Contract N° EIE/04/130/S07.38591

Report on Resource Assessment

-

WINEUR Deliverable 5.1

February 2007

HORISUN

AXENNE

12 rue Paul Cézanne - 69 330 MEYZIEU - Tél : +33 (0)4 37 44 15 80 - Fax : +33 (0)4 37 44 15 89

IT Power

TABLE OF CONTENTS

List of Figures

List of Tables

1 EXECUTIVE SUMMARY

This report has been prepared for the WINEUR Project (Wind Energy Integration in the Urban Environment), an initiative funded by the European Commission's Intelligent Energy Europe Agency under the ALTENER Programme.

This report is part of Work Package 5 (WP5), 'Potential Project Identification' and provides an introduction to wind resource assessment in the urban environment.

1.1 France

In France, urban wind resource assessments were not been specifically undertaken until the start of the WINEUR project. This is hindering the implementation of pilot installations and larger scale deployment of small 'urban' wind technologies. Within this Work package 5, the first French urban wind resource assessment was conducted. Some guidelines and findings have been written down in this report following the conclusions opened from the specific feasibility studies conducted in Grenoble, Lyon and Lille.

France has conducted direct wind measurement but without having any knowledge of methods since it was not existing. In conclusion, it seems quite difficult to evaluate precisely the wind potential around a building. In urban environment, the wind speed and direction are unpredictable where adjacent buildings generate turbulence. As a consequence, we could say that the urban wind resource assessment made in France were empirical since nobody has already made some in such conditions or no models were available. The measuring mast was then erected on site in position which might have not been the best ones.

The main findings from the French resource assessment are that:

- The measuring instruments should be positioned judiciously and it would be better to first have a computer modelling carried out to identify the best position;
- A HAWT should be placed in the middle of the roof of a building and above a height higher than 35%/50% the height of the building to avoid the phenomena related to turbulence;
- On the edge of the roof (e.g. against a parapet wall), a wind turbine should be place at a sufficient mast height to clear the turbulent zone of wind coming over the top of the roof.
- The higher the mast the better the wind capture will be (but will cause visual impacts);
- It should be taken in mind the significant influence of (local) wind rose and building orientation.

Finally, urban wind turbine should be installed away from obstructions, and as high up as possible. Wind speed increases significantly with height above ground. An annual average wind speed in excess of 5m/s is generally required for a project to be economically viable.

The French resource assessments might not have been the most accurate ones since they were no existing knowledge on this issues before the WINEUR project. However this has permitted to give some guidelines for future direct wind measurement and resource assessments.

1.2 UK

The British part of this report first provides an overview of traditional wind resource assessment: wind atlases and the NOABL data base, topographical analysis, direct wind measurement and derivation of long term wind resource. These are the main principles for gathering data and making estimations of wind energy over the long-term for a specific site. It then goes on to look at the particular constraints which apply when trying to assess wind resource in built-up, urban areas. These difficulties are linked to the specific conditions of urban environment (turbulence, unpredictable wind speed and wind direction). This part of report will then discuss methodologies that can be used for resource assessment in urban areas and possible problems with accuracy. It informs urban wind developers and the general public of the limitations of NOABL as a tool for estimating urban wind speeds.

Some real sites in the UK, where wind measurements were taken in urban locations (Reading University, Royal institute of British Architects or the Aylesbury Estate in London) really stress out that there exist differences between real data and predicted or estimated data. It was shown that most of the time the measurements could not be considered as representative but only give an indication. Each location is different and we can not generalize the conclusions obtained under certain conditions to all locations in one city.

It should not be forgotten that installers who estimate the energy capture of their turbines based on the annual mean wind speed in the NOABL database should provide clear guidance to their customers as to the potential inaccuracy of the result.

In conclusion, it is clear that there is no cheap method currently available to assess urban wind resources. The most accurate results will be obtained by actual measurements at the proposed location, however this is too expensive and time-consuming for most small wind projects. Therefore, modelling and database methods need to be developed to improve the estimation of urban wind speeds without having to resort to long measurement campaigns. Improvements or adjustments to NOABL would also be beneficial, as this is a well-known and easily accessed database, which could maybe be modified to take urban characteristics into consideration in order to improve its accuracy.

1.3 The Netherlands

This Dutch part of the combined report presents the results of the survey on wind resources in the Netherlands. It focuses on the location and resource assessment and the potential for UWTs in the Netherlands. The objective of this survey is to answer the following questions:

- What wind conditions are needed for UWTs?
- What are the main issues to consider regarding the location?
- What are the wind conditions for UWTs in The Netherlands?

Then, the results obtained from the Dutch resource assessment study are stated as follows.

First, the turbine model and the local wind regime are the most important factors determining energy yield. Indeed, modest differences in the wind regime may have substantial effects on the electricity yield. The minimum recommended average wind speed at an UWT location is 5.5 m/s.

The strongest wind comes from the direction south west. The regions closer to the coast have better wind conditions on 10 m height due to higher average wind speed. In the central and eastern parts of the country, the average wind speed on 10 m height is less suitable for UWTs. In those regions UWTs should be placed appropriately higher.

The Weibull distribution of the selected site should match the design characteristics of UWT.

One must be well informed about the local wind regime before giving any predictions regarding the electrical yield.

Buildings, trees, noise barriers and other obstacles influence the wind flow and create local, 'micro' wind regimes with more turbulence and gusts. A sloped or cylindrical shape of the building or roof on the side of the prevailing wind direction can have a positive effect on the energy yield of urban turbines.

Due to influence of the surrounding buildings, it is important to place the turbine on the highest building in the area and to ensure that there is enough distance from other obstacles. The yield can be as much as a factor of two higher or lower, depending only on a few meters distance from the obstacles or a few meters difference in height. In general, the higher the turbine is placed, the better. In specific situations, the measurements can be the only way to identify the right spot.

COUNTRY PARTNER: FRANCE

2 FRENCH RESOURCE ASSESSMENTS – INTRODUCTION

Generally in Europe today the framework concerning large-scale wind energy development is precisely defined. The process of resource assessment is well-know and has been proved now. However, various European manufacturers have recently introduced new kind of smaller wind turbines suitable for built-up areas, known as urban turbines (UT). Interest in installing these smaller wind turbines in urban areas is high, particularly amongst local authorities and city municipalities.

However, in France, as in most other European countries, the needed regulations, procedures and guidelines related to the integration of these small wind turbines in urban areas are not yet in place. Resource assessment of wind in urban areas has not been specifically studied until now. This is hindering the implementation of pilot installations and larger scale deployment of small 'urban' wind technologies.

Within the Work package 5 "Potential projects Identification", the first French wind resource assessment in urban areas was conducted. Those guidelines and findings are linked with the specific feasibility studies conducted in Grenoble, Lyon and Lille. This report will first describe the methodology followed to obtain the resource assessment. Secondly, the specific resource assessment from Grenoble, Lyon and Lille will be presented. Finally, some important findings will be highlighted.

3 METHODOLOGY

We've seen that in the UK, estimation was obtained from the UK national wind database, NOABL 2000, when no site monitoring was possible. This database gives an estimate of the average wind speed for each square kilometre of the UK. As the database doesn't take into account local topographical features, real wind speeds are then likely to vary and an error of ± 3 m/s is possible. Most often the wind speed is overestimated by NOABL.

On the contrary, France is not so far in this process. There exists some local wind atlas (http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=15129) but no estimation could be made from those. Thus, the methodology adopted in France was to do site monitoring.

It sounds obvious that the conditions of wind in built environment are particular:

- Frequent wind speed changes;
- Frequent wind direction changes.

Having few knowledge on this wind behaviour, wind measurements have being conducting following the method described below:

First it is worth noting that the building is higher than the surrounding buildings and there are no obstructions in the prevailing wind direction (e.g. trees, antenna, chimney, etc.). Taking this and the results from Météo France wind rose into account, it was considered that there was sufficient wind resource to justify the installation of a measuring mast on the roof.

Several wind measuring devices have been installed on the roof the building (an NRG 40 anemometer, a NRG 200P wind vane, A NRG 9200 logger). The incertitude occurring here resided in the optimal location for the measuring mast. From those various resource assessments, few findings have been made and will be presented in conclusion.

The wind resource measuring procedures chosen for this first resource assessment are the same used for the traditional big scale wind energy: the anemometer measures the wind speed, while the wind vane indicates its direction. All this data will be recorded in two 100-day autonomy memory chips plugged in the logger. For a better precision, measurements should be recorded during a certain period of time: the longer will be the better. For large-scale wind turbine we usually speak of one year measurements at a specific height mast. Within the framework of the WINEUR it was not possible to conduct one-year measurements. Measurements are still on process in Lyon. Moreover, the position of the mast is a critical issue which has been highlighted by these empirical resource assessments. We will discuss this later.

The recorded data will then be processed by a specialised engineer in order to determine the energy yield of this site. This measuring equipment must be inspected periodically in order to guarantee its good functioning. Maintenance operations such as replacing the chips will have to be done.

The measured energy yield will be compared to the data of the region provided by Météo France services over a period up to ten years (wind rose). This information will allow to identify the matching technology for this specific site.

This theoretical methodology applied for the 3 sites of Lille, Lyon and Grenoble will be illustrated by the results obtained for those locations.

4 GRENOBLE RESOURCE ASSESSMENT

4.1 Description of the site

Several meetings between the Grenoble Community and Axenne have lead to the consideration of one particular possible site for the installation of an urban turbine at the following address: 45, rue Anatole France, 38 000 Grenoble.

The wind measurement system was placed on the roof of this social building housing. This building is particularly high so there are no particular obstacles as we could be expecting in an urban area.

Figure 1: Wind measurement tools on social housing building (Cité Mistral).

4.2 Results from the resource assessment

As presented by the methodology, the measured energy yield will be compared with the wind data of the region provided by Météo France services over a period up to ten years (See Figure 2).

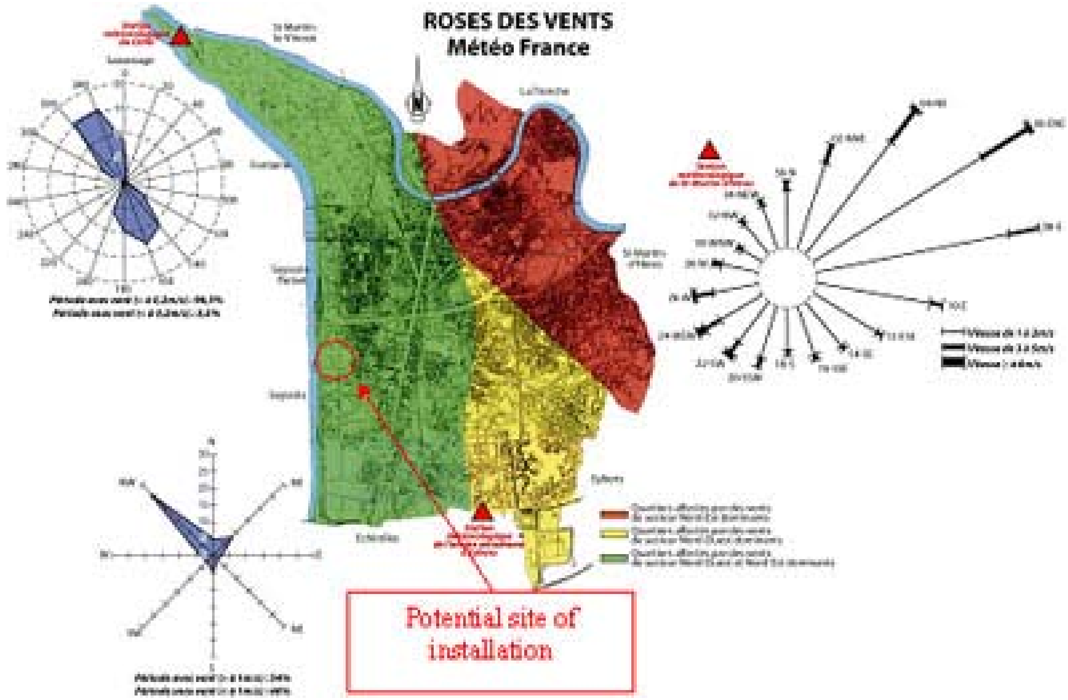
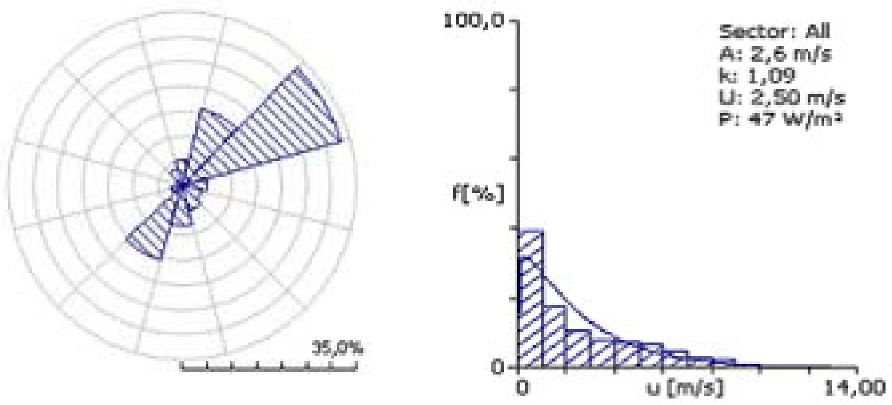


Figure 2: 10 years of meteorological data for the city of Grenoble, Météo France.

After a period of four months of measurements, the following results were obtained. The data treatment was made by a wind expert.

Measuring period	**From October 28th 2005 to February 19th 2006**
Speed availability	68%
Direction availability	52%
Average wind speed (m/s)	**2.36**
% of time when speed>5m/s	15.50%
Average standard deviation	0.82



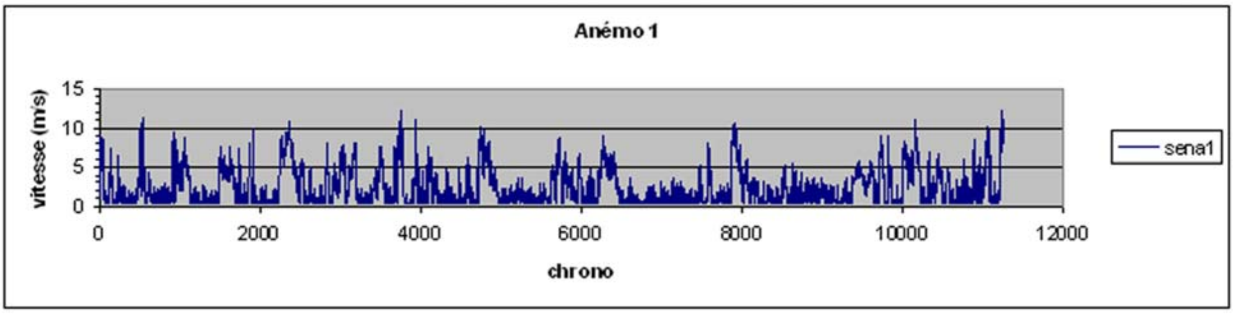


Figure 3: Wind speed variation over the measuring period, Grenoble.

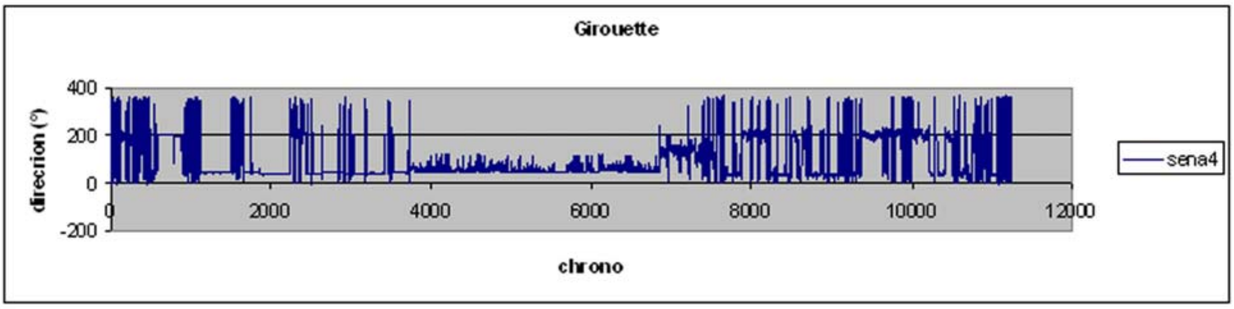


Figure 4: Direction variation over the measuring period, Grenoble.

These results indicate that the site has a weak wind potential. The average wind speed is 2.36 m/s. This can be explained by masking noise around the measurement mast.

5 LILLE RESOURCE ASSESSMENT

5.1 Roubaix

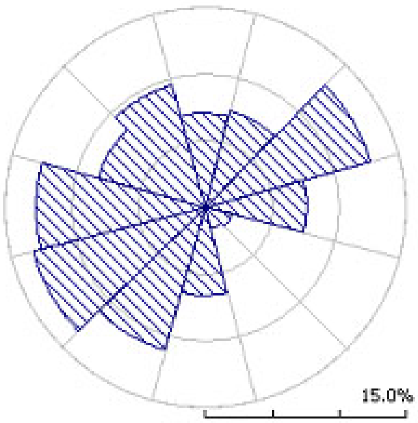
In the region of Lille, the prevailing wind is in the direction South-west with an average wind speed of 5 m/s. To assess more precisely the wind potential, wind measurement equipment were placed on the roof of the building in February 2006. The same measurement procedure as in Grenoble has been followed.

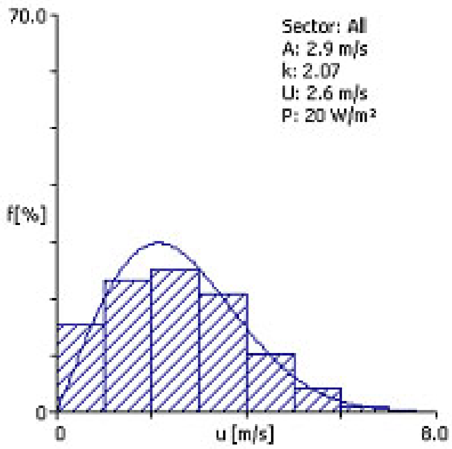
This building is situated in an urban area with a relative weak density (mainly small collective). The building is closed to an old industrial area. On Figure 5 we clearly see that there are no particular obstacles (higher buildings, trees, etc.).

Figure 5: Wind measurement tools on Roubaix building (La Condition Publique).

The results for the measurement period from 1st of February until 13th of March 2006 are summarized in this table:

Measuring period	**From February the 1st to March the 13th 2006**
Speed availability	94%
Direction availability	93%
Average wind speed (m/s)	**2,54**
% of time when speed>5m/s	**4,48%**
Average standard deviation	**1,00**





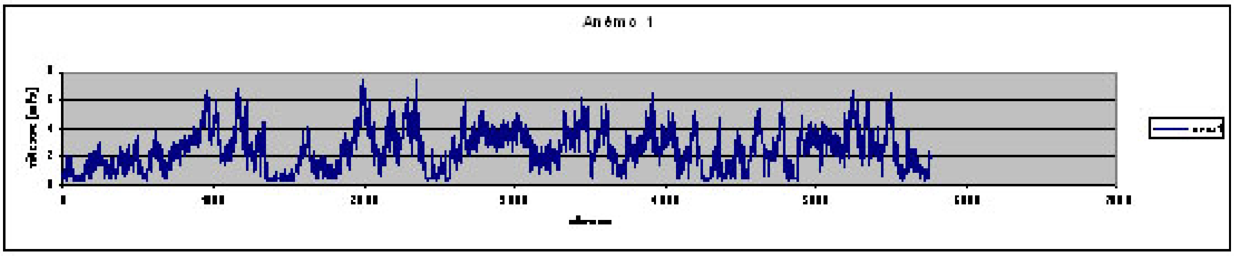


Figure 6: Wind speed variation over the measuring period, Roubaix.

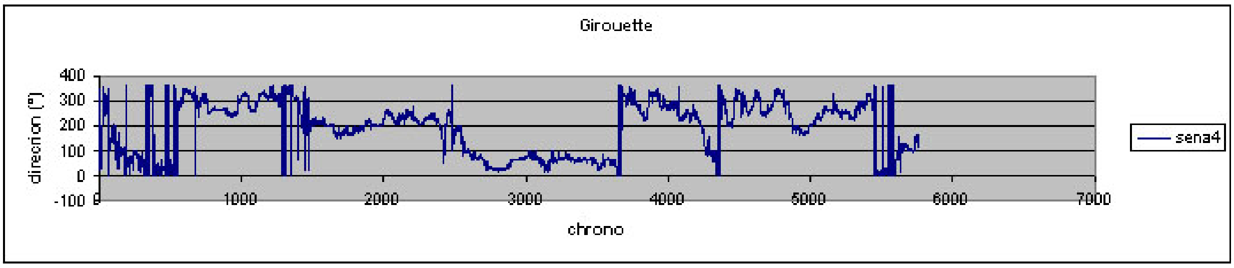


Figure 7: Direction variation over the measuring period, Roubaix.

The average wind speed is not really important

5.2 Templemars

As we have seen for Roubaix, the prevailing winds for Lille Metropole are south-west with an average wind speed of 5 m/s. A precised wind measurement was not possible since budget and time were not sufficient. To obtain accurate measurements, the ideal measurement period is one year. The wind potential for Templemars can only be estimated using the wind rose from Lesquin meteorological station.

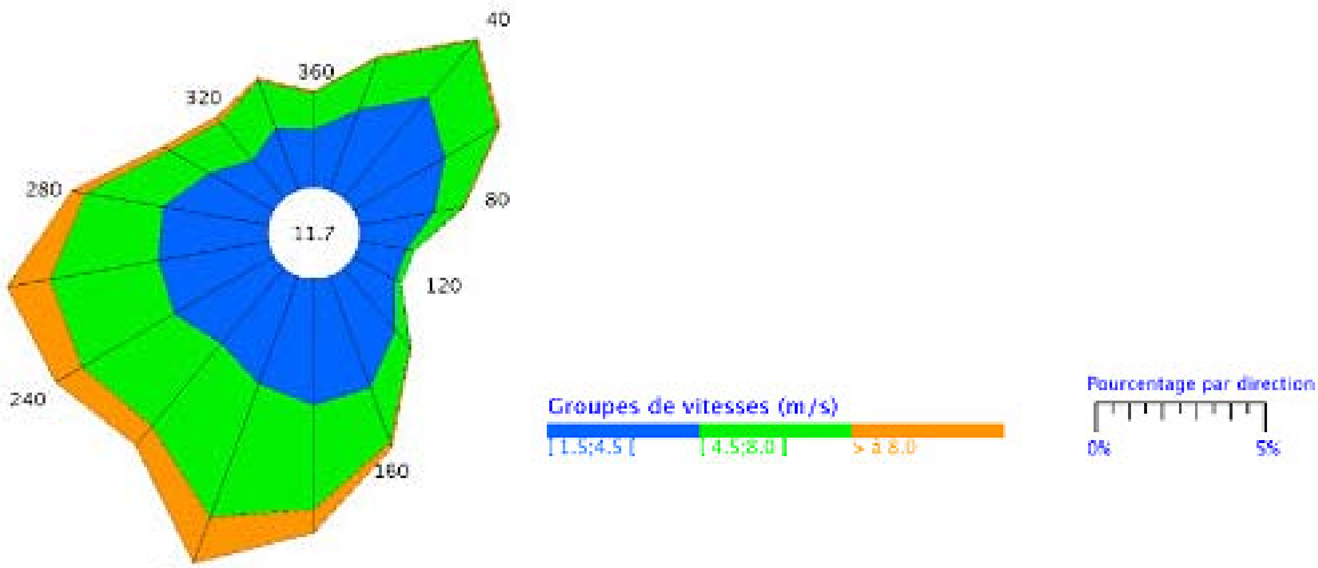


Figure 8: Wind rose from Lesquin.

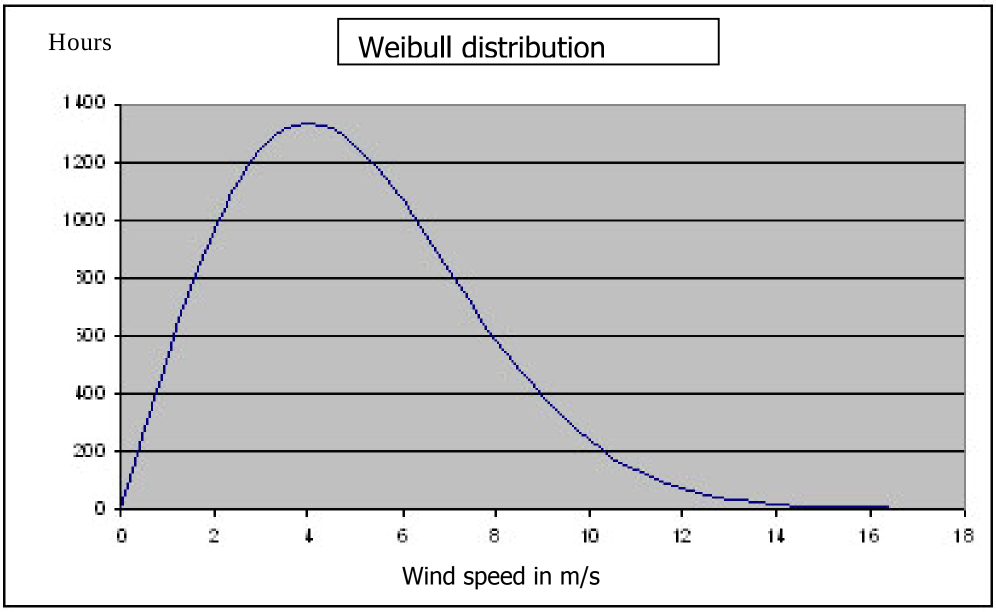
This wind rose is not enough since between two sites there can have big differences. But this confirms the hypothesis of south-west as the prevailing wind direction.

To estimate the annual production of different wind turbine, the study was made for an average wind speed of 5 m/s (see Lesquin wind data). The wind distribution was simulated by Weibull distribution following the formula:

$$P(V) = \frac{k}{A} * (\frac{V}{A})^{k-1} e^{-(V/A)^k}$$

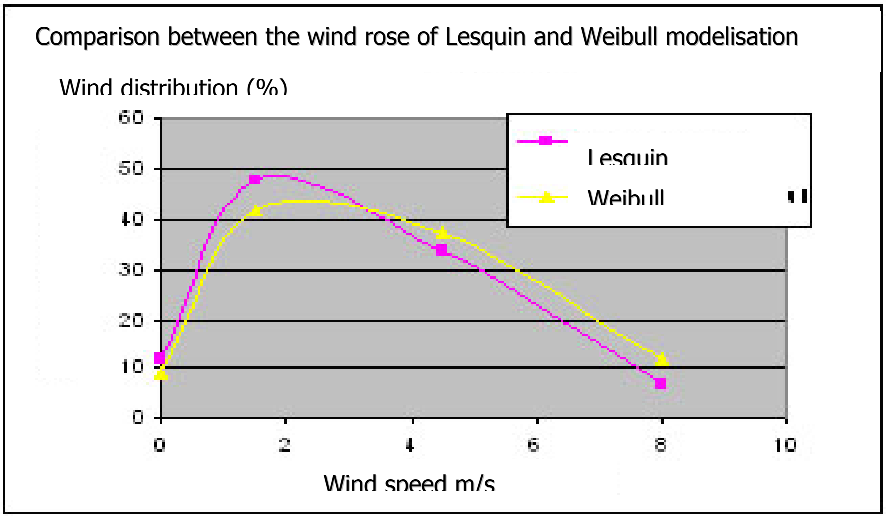
A : scale parameter (m/s)
k : shape parameter (no unit)

Wind turbine manufacturers usually give a shape parameter of 2. The scale parameter, A, is obtained using the average velocity. We can then have our wind distribution



WEIBULL DISTRIBUTION (A=5.64 ; K=2 ; U (AVERAGE)=5M/S ; U (MEDIAN)=4.7M/S)

To validate our simulation, we're comparing them with Lesquin data (see graph below). Our simulation seems to be correct regarding the comparison graph.



6 LYON RESOURCE ASSESSMENT

Up to now, some measures have been collected to compare then to the wind potential obtained from meteorological data from Météo France.

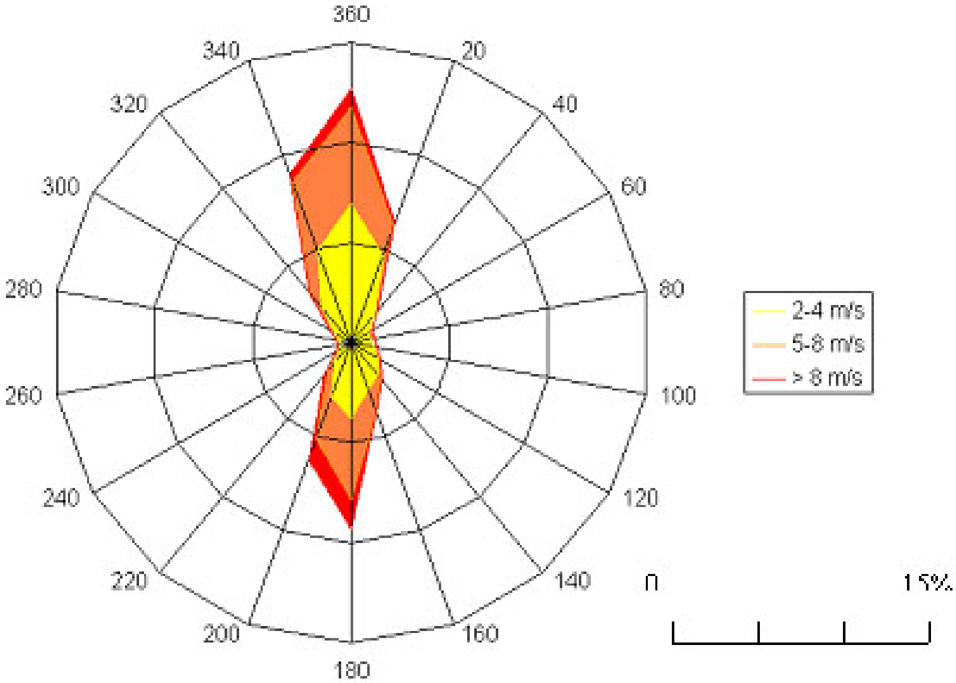


Figure 9: Wind rose from Lyon agglomeration.

The wind rose clearly outlines the main direction which are north-south. It's also related to the geographical conditions of Lyon, situated in the Rhone-native corridor. The two prevailing class of wind are [2-4 m/s] and [5-8 m/s] relative to urban wind conditions.

The measurement period for the site of Lyon was able from April until June. Due to technical constraints, it was not possible to collect more data. It's important to reaffirm here that to obtain a accurate wind potential, it's a necessity to measure the wind speed during one year and compare it to 10 years data from a meteorological office. The conclusions that we're going to present would not be really precise due to the lack of information.

After maintenance on the measuring mast, the measurements were reactivated and still on process.

The results obtained up to now are:

Measuring period	**From April 12th 2006 to June 10th 2006**
Speed availability	87%
Average wind speed (m/s)	**3.0**

The wind speed availability is considered as the percentage of time we can consider to have wind available. This availability is around 87% which is quite good. The average wind speed is around 3 m/s and the wind speed class with the highest percentage of time is [1;2], [2;4] and [4;6], with respectively 18%, 24% and 17%.

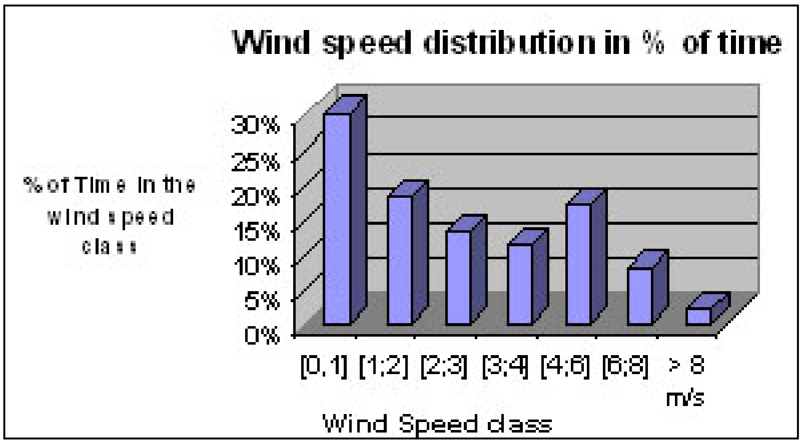


Figure 10: Wind speed distribution for Lyon site (Laënnec).

This results are confirming the ones from the Météo France data. These classes of wind are particularly adapted to urban conditions.

7 FINDINGS AND LESSONS LEARNED

Up to now, it sounds quite difficult to evaluate precisely the wind potential around a building. In urban environments the wind speed and direction are unpredictable where adjacent buildings generate turbulence. This was particularly illustrated by the empirical measurements conducted in France for the resource assessment and the results of simulations.

The main findings from the French resource assessment are that:

- In urban context presenting important roughness, a HAWT placed in the middle of the roof of a building must be place above a height higher than 35%/50% the height of the building to avoid the phenomena related to turbulence.
- The higher the mast the better the wind capture will be (but will cause visual impacts);
- On the edge of the roof (e.g. against a parapet wall), a wind turbine should be place at a sufficient mast height to clear the turbulent zone of wind coming over the top of the roof.
- Alternatively, VAWT collect turbulent flow. Studies undertaken by the university of Delph show that certain VAWT positioned in a judicious way can have an energy effectiveness increased in turbulent phenomena.

The French resource assessment have been carried out following the principles of turbulence highlighted in Figure 11.

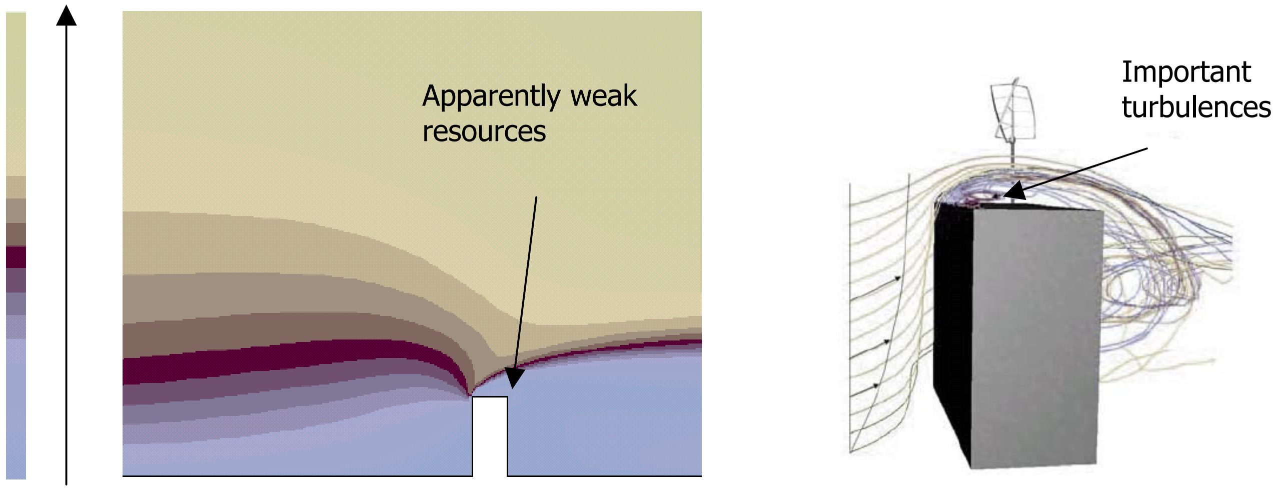


Figure 11: Wind behaviour around a building.

Wind blowing around a building will be diverted by the wind flowing over the top of the building; in order to make optimum use of the wind blowing over the building there must be a degree of vertical clearance between the building edge and the sweep of the turbine. This must be calculated for each site location.

Those phenomena have been studied by the Dutch company DHV which has made a presentation during the WINEUR study tour in the Netherlands. They have made simulations of wind in urban environment for the siting of urban windturbines. DHV conclusions stated that:

- A roof should be chosen well above average roof height of surrounding buildings (around 50 %);
- It should be taken in mind the significant influence of (local) wind rose and building orientation;
- Energy yield at roof sites can easily change a factor 2 on 5 m so the site should carefully be selected;

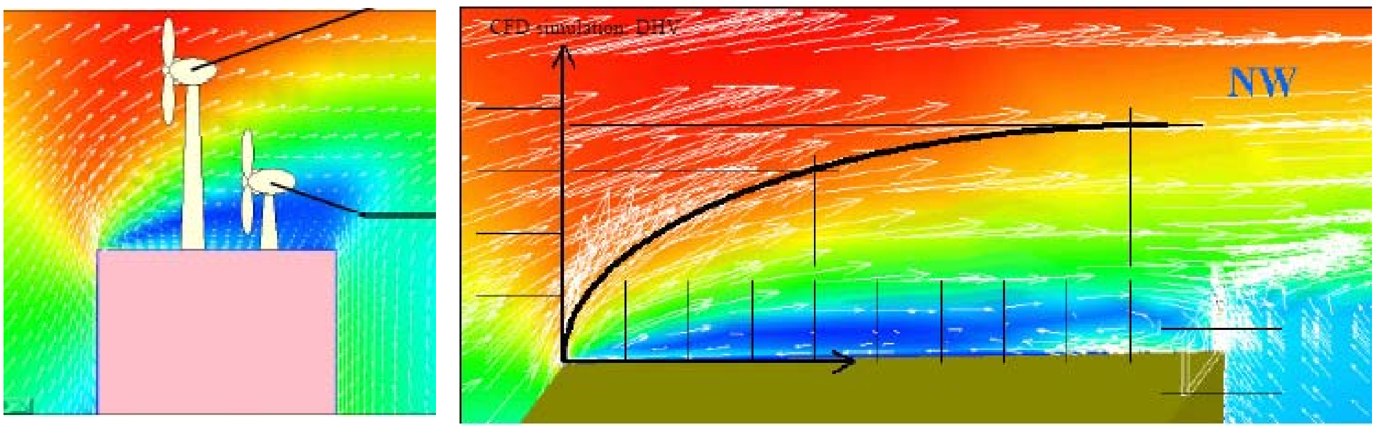


Figure 12: CFD simulation of wind over a building.

Wind turbines operate most effectively in a strong, clean flow of wind, free from turbulence. This is achieved by placing the turbine away from obstructions, and as high up as possible. Wind speed increases significantly with height above ground. An annual average wind speed in excess of 5m/s is generally required for a project to be economically viable. One should be aware that the power in the wind is proportional to the cube of the wind speed, so a 20% increase in wind speed means a 70% increase in instantaneous power.

The main findings from the simulations show that measurement mast should be placed at a certain point. The French resource assessments might not have been the most accurate ones since they were no existing knowledge on this issues before.

COUNTRY PARTNER: UNITED KINGDOM

8 URBAN WIND RESOURCE ASSESSMENT IN THE UK– INTRODUCTION TO WIND RESOURCE ASSESSMENT IN THE URBAN ENVIRONMENT

This part of the combined report on resource assessment is extracted from the country report from the UK. it first provides an overview of traditional wind resource assessment, setting out the main principles for gathering data and making estimations of wind energy over the long-term for a specific site. It then goes on to look at the particular constraints which apply when trying to assess wind resource in built-up, urban areas.

This part of report will then discuss methodologies that can be used for resource assessment in urban areas and possible problems with accuracy. Finally, it will look at some limited data from real sites in the UK and examine differences between real data and predicted or estimated data.

The information presented in this part of report is intended as an introduction to wind resource assessment and will provide a non-expert reader with an understanding of the main constraints to wind resource assessment in built up areas.

The reader is encouraged to use the references provided and to contact their national wind energy association and/or technical experts or consultants in wind energy for more information on urban wind resource assessment and procedures for the installation of small wind turbines in urban areas in their region.

9 STANDARD WIND RESOURCE ASSESSMENT IN THE UK – METHODOLOGIES USED

Prediction of the wind resource at a given site is a crucial stage in the development of a commercial (large-scale) wind energy installation. This is because the energy which can be harvested from a given site and the project economics are both highly dependent on the wind resource at the site. The energy output of a wind farm is a function of the cube of the wind speed – so if the wind speed doubles, the available power will increase by a factor of eight. The more energy produced, the better the return on the investment made.

For example, in Table 1 below (ref 1), an increase in the mean wind speed by a factor of 1.67 results in the energy production increasing by a factor of 2.34. As the capital cost does not depend as strongly on the wind speed, the sensitivity of the project economics to wind resource is clear.

Wind resource is usually expressed as a mean wind speed for initial assessment and a wind speed distribution for more detailed work.

Table 1: Wind resource and energy production

Wind speed (m/s)	Wind speed normalised to 6m/s (%)	Energy production* of a 10MW wind farm (MWh/yr)	Energy production normalised to 6m/s site (%)	Capital cost normalised to 6m/s site (%)
6	100	17,714	100	100
10	167	41,386	234	120

* Assumes typical wind turbine performance, air density 1.225kg/m3, total losses of 12% and Raleigh wind speed distribution

The objective of wind resource prediction is an estimate of the long term wind resource; ideally the wind resource over the expected lifetime of the wind turbine(s), which could be up to

20 years. Usually it is the long term past wind resource that is being estimated at the site, the assumption being that this is unchanging and will therefore be representative of future long-term wind resource. The key parameter for any prospective wind power site is the average wind speed for the site since, in the case of typical (large-scale) wind farm sites, this largely dictates the annual energy capture and hence the revenue generated.

Methodologies used for standard wind assessment

Measuring the wind speed at a site is both time consuming and expensive and is normally not appropriate for the early stages of wind power development. Fortunately, several computational methods are available for initial assessment of wind resource, with varying degrees of resolution and accuracy. These are, in order of increasing accuracy, wind atlases and lookup databases, topological modelling and direct wind resource measurement.

9.1 Wind atlases and the NOABL database

A wide range of wind atlases are available, usually at continental and national level. Regional and local level atlases (with resolutions of less than one square kilometre) are rare.

The European Wind Atlas covers a wide area but its low resolution means that it can only give a general picture of the wind resource. It cannot take account of local variations and effects and is therefore of limited use to wind farm developers.

On a national scale in the UK, the NOABL database gives the mean annual windspeeds for each square kilometre on land and is based on 10 years of data. The NOABL database is accessed via the British Wind Energy Association website (www.bwea.com/noabl) and may be run on line or downloaded and run as a desktop application.

To use the NOABL database, the user input is the site location in the form of the six character Ordnance Survey grid reference. This, in turn, may be obtained online, again via the BWEA NOABL page, using the post code, OS grid reference, Landranger grid reference, lat/long or M grid reference for the site. Given this data, the NOABL database outputs the average wind speed for the 1km grid square at 10m, 25m and 45m above ground level.

However, the database takes no account of local surface obstructions such as buildings and woodland, or local topographical features such as ridges and valleys. Both of these can influence wind speeds locally, so the variation within a particular square could in reality be considerable. Hence, atlases and databases can only give an indication of wind speed in a particular location, but they are useful in identifying areas most likely to contain the locations with the best wind resource.

9.2 Wind resource assessment by the topological modelling

On a more refined scale, wind speeds can be modelled using computer programs such as WAsP, WindFarm or WindFarmer[1], which take into account the effect of elevation, topography and ground surface cover. These models must be primed with data at a known location; this role is usually fulfilled by local meteorological station measurements or other weather-related recorded data. Such packages are used to give a more accurate estimate of wind resource without actually undertaking a wind measurement campaign.

However, they do not substitute for direct wind measurement; rather, they serve to focus investigations and indicate where direct on-site wind speed measurement would be merited. As a further refinement in investigations, in some computer programs wind turbines can be

[1] These are commercial wind farm development packages available from WaSP, ReSoft and Garrad Hassan respectively. See also references 2 to 4.

installed into the model at chosen positions in the proposed wind farm, enabling the user to estimate the annual energy output of the wind farm, noise levels and visual impact at particular points.

9.3 Direct wind Measurement

The most dependable approach to site assessment is to directly measure the wind speed, ideally at the hub height of the proposed turbines so as to remove any uncertainties arising from predicting wind shear (the way in which wind speed increases with height). Measurement at a lower height on the mast is also desirable, as it offers greater security of data collection and allows wind shear on site to be calculated.

One or more guyed, lattice or tubular masts are erected on site, in position or positions identified by the computer modelling carried out in an earlier stage. Measuring instruments are mounted on booms sticking out laterally form the mast, to ensure that the instruments are not aerodynamically affected by the mast. The standard transducer for measuring wind speed is the robust, cheap, cup anemometer.

Cup anemometers cannot measure wind direction, so a separate instrument is required for this purpose. This normally comprises a wind vane, free to rotate and producing a signal indicating instantaneous wind direction. Instruments for measuring air pressure and temperature will also be used, though pressure is not essential. All data will be collected by a data logger at the base of the mast, usually powered by batteries, solar panels or a small wind turbine. In recent years, it has become increasingly common to download data via a modem and the phone (or mobile phone) network.

The European Wind Energy Association recommends that the following signals would typically be recorded for each sensor with a 10 minute averaging period:

- Mean wind speed
- Maximum three second gust speed
- True standard deviation of wind speed
- Mean wind direction
- Mean temperature
- Logger battery voltage

In cold climates, consideration should be given to the possibility that the instruments may suffer from icing. The measurement campaign itself should be long enough to give confidence in the subsequent long term wind resource predictions. The British Wind Energy Association (BWEA) best practice guide for wind energy suggests that the minimum period is 6 months (ref 5).

9.4 Derivation of long term wind resource

As it is not feasible or financial viable to measure the wind resource at a potential wind farm site for a number of years in order to gather enough data for long term resource prediction, the data measured over 6 months (minimum) must be further processed in order to estimate the long term resource.

The most accurate method of achieving this is to use measure-correlate-predict methods. The measured data is matched with a meteorological (met) station for which high quality, long term records are available. Ideally, the met station should be as close to the wind farm site as possible and have a similar exposure. Concurrent data sets for the wind farm and the met station are compared and correlations derived. These correlations are then applied to the long term met station data, to construct an estimate of the wind resource at the wind farm site would have been over the period of the long term data.

Measure-correlate-predict methods take into account the fact that the wind resource will vary from year to year – the period of measurement is unlikely to be representative of the long term wind resource without this manipulation.

10 ASSESSING URBAN WIND RESOURCES

Two features particularly characterise the urban wind regime: lower Annual Mean Wind Speeds (AMWS) compared to rural, open areas, and more turbulent flow. The lower AMWS are caused by the "rough uneven ground" created by buildings, trees, street furniture and other features of an urban landscape. The turbulent flow is a result of the wind interacting with the buildings and other obstacles.

Despite the advantages in bringing local wind generation to cities, the low AMWS and turbulent flow have thus far discouraged many people who may otherwise have been interested, as wind economics are very dependent on the available wind resource, i.e. the annual mean wind speed.

When considering a wind installation in a built-up area the options are either to find a turbine that copes well with turbulence, or to find the least turbulent areas of the urban environment. Of the latter, building-tops show a great deal of promise, partly because the wind flow there could be substantially greater as it gets concentrated by passing around and over the building. Other less turbulent areas are open areas on the ground such as school playing fields or parks.

However, it is much harder to assess wind resource in a built-up environment, so although lower AMWS is expected, exact figures are very hard to come by. Models and methodologies for assessment of wind speed and direction in urban environments are still in the early stages of development in research institutes and universities and there are limited samples of measured data from built-up areas.

One of the reasons for limited measurements being carried out in built-up areas is also the cost of setting up the mast and monitoring in an urban environment, including the time and costs involved in obtaining the necessary planning permission. Because of the size of turbines that could be installed the standard methodologies used are too expensive compared to the return from the energy that may be produced from the small urban machines.

Taking this into consideration, the following paragraphs attempt to summarise the difficulties in assessing wind resource in the urban environment and to mention possible solutions and methodologies that have or could be used for achieving a more accurate idea of average wind speeds in urban areas than that which the NOABL database can give. The aim is to make project developers aware of the limitations of the NOABL database, while at the same time making available some initial information on options for getting more accurate wind speed assessments, depending on the budget they have available to them.

The following information is not comprehensive and further reading from the references given at the end of the report and from other sources is recommended.

10.1 Difficulties and peculiarities of an urban wind regime

Prediction of the wind speed in the built environment is difficult. One of the reasons is "surface roughness". The many obstacles and different heights of buildings give the built environment a high roughness coefficient[2], compared to open, rural locations. The roughness coefficient is

[2] Roughness coefficient (or Roughness length)

generally used to extrapolate wind speed at different heights from measurement at only one or two heights and locations. A high roughness coefficient means slower acceleration of speed as height increases and therefore lower energy yields.

Table 2 gives the roughness coefficient (or length) generally used for a type of surface. It is worth noting the difference between open agricultural area (even with some houses and hedgerows) at 0.055 to 0.1 roughness, compared to 0.8 for larger cities with tall buildings – which are typical of the locations now being considered for small wind installations.

Due to the high roughness in the built environment, the wind speed close to the ground becomes a local parameter (dependent on local conditions near the ground). It is then not possible to measure a local parameter (wind speed) on the basis of some average characteristics of the roughness of the broader area of the built environment.

Table 2. Roughness coefficients for different surfaces

Roughness Length m	Landscape Type
0.0002	Water surface
0.0024	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
0.03	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
0.055	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
0.1	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
0.2	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
0.4	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
0.8	Larger cities with tall buildings
1.6	Very large cities with tall buildings and skycrapers

On the rooftops of buildings the local wind flow features depends on an even larger number of local parameters. In this case, in order to predict the average energy yield of a wind turbine on the roof, a model which includes characteristics of the wind flow around and over the building is needed to predict the average wind speed at the roof level. The flows around the building can be very complex and therefore developing these kind of models can be difficult with many parameters to take into account. It is also difficult to develop “standard” models, as each building is different.

Wind turbulence, the other factor making wind speed and direction prediction difficult in the urban environment is also dependent on many local characteristics, including building size, height and orientation. There are some models that look at turbulence over the roof of buildings. The shape of the roof obviously makes a big difference. There will be different areas of turbulence for a sloped roof and flat roof, but in both cases there has to be some clearance between the roof and the blades of the turbine in order to avoid the most turbulent areas.

10.2 Inadequacies of NOABL

Use of NOABL by itself for prediction of wind and energy outputs for small wind systems is widely considered inappropriate for small wind systems. The paragraphs below are from a statement issued by the Paul Hannah of the BWEA Resource Group in 2006.

The UK National Windspeed Database was created using the mass consistent flow model NOABL (Traci et al., 1987), and is generally referred to by that name. The analysis was performed using long-term windspeed and direction data from a number of initiating stations provided by the UK Met. Office. All data were collected in the 1970s and 1980s and all data were collected at 10m above the ground.

The results of the analysis are presented in a series of maps. A software package was also created to interrogate the database. Windspeeds for each 1km square across the UK and Northern Ireland can be presented at 10m, 25m and 45m above the ground. A uniform shear profile connects the values at the three heights. A grid facility allows a 3km x 3km window of values to be shown. No directionality is provided.

NOABL is a very approximate, indicative tool for windspeed assessment. Due to the poor horizontal resolution of the data, in areas of significant topographic variation within the 1km square, the value is of little use. Even in areas of relatively flat terrain, large discrepancies have been observed between NOABL estimates and those estimates based on more robust methods (measurement on the site, correlation with long-term reference sites, etc.).

The use of NOABL in an urban environment is similarly limited. The urban environment includes significant amounts of obstacles (buildings), and much higher levels of roughness than are seen in the open countryside. Urban wind regimes are also subject to localised directionality, such as can be seen near tower blocks and other large structures. To use NOABL in the assessment of the potential yield of a small wind facility in an urban setting without any adjustment will, almost certainly, result in a wholly inaccurate result. The scale and costs of small wind development would not, however, support carrying out a measurement campaign.

The conclusion is that some other methods need to be used to verify any results from NOABL. It is also suggested by Mr. Hannah that NOABL should be adjusted to take account of local conditions and improve its accuracy when used in a built-up environment.

10.3 Methods for urban wind assessment

The first stage of any wind energy project is assessing the availability of the resource base. Electricity produced by a turbine over the course of the year depends critically on the annual mean wind speed at the site – higher wind speeds produce more energy. Conversely low average wind speeds may mean that the turbine will not operate much of the time. There are basically two options for ascertaining wind speed: on-site assessment or database modelling.

On-site assessment

The best option in terms of likelihood of achieving accurate results is to carry out an on-site assessment of the wind resource. This can be done in a variety of ways. However, in the urban environment it can be more complex than in open spaces. The following issues should be taken into account:

- In order to achieve an accurate figure, wind speed should be measured at the proposed location for the wind turbine using an anemometer;
- The wind speed should be measured at the exact location proposed for the wind turbine, as even a slight change in location can have big effect on wind speed and therefore energy production in turbulent urban locations;

- Ideally, some initial information should be taken into account first, before choosing the location for the wind turbine and therefore for the anemometer, i.e. wind direction, location of nearby obstacles (buildings, trees) and any possible wind-tunnel effect.

The measurements need to be taken over the course of several months, ideally one year. If it is not possible to get the readings over a whole year, it is better to measure the winter months when typically the wind speeds are higher.

It may be possible to purchase an anemometer and then hire a mast and monitoring equipment. Some manufacturers may be able to loan an anemometer and logging equipment, or a local energy agency may be able to lend an anemometer. It is also possible to employ consultants to install the anemometer and mast and take and analyse the measurements but this would very likely be too expensive for any small–scale project.

Measuring wind speed on-site can be complex, especially in a built-up environment, where each location can have very specific wind characteristics. For example, data will need to be interpreted and physically it may be difficult to erect the anemometer at height on the proposed turbine location. Pocket anemometers or a small weather station can be purchased at a cost of approximately £100-£300 and can be a good starting point.

A weather station can also be used, which tracks wind speed and direction, and logs data to its own memory, including average and peak readings, and can be set up to interface directly to a PC or laptop. If a project developer is considering spending a significant amount of money on a small wind system or several small wind systems, on-site wind measurement can be worth the investment.

The following websites provide further detail on determining wind speed at the local level, list equipment that can be used and provide some idea of cost of different types of measuring equipment: www.windsurvey.co.uk , www.delta-t.co.uk , www.nrgsystems.com .

However, getting permission to set up an anemometer can be a long process, as sometimes planning permission is needed. It can also be expensive. This sometimes means that carrying out on-site measurements can be almost or as expensive as installing a small wind turbine itself. This often deters projects developers from using the on-site assessment method, and results in developers either putting up a wind turbine based purely on findings from NOABL (unreliable) with maybe some consideration of local information (common wind direction, data from other existing sources) or using data-modelling application to try and get a reasonably accurate assessment of the wind resource without resorting to costly and time-consuming on-site assessment.

Using NOABL

Designed for open, exposed locations, NOABL, the UK National Wind Speed Database is the result of an air flow model that estimates the effect of topography on wind speed. Each value stored in the database is the estimated average for a 1 km square at 10 m, 25 m or 45 m above ground level. NOABL has been designed for exposed locations, and may give an indication of average wind speed in different parts of the country. However it is very unlikely to give an accurate idea of wind speed at a proposed site for a small wind system, particularly in urban or built up areas.

The urban environment includes numerous and significant obstacles and much higher levels of roughness (such as tall crops, stone walls or trees) than are seen in the open countryside. Urban wind regimes are also subject to localised directionality, such as can be seen near tower blocks and other large structures. To use NOABL in the assessment of the potential yield of a small wind facility in an urban setting without any adjustment is very likely to result in an inaccurate result.

If NOABL is used for rural or exposed areas then the following site specific factors should be considered:

- The data is more accurate for flat, open countryside, and less so for complicated, rough terrain;
- NOABL makes no allowance for the effect of local thermally driven winds such as sea breezes or mountain/valley breezes, therefore for coastal sites add 0.5-1.0 m/s;
- NOABL takes no account of topography on a small scale or local surface roughness, which may have a considerable effect on the wind speed. Therefore if your site has a lot of surface roughness revise average wind speed down – in a fully built-up area the average wind speed maybe 1 to 3 m/s lower than the database!
- A site at the bottom of a valley or hollow will have a lower wind speed than the average, therefore revise the average wind speed down;
- A site on top of a hill or knoll will have a higher wind speed than the average, therefore revise the average wind speed up;
- If there is an obstacle between the turbine and the prevailing wind then expect a significantly reduced wind-speed;
- If there is an obstacle (like a wall) directly behind the turbine then output could be reduced as the wind hits the wall behind and create turbulence, even if there are no other obstacles;
- If the height of the turbine is less than 10m, a correction to the 10m estimate will need to be made. At 5m, the wind speed will be roughly 10-20% lower.

Using existing data from other sources

Other methods of estimating wind speed using existing data could include the use of measured data from local meteorological stations and further data from real measurements may also be available from universities or other organisations with an interest. Again this data will only give an approximation for a particular part of the country and may not be accurate at a specific location.

However, for developers of small wind projects asking local meteorological stations and Universities if data is available is worthwhile, as this gives some secondary data to compare to the NOABL estimate.

Data-modelling

Data-modelling is the final option available, although this is time consuming and requires very good knowledge of aerodynamic principles or a software package which can be adapted to the local areas where wind resource needs to be analysed. Software packages for urban wind assessment are not yet available on the market, although initial development is underway at some Universities in the UK and The Netherlands.

Aerodynamic modelling to ascertain wind characteristics in a built-up environment is based on three main tools: mathematical models; measurements; and simulations or Computational Fluid Dynamic (CFD) calculations. These tools are used as analysis tools for calculations of flows, including wind flows. In some cases these tools are also appropriate for modeling wind flows around buildings and other objects found in the urban environment. Each of these tools has advantages and disadvantages that define the suitability of the tool for analysis of certain situations. The measurements and CFD calculations provide numbers. For coherence between those numbers and a physical explanation of the observations, for design purposes, a mathematical model is needed. The mathematical model in turn also needs the measurements and the CFD calculations to verify its assumptions. However, accurate measurements of a certain quantity are sometimes difficult to obtain. In this case, the measurements can be supported by CFD calculations.

When using models to assess wind resource, the user of the results must always remember that the behaviour of wind in the built environment is very complex and thus very difficult to model. All models use many assumptions and situations are often simplified so that they can be modelled. This is often forgotten and results of calculations are used without taking into account the constraints of the modeling process. There is still some work to be done before wind behaviour in an urban environment can be satisfactorily understood using modelling techniques and for the time being this method remains the domain of research and development.

10.4 Urban wind assessment around the UK

10.4.1 Measurements taken in urban locations

Over the last few years a number of Universities, private individuals and project developers have undertaken modest wind measurement campaigns in urban locations. Where this data has been made publicly available, it is included here to give some indication of real wind measurements in built-up environments.

Reading University

The map in Figure 13 below shows the area of central Reading. The residential areas in central Reading principally consist of closely built houses, where buildings rarely exceed 12m in height.

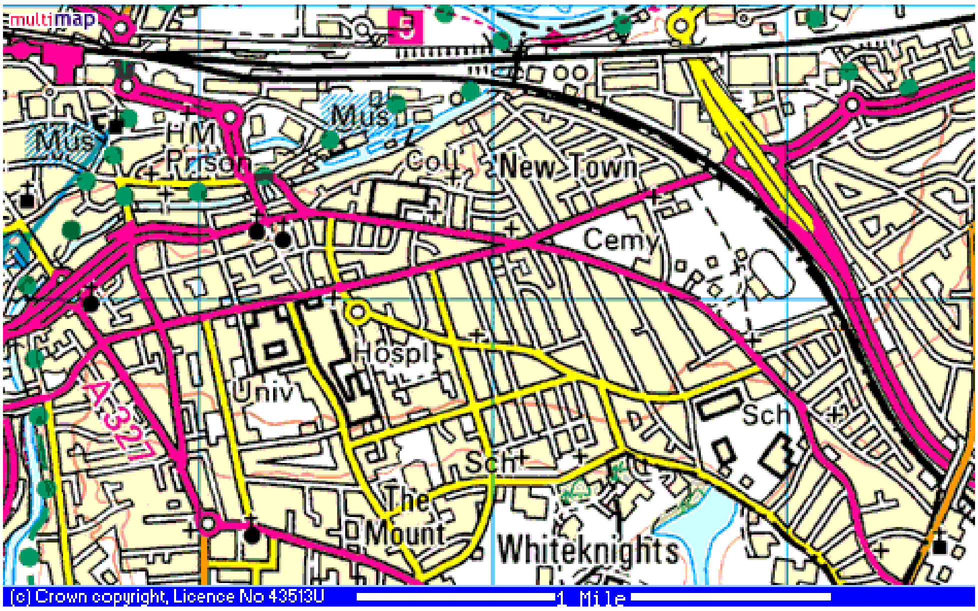


Figure 13: Map of central Reading © www.multimap.com

The Meteorology Department of Reading University (based in the Whiteknights campus visible on the map and very close to the city centre) collected data between 1971 and 1990 from an 8m mast in the University grounds. This data gives an estimated annual mean wind speed of 2.8m/s.[3]

A search on NOABL using the postcode of the University gave an estimated wind speed at 10m above ground at 4.8m/s – a difference of -2m/s compared to the reading from the Meteorology Department mast. This is an example of the discrepancy between real measurements and NOABL predictions, indicating NOABL's unreliability where local topography is complex.

However, in this case even the measurement of 2.8 m/s cannot be taken as indicative for all locations in Reading, since:

- the measurements were taken at 8m and this is lower than a turbine would probably be placed;
- the mast is (effectively) in a field in the middle of Reading and it is surrounded by higher obstacles and buildings; and
- most houses are surrounded by houses of the same height

These factors mean that the measurement taken on the University campus cannot be held as representative for the whole of Reading, as each location will have its unique characteristics. However, it does give an indication that wind speeds are likely to be lower than the NOABL estimate.

The Royal institute of British Architects, London

The Royal Institute of British Architects (RIBA) have been interested in installing a wind turbine on the roof of their building for some years[4]. In the map below, the RIBA building is located just off the A4201, post code W1B 1AD. It is slightly taller than the buildings in the surrounding area, which is makes the location promising.

[3] Small Wind Turbines for the urban Environment: state of the art, case studies and economic analysis, P. Robinson, Reading University, September 2005

[4] They were refused planning permission for such a project prior to PPS22 and the GLA's support, but may try again now that the policy environment is more favourable.

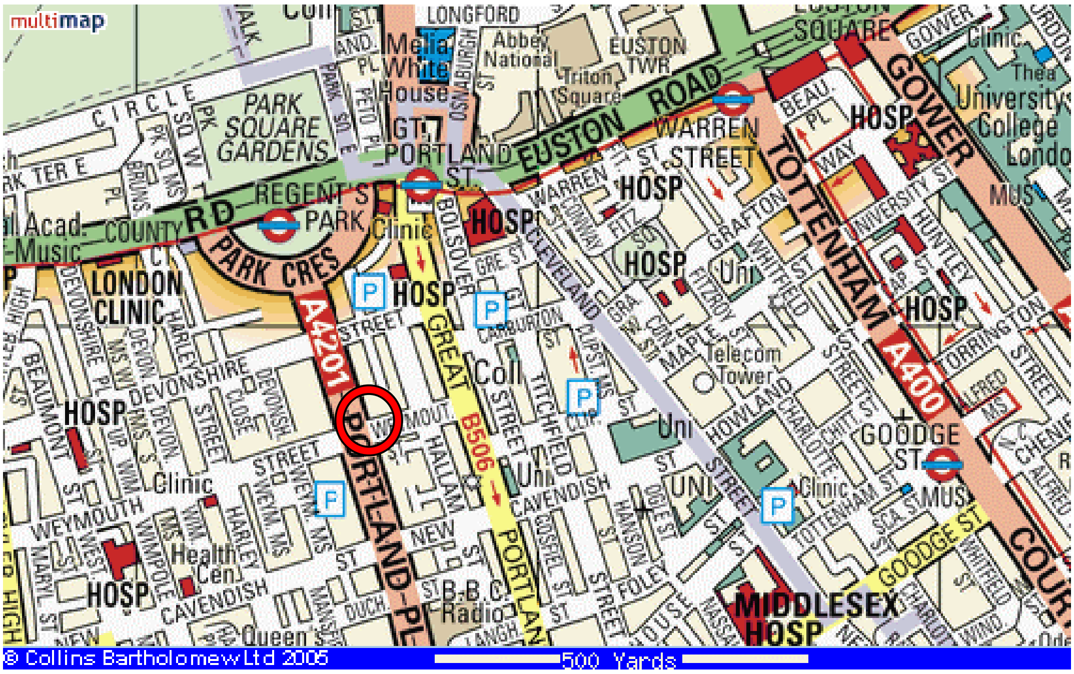


Figure 14. Map of RIBA's location in London © www.multimap.com

Wind speed data is available for the location, because data was measured on the rooftop of the RIBA building[5]. Average wind speed for a year was found to be 3.4m/s.[6] At RIBA, NOABL estimates the wind speed to be 5.7m/s at 25m height, however the RIBA anemometer was placed at 36.5m height at the top of the building. Therefore again there is a significant discrepancy between the results from real measurements and the estimation obtained from NOABL.

The Aylesbury Estate, London

The Aylesbury Estate in London was also investigating the possibility of installing some wind turbines on the rooftops of their tower blocks. The Aylesbury estate comprises of a number of tall tower blocks, covering much of the area south of East Street, around Thurlow Street, post code SE17 2UZ. It is Europe's largest estate and the tower blocks are significantly taller than any surrounding buildings or trees. A map of the estate is shown in Figure 15.

Data measured from the rooftop of a tower block of Portland Estate (near Aylesbury Estate) by Southwark Council found the average annual wind speed to be 8m/s.[7] Comparing with NOABL, at the Aylesbury Estate NOABL finds the wind speed to be 6.1m/s at 45m height. This seems to be a better match with the measured results than the previous examples, as the towers could be higher than 45m, therefore leading to higher wind speeds.

[5] Thomas R (2003) "Sustainable Urban Design", Spon Press, London and Thomas R (2003) "Energy and information", Sustainable Urban Design, Thomas R, Spon Press, London.

[6] Small Wind Turbines for the urban Environment: state of the art, case studies and economic analysis, P. Robinson, Reading University, September 2005

[7] Southwark Council take no responsibility for any conclusions that might be drawn from the use of this wind speed data.

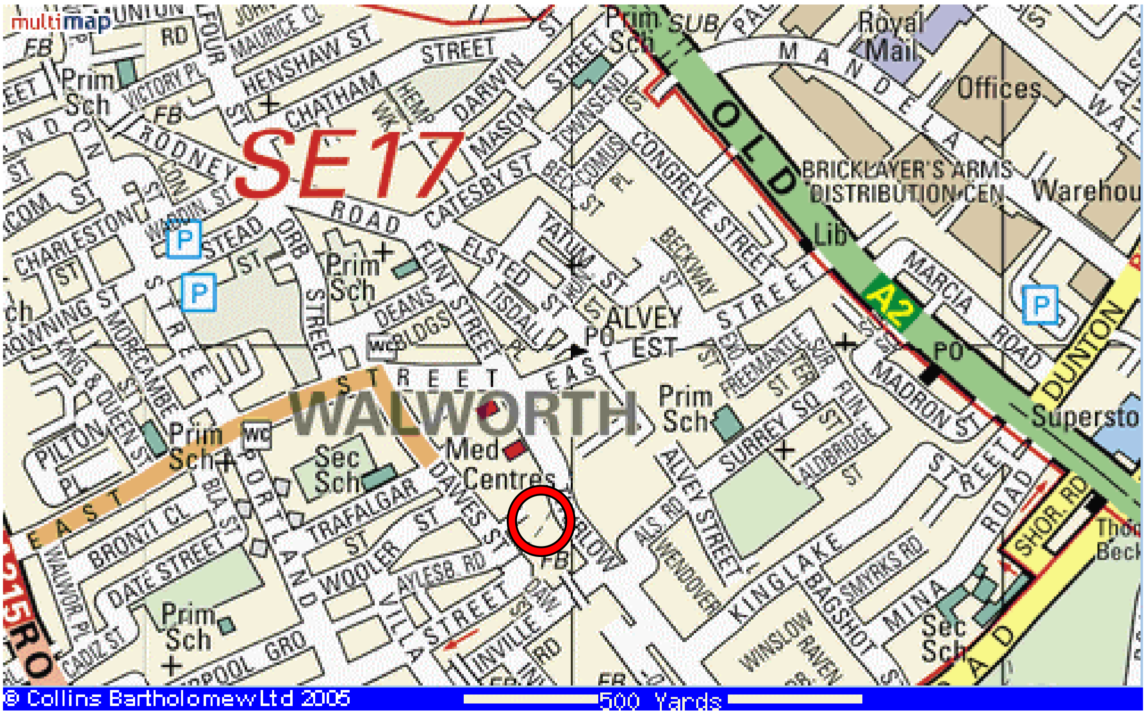


Figure 15. Map of Aylesbury Estate in London © www.multimap.com

10.4.2 Impact on urban wind projects

Erreur ! Source du renvoi introuvable. below shows the average wind speed from three sites[8] where small wind turbines have been installed. The wind speed has been calculated after installation of the turbine from their stated annual electricity production. The calculated wind speed is compared to the wind speed provided by the NOABL database. These calculations assume an 85% availability of the turbine, a 97% electrical efficiency of the system and a Rayleigh distribution of wind speeds. The results showed the calculated mean wind speed to be significantly lower, especially when the hub height of the turbine was comparatively low.[9]

Table 3: Calculated wind speeds at urban sites

Site	Hub Height (m)	Calculated Wind Speed (m/s)	NOABL Wind Speed (m/s)
Sports-centre, Scotland	9	2.7	4.3
Primary School, Bucks.	9	3.8	6.3
Eco-Centre, Teesside	30	5.2	6.1

The examples above show how much difference there can be between the estimate given by NOABL and the real average wind speed of a site. Of course, the wind speed at a particular site could also be higher than NOABL's prediction, as seen in the Aylesbury Estate example. However, in the majority of cases in an *urban* context, NOABL overestimates the wind speed by at least 1 m/s and often by at least 2m/s. At low wind speeds of between 4 and 5m/s, this margin of error can make a big difference in electricity production from small wind turbines. In

[8] WINEUR questionnaires, 2005
[9] Investigation into the Installation of Small Wind Turbines in an Urban Environment, S. Carroll, Loughborough University, September 2005

fact, in some cases it can be the difference between producing some electricity or producing none at all.

11 CONCLUSIONS

In the past project owners of urban turbines have tended to be disappointed with their energy yield and the above examples go some way to explaining why. Urban wind developers and the general public need to be better informed of the limitations of NOABL as a tool for estimating urban wind speeds. Also, installers who estimate the energy capture of their turbines based on the annual mean wind speed in the NOABL database should provide clear guidance to their customers as to the potential inaccuracy of the result.

At the same time it is clear that there is no cheap method currently available to assess urban wind resources. The most accurate results will be obtained by actual measurements at the proposed location, however this is too expensive and time-consuming for most small wind projects. Therefore, modelling and database methods need to be developed to improve the estimation of urban wind speeds without having to resort to long measurement campaigns. Improvements or adjustments to NOABL would also be beneficial, as this is a well-known and easily accessed database, which could maybe be modified to take urban characteristics into consideration in order to improve its accuracy.

While waiting for more accurate databases and modelling methods to be developed to predict urban wind speed or cheaper ways to measure it, there are some rules of thumb that can assist someone wishing to install a small wind turbine in a built-up environment. These are described in Annex 2.

COUNTRY PARTNER: THE NETHERLANDS

12 DUTCH RESOURCE ASSESSMENT – INTRODUCTION

This part of the combined report presents the results of the survey on wind resources in the Netherlands.

In the previous reports in WP1, 1, 3, and 4 the technical, financial, legal and social aspects of urban wind turbines (UWTs) have been described. This study focuses on the location and resource assessment and the potential for UWTs in the Netherlands.

The objective of this survey is to answer the following questions:

- What wind conditions are needed for UWTs?
- What are the main issues to consider regarding the location?
- What are the wind conditions for UWTs in The Netherlands?

13 WHAT WIND CONDITIONS ARE NEEDED FOR UWTS?

According to the technical data of UWTs as provided by the manufacturers, the nominal wind speed for different types of UWTs lies between 9 m/s and 15 m/s. The cut-in (start speed) wind speed is between 2 m/s and 3.5 m/s. Some UWTs need to be halted when the wind speed exceeds specific limit; this speed is referred to as cut-out speed (stop speed). This means that the optimal wind speed for UWTs should be somewhere between the start and the stop speed, but preferably around the nominal wind speed. The Table 4 shows the three characteristic wind speed values for the Dutch UWTs that have been presented in the reports WP1 and WP2.

Table 4: Characteristic wind speed for different types of UWTs

Wind speed (m/s)	*Fortis Montana*	*WES5 Tulipo*	*Turby*	*Energy Ball*	*Ropatec WRE030*
Start wind speed	2,5	3	3,5	2	2,5
Nominal wind speed	10	9	12	15	12
Stop wind speed	n.a.	20	14	n.a.	n.a.

The electricity yield is directly related to the wind conditions on the location were UWT is installed. The financial feasibility is again directly related to the electricity yield. To illustrate the effects of the wind conditions on electricity generation we have compared the electrical power for 5 types of UWTs at two different wind speeds.

Because no measurement results are available, the reference yield was calculated by using the data from the manufacturer. The calculations were made with wind speeds of 5.5 m/s and 12 m/s. The value of 5.5 m/s is chosen by the UWT manufacturers as the minimum average wind speed needed to keep UWT in operation. Some manufacturers state that an average wind speed of 4,5 m/s is satisfactory for their UWT. The wind speed of 12 m/s is chosen because it is a figure close to the nominal wind speed of the most UWTs. Table 5 and Table 6 below show the results of the calculations.

Explanation:

A = rotor area
V = wind speed
P = electric power

V_{nom}, P_{nom} and A have been provided by the manufacturers.

P_{ref} is the result of the calculation: $P_{ref} = (V_{ref}/V_{nom})^3 \times P_{nom}$

Table 5: Reference figures using a wind speed of 12 m/s

	v wind ref m/s	v wind nom m/s	P nom kW	P ref kW	A m2	P ref spec kW/m2
Montana	12	10	2,7	4,67	19,60	0,24
WES[5] Tulipo	12	9	2,5	5,93	19,60	0,30
Turby	12	12	1,9	1,90	5,30	0,36
Energy Ball	12	15	0,5	0,26	1,00	0,26
Ropatec	12	12	2,5	2,50	7,26	0,34

Table 6: Reference figures using a wind speed of 5,5 m/s

	v wind ref m/s	v wind nom m/s	P nom kW	P ref kW	A m2	P ref spec kW/m2
Montana	5,5	10	2,7	0,45	19,60	0,02
WES[5] Tulipo	5,5	9	2,5	0,57	19,60	0,03
Turby	5,5	12	1,9	0,18	5,30	0,03
Energy Ball	5,5	15	0,5	0,02	1,00	0,02
Ropatec	5,5	12	2,5	0,24	7,26	0,03

This exercise shows how big the effect of the wind speed is on the energy yield of UWTs: the energy yield is directly related to the third power of wind speed. As an example: if the wind speed changes for factor 2, the energy yield will change for factor 8.

To conclude: minor errors in estimating the wind speed may lead to significantly incorrect electric yield estimation.

Therefore, the suppliers must be well informed about the local wind regime before giving any predictions regarding the electrical yield.

14 WHAT ARE THE MAIN ISSUES TO CONSIDER?

In the report 'Socio-economic issues related to the installation of small wind turbines in the built environment', that has been published within WP4, the most important issues regarding the urban planning and spatial integration of UWTs have been elaborated. This is an overview of recommendations:

- Turbines should be preferably placed on large buildings with a flat roof.
- Investigate which turbine type and model is the best for the chosen building or location.
- Deploy multiple turbines at the same location if possible.
- Investigate if the building and the surroundings are suitable for UWT deployment.
- Ensure acceptance of the turbines in the neighbourhood
- Investigate the visual impact: the blade movements may bring a certain dynamic appearance to the area, however flicker or general visual disturbances are also possible.
- Concentrate the deployment in certain targeted areas.

- o Ensure that the turbines are recognised in the spatial development plan and that the deployment plans respect the vision other stakeholders have about the location.
- o Give enough attention to the aesthetic aspects of the integration. The turbine needs to visually integrate well with the building and the area.

This report reiterates these recommendations and focuses further on the wind conditions on location.

14.1 General wind conditions in the Netherlands

The Netherlands is a very flat country with a long and low coastal line. The electricity generation by utilizing wind turbines has a long tradition in the Netherlands. In the same tradition there is also a well developed infrastructure for the wind monitoring on different locations in the country. These metering stations of the meteorological institute KNMI monitor all relevant climate aspects. The collected data is thoroughly analyzed and a variety of information is available. One of the measured values is the wind speed on 10 m height.

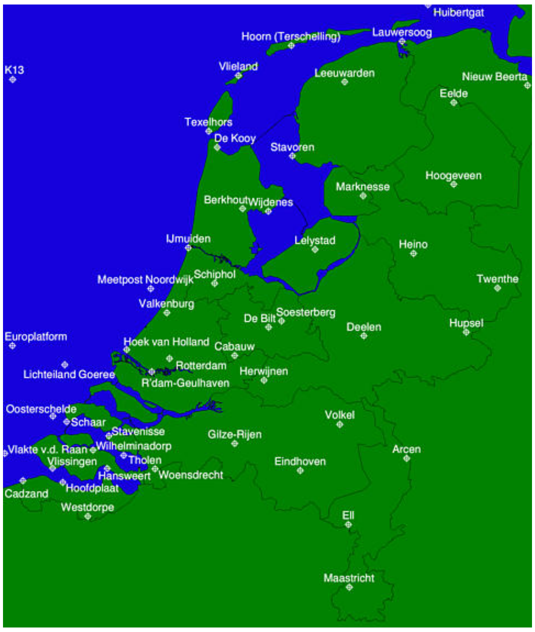


Figure 16: Measuring stations of KNMI

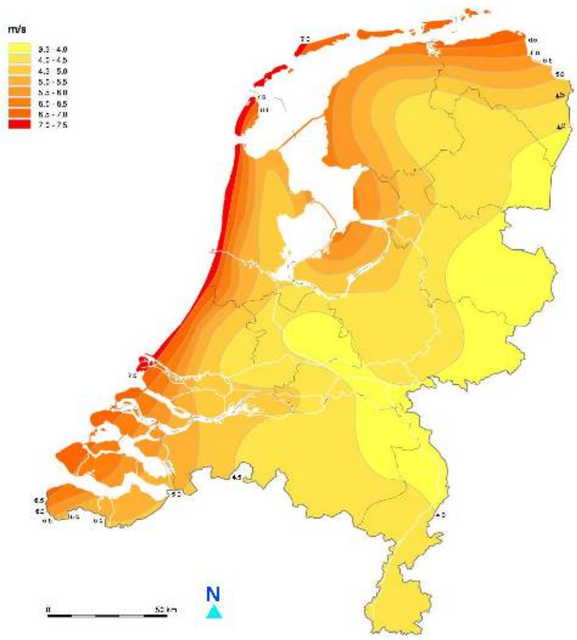


Figure 17: Wind speed zones in The Netherlands

(available at: http://www.knmi.nl/klimatologie/normalen1971-2000/wind_jaargemiddelde.html).

The strongest average wind speeds of 7 – 7.5 m/s are measured along the coast line in the west of the country (marked red). The average wind speed decreases with the distance from the coast. The lowest average wind speeds of 3.5 – 4 m/s are measured in the central and most eastern parts of the country (marked yellow).

The long seacoast and the flat landscape make the Netherlands a windy country. The wind may come from all directions, but the strong winds come mostly from the directions southwest and west. This is also visible on the three wind roses shown in Figure 18, Figure **19** and Figure **20** below.

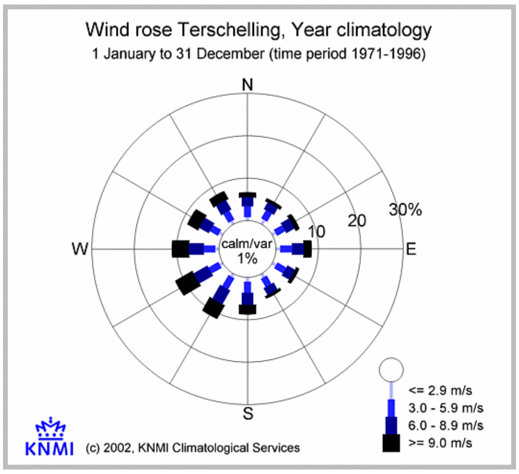


Figure 18: Wind rose of Terschelling

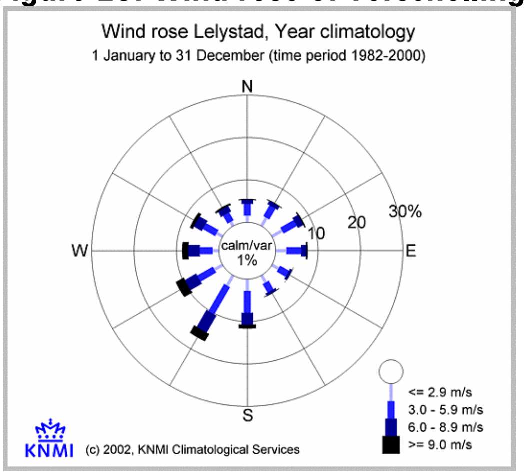


Figure 19: Wind rose of Lelystad

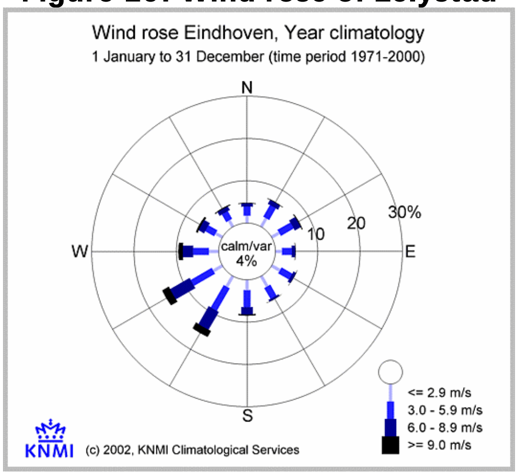


Figure 20: Wind rose of Eindhoven

The wind rose illustrates the frequency and direction of different wind speeds on a certain location measured over 25 years. The length of the bars shows the frequency while the width and the colour depict the strengths of the wind. The longer bars stand for higher frequency, the wider and darker bars for stronger wind. Each bar represents the average wind measured within the range of 30 degrees. The sum of all bars represents the 100% of the wind on that location.

The strength of the wind is presented in four groups: ≤ 2,9 m/s, 3,0 – 5,9 m/s, 6,0 – 8,9 m/s and ≥ 9,0 m/s.

The first wind rose is from the island Terschelling in the northwest of the country. This location falls within the red wind speed zone as shown in **Erreur ! Source du renvoi introuvable.**. Lelystad is situated in the middle on the artificial island, the so called 'polder' Flevoland, on the border between the dark orange and light orange zones.

The last one, Eindhoven, is situated in the southeast of the country, in the pale orange zone with the average wind speed between 4,0 – 4,5 m/s.

In order to make it easier to follow for those who calculate in Beaufort or in miles/h (MPH), the relations between different calibration systems are illustrated in the Table 7 below.

Wind roses for all KNMI measuring stations can be downloaded from:

The following information, significant for the UWTs can be summarized:

The average wind speed of at least 4,5 - 5,5 m/s, which is the minimal requirement for the deployment of UWTs is available from all directions. In average, the strongest wind comes from the direction south west. The regions closer to the coast have better wind conditions on 10 m height due to higher average wind speed. In the central and eastern parts of the country, the average wind speed on 10 m height is less suitable for UWTs. In those regions UWTs should be placed appropriately higher.

http://www.knmi.nl/samenw/hydra/cgi-bin/freqtab.cgi

Table 7: Relation between different systems for the calibration of wind speed

	Wind Speed			weather
(m/s)	Beaufort	(MPH)	Effects observed on land	forecast
< 0,2	0	0 - 1	Calm, smoke rises vertically	Calm
0,3 – 1,5	1	1 - 3	Direction of wind shown by smoke	Light
1,6 – 3,3	2	4 - 7	Wind felt on face, leaves rustle. Ordinary vane moved by wind	Light
3,4 – 5,4	3	8 - 12	Leaves and small twigs in constant. Motion. Wind extends light flag	Gentle
5,5 – 7,9	4	13 - 18	Raises dust and loose paper; small. Branches are moved	Moderate
8,0 – 10,7	5	19 - 24	Small trees in leaf begin to sway. Crested wavelets form on inland waters.	Fresh
10,8 – 13,8	6	25 - 31	Large branches in motion, whistling. Heard in telephone wires; umbrellas used with difficulty.	Strong
13,9 – 17,1	7	32 - 38	Whole trees in motion, inconvenience. Felt walking against the wind.	Strong
17,2 – 20,7	8	39 - 46	Breaks twigs off trees	Gale
20,8 – 24,4	9	47 - 54	Slight structural damage occurs. Chimney pots and stales removed.	Gale
24,5 – 28,4	10	55 - 63	Seldom experienced inland. Trees uprooted, considerable structural damage occurs.	Whole gale
28,5 – 32,6	11	64 - 72	Very rarely experienced inland, accompanied by widespread damage.	Whole gale
> 32,6	12	73 or more	Very rarely experienced, accompanied by widespread damage	Hurricane

14.2 Variations in wind resource

Data collected over longer periods shows that the wind resource differs per year. Figure 21 shows the indexed wind resource by months (windex) in The Netherlands. The figure shows the wind index per month for the best year (1988), the worse year (2003) and the average value for the period 1996-2005. The monitoring period was between 1988 and 2005. In the best year the wind resources were 24% better and in 2003 they were 16% worse that the average values. Graphs are based on production data from some 70 wind projects in The Netherlands (Source WSH: http://home.planet.nl/~windsh/windexen.html).

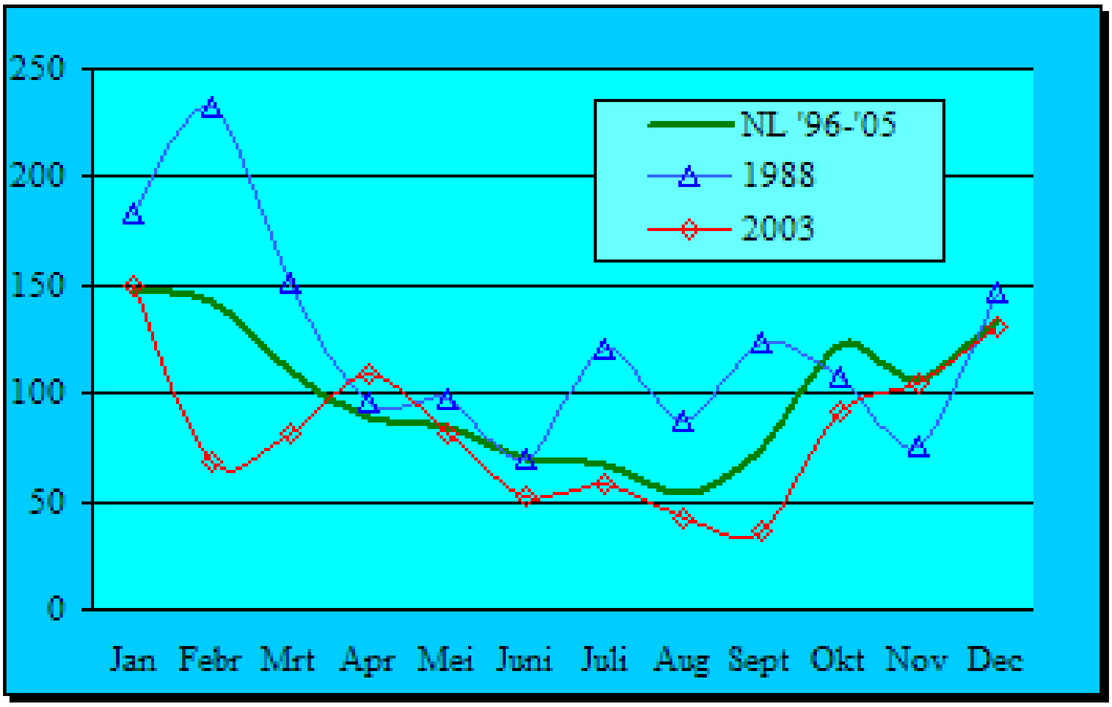


Figure 21: Wind resource by months in The Netherlands

The wind speeds vary from place to place depending on local climate, geographical and surface conditions. The pattern of wind speed variation is called Weibull distribution. It can be characterized by a graphic or by a 'Weibull K' coefficient. Generally, analysis of the wind distribution and the electricity yield of wind turbines shows that the biggest part of the electricity yield comes from moderate winds, and the rest from strong winds. The values of the Weibull K are given in Table 8. The Weibull distribution of the selected site should match the design characteristics of UWT.

Table 8: Values of Weibull K10 for different kind of sites

Weibull K	
4	sites with constant wind speed
3	coastal sites
2	inland sites
1,5	very variant wind speed sites

The long term analysis shows a slight decrease of the wind resource in the Netherlands (and in other countries were the wind resource is being monitored). Figure 22 below shows the variation in wind resources during the period form 1988 to 2006 for the Netherlands, Denmark, Sweden, north France and UK. The variations in wind resource can have an impact on the electrical yield of UWTs.

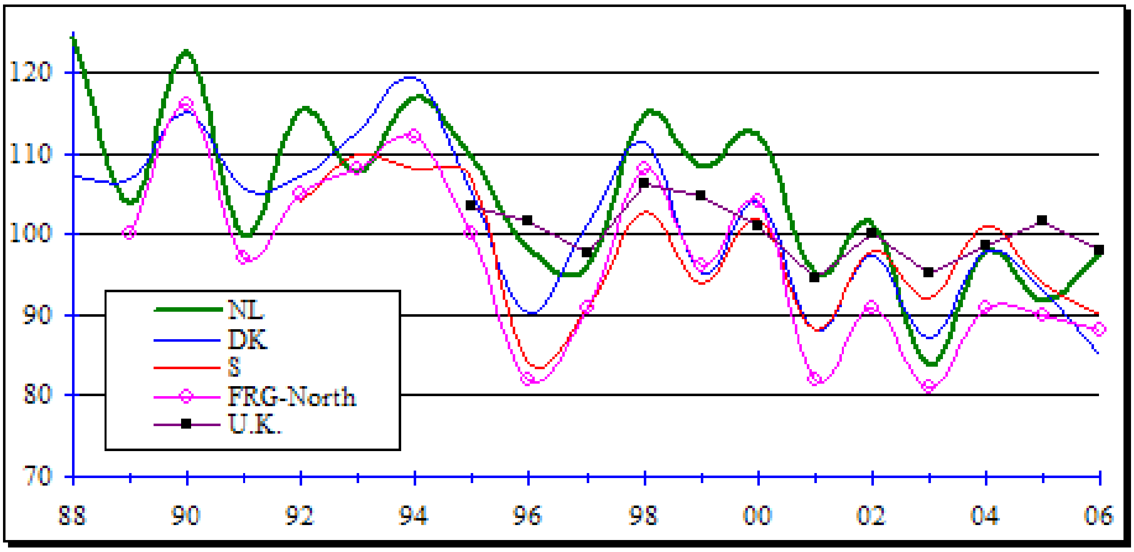


Figure 22: Variations in wind resources between 1988 and 2006 in several countries in Europe

14.3 Local wind conditions

The country wind map and the wind rose provide the information about the general wind conditions in a certain area. However, these conditions can be locally seriously affected by all kinds of obstacles like trees, buildings and other constructions in the built environment. These obstacles can have a positive or a negative effect on the electrical yield of UWTs.

14.3.1 Roughness

The built surrounding can slow the wind down considerably, while the flat highways, airports and water surfaces have a minimal impact. The long grass, bushes and trees can also have a considerable slowing down effect. This influence of obstacles to the wind flow is called roughness. Table 9 below gives the classes as used to explain the roughness conditions in some area.

[10] Different sources use different values for Weibull K. The values in the table come from the manufacturer Ropatec

Table 9: Roughness classes

Roughness class	
0	water surface
1	open agricultural area with very scattered buildings
2	agricultural area with many houses
3	villages, small towns, agricultural land with many or tall sheltering hedgerows
4	large cities with tall buildings and skyscrapers

The effect of roughness to slowing down the wind flow is illustrated in Figure 23 below. The graphic presents the relation between the height and the wind speed. The graphic shows that the greater the height, the higher the wind speed. Closer to the ground is the wind speed slowed down. The higher the roughness, the more the wind will be slowed down.

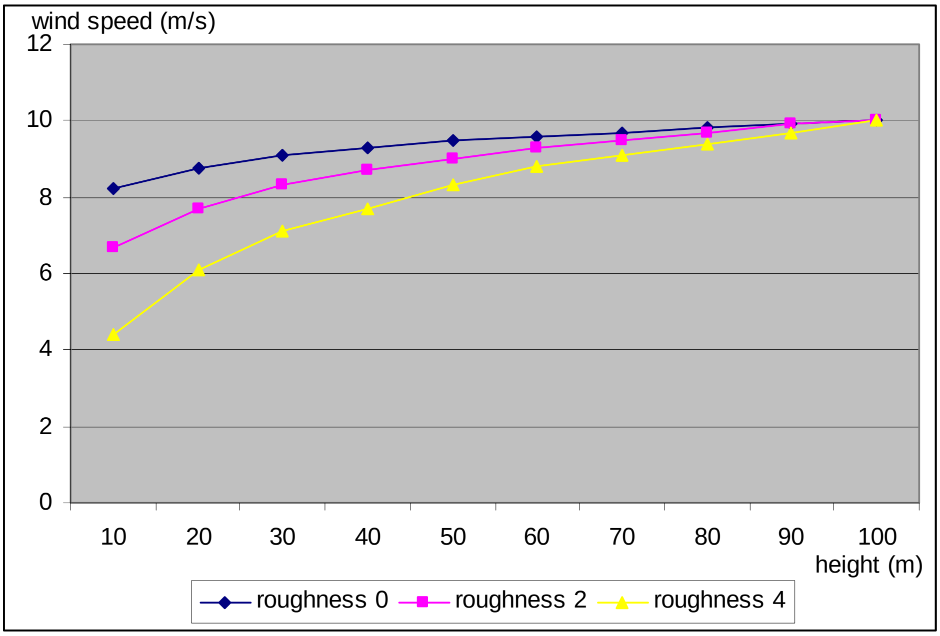


Figure 23: Effect of roughness to slowing down the wind flow[11]

14.3.2 Tunnel effect

The wind speed can increase considerably between the buildings in the long straight streets oriented in the prevailing wind direction. This effect is called a 'tunnel effect'. When placing UWTs on the ground, it could be profitable for the electricity yield to choose for this kind of sites.

[11] L.J. van Groningen and M. Tarra: STEDELIJKE WINDTURBINES DEN HAAG, Haagse Hogeschool

14.3.3 Inclined and spherical buildings

According to the outcomes from the PHD study at TU Delft[2], the wind flow accelerates along inclined or spherical façade and roof lines. Putting the UWTs on this kind of objects can also be profitable for the electricity yield.

14.3.4 Obstacles

When coming to an obstacle, wind flows around it and slows down forming turbulences in front and behind the obstacle. The turbulence is more pronounced behind than in front of the obstacle. The turbulent zone behind the obstacle may extend to some three times the height of the obstacle. The slow down effect on the wind from an obstacle increases with the height and the length of the obstacle. Therefore, it is the best to avoid placing of UWTs close to major obstacles, particularly if they would be in front of UWT (upwind), in the prevailing wind direction. The effect of obstacles in the wind flow is illustrated in Figure 24.

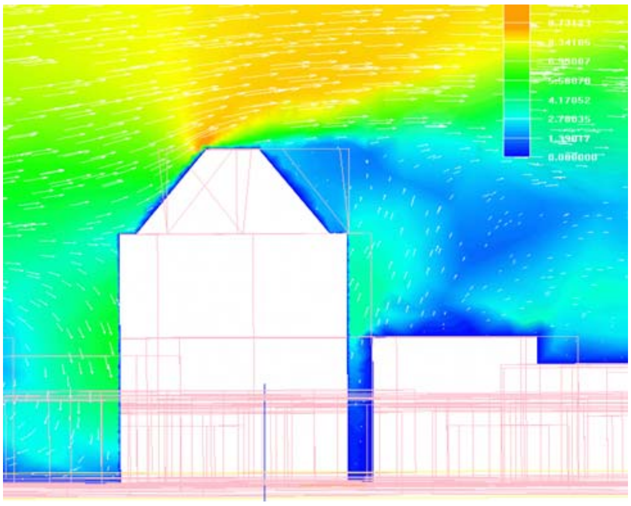
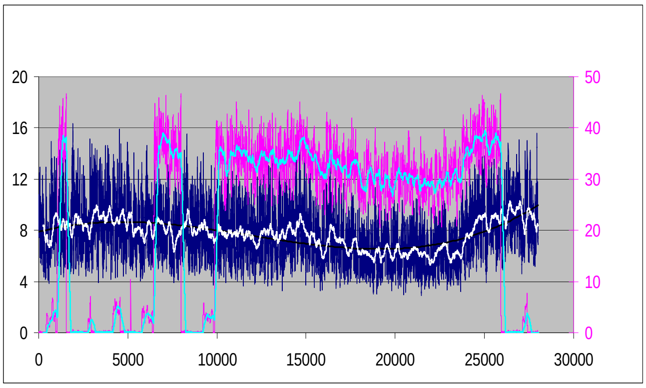


Figure 24: Wind flow around buildings[12]

Figure 24 shows a simulation of the wind flow around buildings. The simulation was generated by CFD modelling (Computational Fluid Dynamics). Blue colour represents zone with turbulences, zones with a week wind flow (shadow) are green. Red and orange zones are zones with a strong and constant wind flow.

Due to uneven profile of the built surrounding, a little change in the direction or the strength of the main wind flow can result in a very strong wind gusts which, for a few seconds, exceed the stop-speed of UWT.

12 S. Mertens: Wind Energy in the Built Environment, TU Delft



----- generator frequency = rotation speed rotor
----- wind speed
----- average generator frequency
[redacted]

This may lead to stopping of UWT while the average wind speed is well bellow the stop-speed. Figure 25 shows the monitoring results of one pilot project in The Netherlands. The white line in the middle shows the average wind speed and the dark blue line the measured wind speed.

The short lasting gusts bring the turbine to high rotation speed (pink colour) which then causes the turbine to shut-down.

Turbulences also have negative effect on the operation of the turbine because it will "hunt" for the wind and will not be using the wind effectively. This causes more stress on UWT parts which then shortens the life of the wind turbine.

15 POSITION OF UWT ON THE ROOF

The wind conditions on the roof are constrained by the general wind conditions in the area and influenced by the surrounding structures. The wind flow may be slowed down by remote obstacles and the close-by obstacles may cause turbulences. Also, the wind flow can be accelerated because of long straight streets or by inclined or spherical form of the building or the roof. All these phenomena together create the very specific micro conditions on each potential placement point in the built environment. These conditions vary from spot to spot. Even on the same roof, the conditions can be significantly different within small distances of just a few meters in horizontal or vertical direction. Figure 26 shows the expected wind energy per m^2 on the height 1 m, 3 m and 6 m above roof. The blue areas are the areas with smallest and the red spots with the highest energy content. The figure is the result of CFD modelling.

[13] Production measurement, model Turby

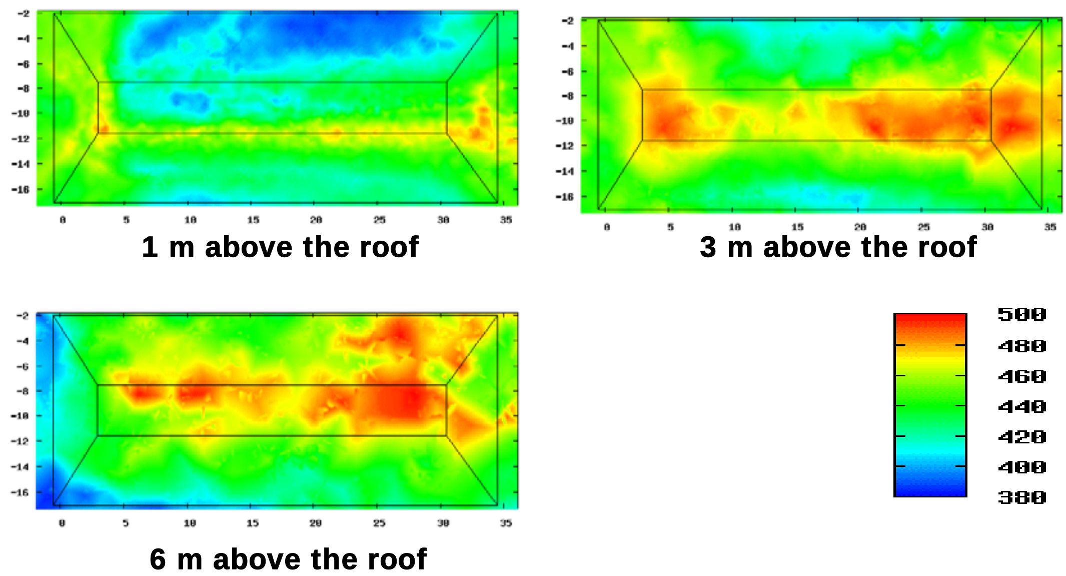


Figure 26: Wind flow on different heights above the roof [3]

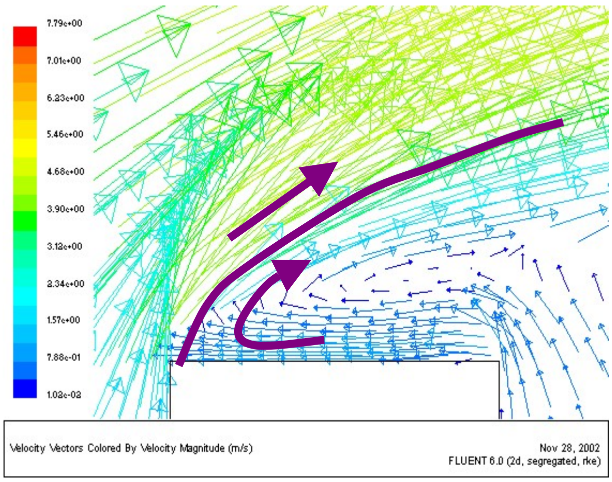


Figure 27: Wind flow above buildings[3]

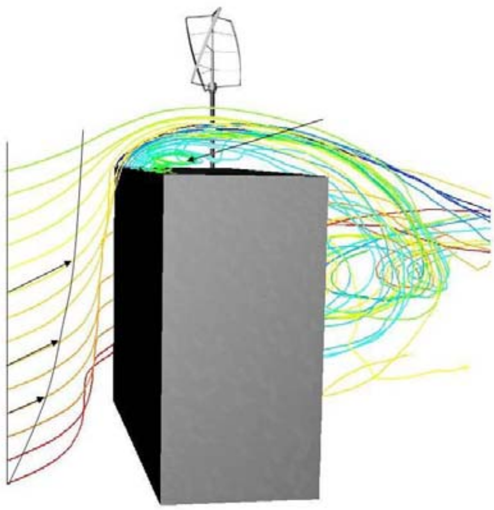


Figure 28: Placing of UWT on the roof[3]

In Figure 27, the top of a building with flat roof is shown from aside. The intensity of the wind is conveyed through the size of the arrows. Short arrows and the blue colour represent weak wind flow. The longer the arrows, the higher the wind speed. The area with the yellow arrows has the strongest wind with a mostly constant direction. In order to be able to maximally profit form the strong and constant wind flow, UWT should be placed approximately in the middle of the roof above the areas of turbulence. For this, the roof on which UWT is located should be well above the surrounding and the lowest position of the rotor should be well above the roof as shown in Figure 28. The arrow shows the turbulent areas which should be avoided.

16 CONCLUSIONS

The turbine model and the local wind regime are the most important factors determining energy yield. The energy available from wind increases with the cube of the wind speed, therefore modest differences in the wind regime may have substantial effects on the electricity yield. The minimum recommended average wind speed at an UWT location is 5.5 m/s.

The average wind speed of at least 5,5 m/s, which is the minimal requirement for the deployment of UWTs is available from all directions. The strongest wind comes from the direction south west. The regions closer to the coast have better wind conditions on 10 m height due to higher average wind speed. In the central and eastern parts of the country, the average wind speed on 10 m height is less suitable for UWTs. In those regions UWTs should be placed appropriately higher.

The Weibull distribution of the selected site should match the design characteristics of UWT.

One must be well informed about the local wind regime before giving any predictions regarding the electrical yield.

Buildings, trees, noise barriers and other obstacles influence the wind flow and create local, 'micro' wind regimes with more turbulence and gusts. A sloped or cylindrical shape of the building or roof on the side of the prevailing wind direction can have a positive effect on the energy yield of urban turbines.

Due to influence of the surrounding buildings, it is important to place the turbine on the highest building in the area and to ensure that there is enough distance from other obstacles. The yield can be as much as a factor of two higher or lower, depending only on a few meters distance from the obstacles or a few meters difference in height. In general, the higher the turbine is placed, the better. In specific situations, the measurements can be the only way to identify the right spot.

ANNEXES

17 ANNEX 1: BRITISH REFERENCES

1. European Wind Energy Association, "Wind Energy – The Facts: An Analysis of Wind Energy in the EU-25", 2003.

2. WAsP – the Wind Atlas Analysis and Application Program, www.wasp.dk, accessed 28/12/2006.

3. ReSoft, WindFarm, Wind Farm Analysis, Design and Optimisation, www.resoft.co.uk, accessed 28/12/2006.

4. Garrad Hassan, GH WindFarmer: Wind Farm Design Software, www.garradhassan.com, accessed 28/12/2006.

5. British Wind Energy Association, "Best Practice Guidelines for Wind Energy Development", November 1994.

6. Wind Energy in the Built Environment, S. Mertens, Multi-Science, 2006.

7. Small Wind Turbines for the urban Environment: state of the art, case studies and economic analysis, P. Robinson, Reading University, September 2005.

8. Investigation into the Installation of Small Wind Turbines in an Urban Environment, S. Carroll, Loughborough University, September 2005

18 ANNEX 2: SITING A SMALL WIND TURBINE IN URBAN AREAS

Good siting is crucial for a small wind system in an urban environment, in order to maximise already lower wind resources and to try to avoid some features of urban environments that can negatively effect electricity production. Some tips for siting are set out below[14]:

1. Wind speed

The greater the average annual wind speed at the proposed location, the better. So even though NOABL has its limitations, it is generally best to try to select a site with the highest estimated wind speed possible. Turbine output is a function of the cube of the wind speed, so if the wind speed doubles, the available power will increase by a factor of eight. In general, it is best to select sites that have at least 5.5 m/s average wind speed as given by NOABL.

2. Prevailing wind

Work out from which directions the prevailing winds in the area usually come. This can be done by observation during wind storms, and by looking at the trees near the proposed site; trees that are all leaning the same direction and that have branches mostly on one side of the trunk are a good indication of prevailing wind direction. Local airports and weather stations may also be able to provide you with this information. Even better is to try find a site where the prevailing wind is usually from one direction only.

3. Height

a. Wind turbines installed on the ground: The higher the mast, the better the wind resource that will be available to the turbine. Turbines should ideally be mounted 9 metres above any obstruction that is within 100 metres. If possible the turbine should be mounted on the highest available mast, planning permission and other considerations permitting.

b. With building-mounted turbines it may not be possible to use a 9m mast. However, the important issue is to avoid the layer of turbulence that is created at low levels around the edge of a building as the wind hits it. A rough guide would be to try to use a mast of at least 6m to avoid this layer of turbulence and reach above the turbulence "boundary" to smoother wind flows. It is also best to try to select a building that is higher than surrounding buildings, as this will increase the chances of access to a strong wind with smooth flow.

4. Obstructions and turbulence

If there is severe turbulence caused by nearby obstructions this leads to significant loss of potential power, and will cause extra wear on the turbine and its components. Ensure that there are no obstructions between the turbine and the prevailing wind. Elevated positions with smooth approaches are preferable to those near sharp ridges or cliffs. Also ensure that there are no big obstructions directly behind the wind turbine in the direction of the prevailing wind as when the wind passes through the wind turbine and hits the obstruction behind it, turbulence will be created which rebounds back in the direction of the turbine.

A wind turbine should not be located in a position where it will be subject to very turbulent air flow. Therefore keep the turbine clear as clear of obstructions as possible (see above), including trees and buildings. Light turbulence will decrease performance since a turbine cannot react to rapid changes in wind direction; while heavy turbulence may reduce the turbine's operational life. You can detect turbulence by streaming a long ribbon from a guyed pole or mast at the height of the proposed turbine. If the ribbon streams easily and smoothly in high winds from various directions the wind flow should be suitable.

---

[14] These tips are intended as rough guidelines to help project developers. However, they cannot be considered comprehensive and cannot guarantee good electricity production from an urban wind installation. The author cannot be held responsible for any use made of this information.

5. Building mounted turbines

The ideal site for a small wind turbine is mounted on a free-standing mast in an exposed location. Many conventional designs of wind turbines should not be mounted to buildings, however if the only site available is on a building then installing a small wind system may still be feasible if mounted high enough to minimise turbulence or if the wind regime at that particular location is favourable. If this is the case, it should be noted that performance will still be reduced compared to an equivalent mast mounted machine. The building itself will act as an obstruction and can result in turbulent air flow – this may not allow the turbine to operate as smoothly and could shorten its operational life. To avoid turbulence it is best to avoid the edge of buildings and try to position turbine on a high mast near the centre of the roof.

6. Variations in built up locations

For a building-mounted turbine site in an open area, wind speed theoretically can actually increase as it passes over the top of a building, however this is only likely if the building itself is in a very exposed location. Coastal locations could have an advantage if prevailing wind direction is from the sea where no obstacles will cause obstruction. A building on the edge of a settlement may also be subject to acceptable wind speeds and reasonably smooth airflow on the occasions that the wind is blowing from the direction of exposed land; however when the wind blows from the direction of the settlement, then the wind regime will be poor. A building located in the middle of a settlement or built up area is highly unlikely to benefit from a good wind regime. However, wind speed in the built environment can be high at the top of tall buildings, especially those which are substantially (at least 50%) taller than the buildings surrounding them.

7. Type and number of wind turbines

Before purchase and installation, it is worth investigating which turbine type is the best for the chosen location. It will probably be a different turbine if installed in the ground or on a building. Considering the number of relatively new products for building-mounted installation, it is worth doing some research to verify manufacturer claims and to select a wind turbine that more than one source says is suitable for installation on top of buildings in terms of potential energy production but also of robustness to deal with turbulence.

Also, if possible, installing multiple turbines at the chosen location, be it an open space or a building can be advantageous. This way, the average cost per kW installed (or per turbine) is reduced while the potential energy production is increased.

8. Visibility and other considerations

It is also worth investigating the visual impact of the wind turbine: the blade movements may bring a certain dynamic appearance to the area, however flicker or general visual disturbance are also possible. Attention should be given to the aesthetic integration of the turbine at the proposed location – the turbine needs to visually integrate well with the building and the area. It may be worth doing a photo mock-up or artist's impression of the turbine at the proposed location.

There are also other non-wind resource considerations such as noise, health and safety and, in the case of building-mounted turbines, vibration and structural integrity. This list does not deal with these aspects, however, they are important and should be given due consideration separately of the issue of availability of wind resource.