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Urban Wind Resource Assessment in the UK

An introduction to wind resource assessment in the urban environment

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1 INTRODUCTION

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.

The report 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. The report then goes on to look at the particular constraints which apply when trying to assess wind resource in built-up, urban areas.

The report will then discuss methodologies that can be used for resource assessment in urban areas and possible problems with accuracy. Finally, the report 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 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.

2 BACKGROUND

Until recently, the main renewable energy technologies implemented in urban surroundings were solar thermal, solar photovoltaics and heat pumps. In the last few years, small wind turbines have started to become available and are also being installed in urban areas. Like photovoltaics, urban wind turbines generate electricity on site, avoiding transmission losses and enabling individuals and organisations to visibly express their commitment to the generation of green electricity.

However, small wind turbines for the urban environment are a relatively new product. The market is underdeveloped and there is limited experience with the installation and grid-connection of these products. Consequently, the need for information related to the existing technologies, the economics, the regulations, planning procedures and guidelines specifically related to urban wind turbines is fundamental to enable market development.

The main objective of the WINEUR project is therefore to identify the conditions necessary for the greater integration of small wind turbines in the urban environment and to promote the emergence of this technology as a real option for electricity supply in towns and cities across Europe.

The first Work Package (WP1) of WINEUR, "State of art and experiences gained", produced a comprehensive catalogue of small wind turbines available in Europe suitable for urban areas and a report on the current wind energy situation in a selection of countries in Europe and worldwide.

The second Work Package (WP2), "Techno-economic and grid connection aspects" produced two reports covering the cost of installation of the different technologies and their economic viability and grid connection issues.

The third Work Package (WP3), 'Administrative and Planning Issues' produced reports examining the administrative and planning issues, barriers and solutions relevant to the integration of small wind systems in urban areas across Europe.

The fourth Work Package (WP4), 'Socio-economic and non-technical issues related to urban turbine implementation', produced a socio-economic report on opinions and perception of renewable energy and small wind turbines by local authorities, architects and homeowners.

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

Further information on the WINEUR project, all published documents and reports and a brief outline of activities under all work packages are available to download from the project website at www.urban-wind.org .

3 STANDARD WIND RESOURCE ASSESSMENT IN THE UK

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.

3.1 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.

3.1.1 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.

3.1.2 Wind resource assessment by 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 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.

3.1.3 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 :

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

- 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).

3.1.4 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.

4 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.

4.1 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 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.

[2] Roughness coefficient (or Roughness length)

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.

4.2 Inadequancies 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.

4.3 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: onsite 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.

5 URBAN WIND ASSESSMENT AROUND THE UK

5.1 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 1 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.

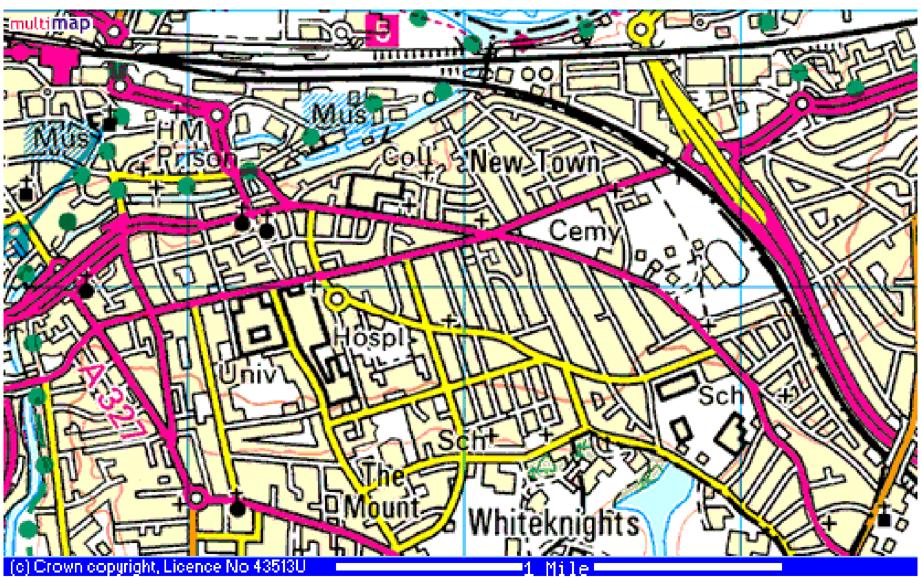

Figure 1. Map of central Reading © www.multimap.com

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]

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

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.

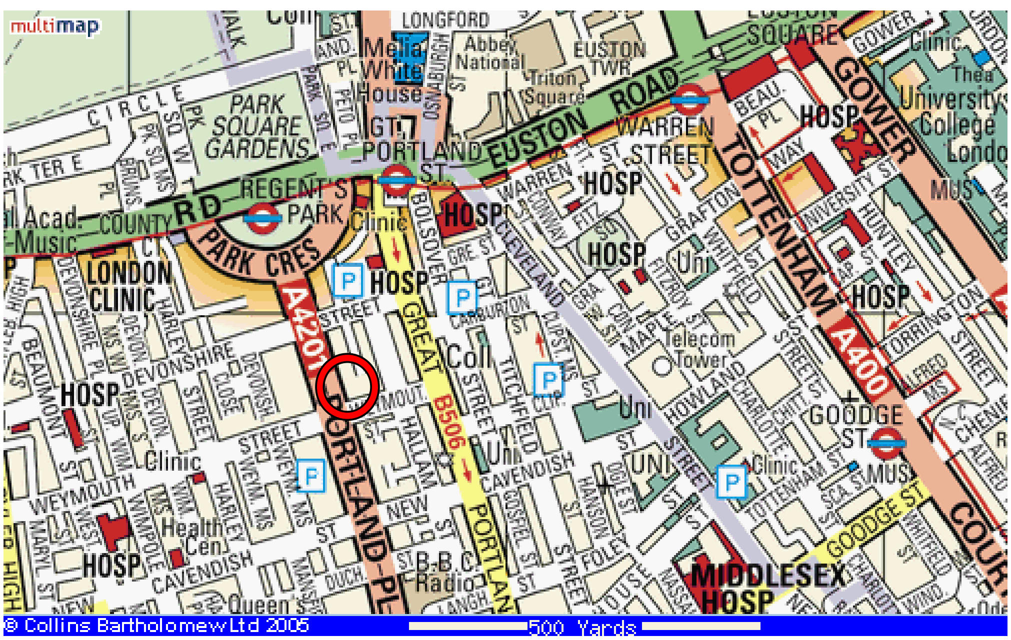

Figure 2. Map of RIBA's location in London © www.multimap.com

[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.

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 3.

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.

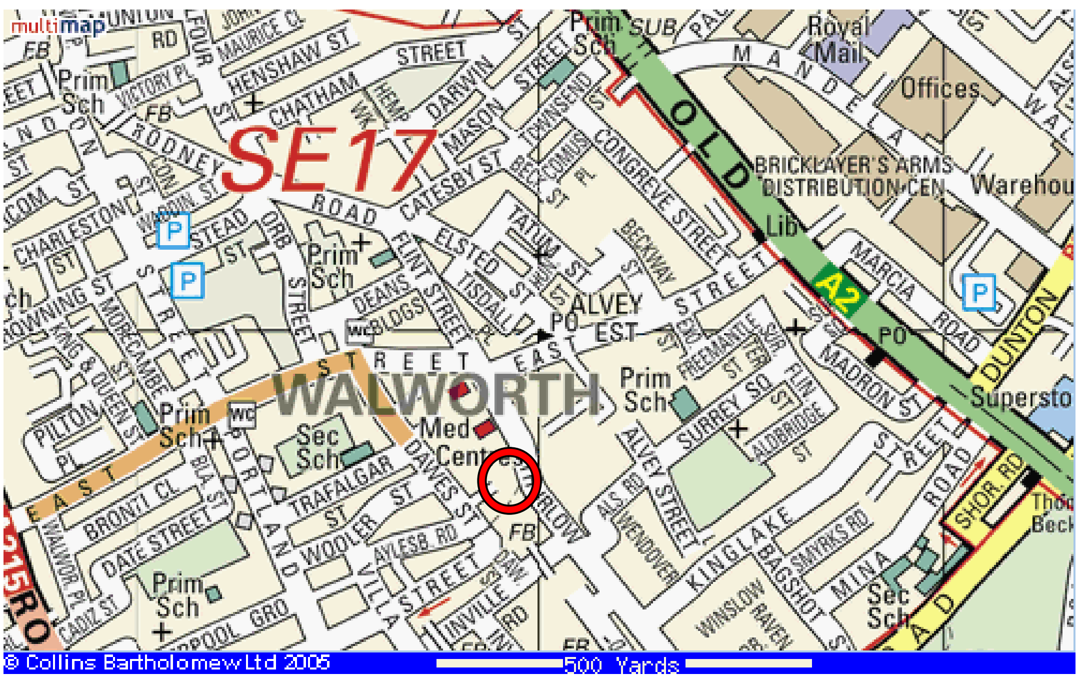

Figure 3. Map of Aylesbury Estate in London © www.multimap.com

[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.

5.2 Impact on urban wind projects

Table 3 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 fact, in some cases it can be the difference between producing some electricity or producing none at all.

6 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 1.

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

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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.

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ANNEX 1: 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[10]:

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 a t 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

[10] 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.

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.

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.