about the centre of rotation due to the driving force imparted by the wind to the rotor blades. Torque is usually measured in newton metres (Nm). For a given amount of power, the lower the angular velocity the higher the torque; and conversely, the higher the angular velocity the lower the torque.

The pumps that are used with water pumping wind turbines require a high starting torque to function. Multi-bladed turbines are therefore generally used here because of their low tip speed ratios and resulting high torque characteristics.

Conventional electrical generators run at speeds many times greater than most wind turbine rotors so they generally require some form of gearing when used with wind turbines. Low-solidity wind turbines are better suited to electricity generation because they operate at high tip speed ratios and therefore do not require as high a gear ratio to match the speed of the rotor to that of the generator.
Appendix 3.2 - Page 9

Some Examples of the Machines that have been Proposed for Wind Energy Conversion

Source of the picture: [Godfrey Boyle, (2004), Page.251]
Appendix 3.3 - Page 10
The Wind Shear Exponent α
Source of the data: Selected from [Paul Gipe, (2004), Page.41]

The wind shear exponent α varies with the time of day, season, terrain, and stability of the atmosphere. Shear is low where there is minimum surface roughness and high where there are numerous objects to disturb the flow. German engineer Jens-Peter Molly in his book “Wind Energy” presents a simple formula for calculating α from a measure of the surface roughness.

\[ \alpha = \frac{1}{\ln(z/z_0)} \]

Where \( z_0 \) is the surface roughness length in meters and \( z \) is the reference height. For example, when the surface roughness length is 0.01 meter, and the reference height is 10 meter, then

\[ \alpha = \frac{1}{\ln(10/0.01)} = \frac{1}{\ln(1000)} = 0.144 \]

Appendix 3.4 - Page 10
Annual Energy Output Estimates for Small and Medium-Size Wind Turbines
Source of the data: [Paul Gipe, (2004), Page.58]

<table>
<thead>
<tr>
<th>Annual Average Wind Speed (m/s)</th>
<th>Nominal (mph)</th>
<th>Annual Power Density (W/m²)</th>
<th>Annual Energy Density (kWh/m²)</th>
<th>Small Turbines</th>
<th>Medium Turbines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Overall Conversion Efficiency (%)</td>
<td>Annual Energy Output (kWh/m²)</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>75</td>
<td>656</td>
<td>20</td>
<td>130</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>146</td>
<td>1281</td>
<td>20</td>
<td>260</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>253</td>
<td>2214</td>
<td>19</td>
<td>410</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>401</td>
<td>3515</td>
<td>16</td>
<td>570</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
<td>599</td>
<td>5247</td>
<td>15</td>
<td>770</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>853</td>
<td>7471</td>
<td>14</td>
<td>1020</td>
</tr>
</tbody>
</table>

Notes:
Small wind turbine efficiency derived from measurements at the Wulf Test Field. One micro turbine tested delivered 23% efficiency in higher-speed wind regimes, but this is not the norm.
Medium-size wind turbine efficiency derived from tests by DEWI, Windtest KWK, and product literature.

Appendix 3.5 - Page 10
Energy Production Data of Wind Technik Nord WTN250 (hub height 30 m)
Source of data: Selected from [RM Energy Ltd, “RME,WTN250: Turbine Summary”, Page. 3]

WTN250 Power Curve

<table>
<thead>
<tr>
<th>Wind at hub height (m/s)</th>
<th>Output kW</th>
<th>Wind at hub height (m/s)</th>
<th>Output kW</th>
<th>Wind at hub height (m/s)</th>
<th>Output kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.0</td>
<td>9</td>
<td>123.3</td>
<td>1</td>
<td>250.0</td>
</tr>
<tr>
<td>4</td>
<td>7.5</td>
<td>10</td>
<td>151.8</td>
<td>14</td>
<td>346.3</td>
</tr>
<tr>
<td>5</td>
<td>17.2</td>
<td>11</td>
<td>178.4</td>
<td>18</td>
<td>344.7</td>
</tr>
<tr>
<td>6</td>
<td>28.9</td>
<td>12</td>
<td>202.7</td>
<td>20</td>
<td>242.3</td>
</tr>
<tr>
<td>7</td>
<td>56.9</td>
<td>13</td>
<td>225.9</td>
<td>22</td>
<td>234.4</td>
</tr>
<tr>
<td>8</td>
<td>91.1</td>
<td>14</td>
<td>242.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Annual Energy Production (AEP)

<table>
<thead>
<tr>
<th>Average Wind Speed at hub height (m/s)</th>
<th>Approx energy yield per annum MWh</th>
<th>Capacity factor %/year full load</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>95</td>
<td>4.4%</td>
</tr>
<tr>
<td>4.0</td>
<td>152</td>
<td>7.0%</td>
</tr>
<tr>
<td>4.5</td>
<td>221</td>
<td>10.2%</td>
</tr>
<tr>
<td>5.0</td>
<td>301</td>
<td>13.9%</td>
</tr>
<tr>
<td>5.5</td>
<td>387</td>
<td>17.9%</td>
</tr>
</tbody>
</table>

Figures based on 360 days/yr availability and the 30m rotor diameter.
Wind speeds decrease and turbulence increases in the vicinity of obstructions. The effects are most pronounced downwind but also occur upwind as the air piles up in front of the obstruction. The flow over a hedgerow of group of trees in a shelter belt is disturbed in a similar manner.

**Appendix 3.7 - Page 11**

**Noise Pattern from a Typical Wind Turbine**

Source of diagram: [Godfrey Boyle, (2004), Page.271]
Papers, Articles, and Reports


AGFW, Solites. (2012). SDH take-off - Solar District heating in Europe. Germany

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TSMC Company. (2014). TS CIGS SERIES HIGH-EFFICIENCY CIGS SOLAR MODULE, Germany


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Weather Data - U.S. Department of Energy
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http://www.energykitesystems.net/AltaerosEnergies/index.html

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