A first methodology for wind energy resource assessment in urbanised areas in Portugal

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Abstract

The onshore wind power capacity in Portugal has increased very rapidly in the last five years and this high rate of development is expected to continue up to 2013 although at a slower rate. By then almost all sustainable onshore resource assessment will be deployed. Nevertheless, the full exploitation of the wind resource in Portugal offers other possibilities, among them the installation of small wind turbines (SWT), namely micro-turbines for domestic use in urban and constructed environments. To contribute to the needs of developers, investors and the overall population's expectations and needs into this newer type of renewable market, a new a new line of research related to the wind resource assessment in urban and constructed areas was initiated. The present work presents a first user-friendly method to assess the urban wind potential at low experimental and computational costs, compatible with the scale of investment of micro-generation. A case study, where an urban area is identified and treated as very complex topography, was characterized in terms of wind resource, being the preliminary results presented here.

Keywords: Microgeneration, sustainability, small wind turbines.

1. Introduction

In the last years Portugal has installed a great amount of onshore wind parks. By the end of 2008, 2816 MW of its wind energy capacity was already connected to the electric grid and in full operation. INETI has contributed to this tendency since it has performed great part of the wind parks energy estimates and sitting assessment for the wind energy promoters.

The expertise and knowledge acquired, have naturally lead INETI to focus on other sub-sectors of the renewable energies, such as the small wind turbine systems. This sector is assuming special relevance in the present time and is expected to continue in near future, with some advantages for the environment – lowering CO_2 impacts in the atmosphere, according to Kyoto protocol, and also due to the recent and lower cost technological solutions that are beginning to appear in the market. Although photovoltaic solar energy, is easier to integrate in urban areas (roofs and facades of buildings), it presents a few technical limitations, namely the non-production during nigh time or when the sky is totally cloud covered. The use of small sized wind turbines can be easily used to fulfil the gaps of solar energy supply, thus contribution to a smoother generation of the microgeneration domestic sector.

In this sequence, new legislation was recently published, Dec. Law 363/2007 from 2nd November [1] 2007 that establishes rules for the installation of microgeneration systems and tariffs to apply in two different regimes that vary with capacity to install and tariffs to be paid to the micro producer of renewable electricity. As a result of the measures taken in the sequence of the new legislation, the lack of information related to wind potential in urban environments became the most urgent problem to solve, and R&D groups begun their work in the development of tools and information gathering to respond to the potential micro-producers demands. Several projects are already undergoing and some work is already done in this area, although cost-effective and easy to use methodologies are still not available.

This paper presents a new methodology based on the construction of a surface above the urban environment in order to be inputted in a selected model, (CFD, mesoscale, physical or microscale), and be treated as a very complex topography. Also brainstorm methodologies will be presented although results are not available for all types of model. A case study to test the surface method where resource assessment is performed by using microscale WA^{S}P [2] model and a study to identify suitable areas under urban environment for small wind turbines by using a geographical information system is presented.

2. State of the art

Wind flow in urban environment

Wind flow over urban areas is characterized by strong 3D effects and separation in the top edges of the buildings. Several experiments and studies have already been made to evaluate the wind behaviour around buildings and above the urban canopy. In this line of study, if one considers a large area with homogeneous roughness and flat terrain with a region of roughness length corresponding to urban environment, a great amount of considerations can be made about the wind behaviour [3]. Reduction of the wind flow (usually higher than 20%), increase in the shear stress and veering of the streamlines are examples of what usually occurs when the wind passes from a region with homogeneous and low roughness to another with high roughness value (e.g. urban area). In this case, a new boundary layer is formed (inner layer), which depth grows slowly in the interior than in the exterior. Also vortices are formed due to the difference between the high turbulence generated by the higher roughness and the smaller turbulence existing out of this region. In this case, turbulence increase as the wind speed decreases.

Also if one considers wind flow over a simple cubic building, the following considerations can be made:

- The wind flow over a building generates a positive pressure zone upwind and negative pressure zones in the lateral faces. Although the pressure magnitudes change with the wind speed for a certain orientation, the relative magnitudes aren't affected.

- The pressure zones induce a veering of the streamlines, movements of the secondary flow, separation and consequently, additional turbulence.

- When the wind is normal to the face downwind of a simple cubic building, the vortices zone will be about 1.5 to 2 times the height of the building measured from the face downwind.

- If the building is larger the interference in the flow increases and the vortices area length is about 12 times the height of the building.

- For an isolated building, the wind profile can induce a set of vortices in horseshoe shape that evolve the base of the building and continue downwind (figure 1).

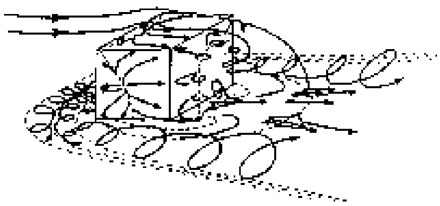


Figure. 1 – Horseshoe shape vortices evolving the base of a cubic building [4].

- Beyond the vortices region, separation effects and movements of the secondary flow induced by the presence of the buildings, also cause deficit of the wind speed and excess of turbulence in the wake region that continue up to 5 to 20 heights of the buildings downwind (figure 2).

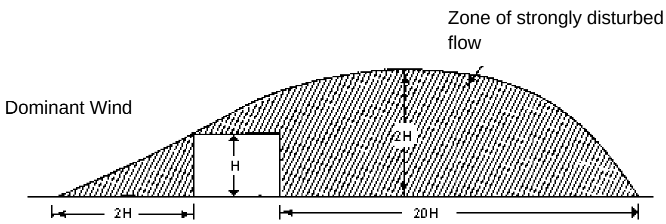


Figure. 2 – Disturbed flow by the presence of a cubic building [4].

Wind resource assessment and models

Standard microscale models are not able to account for the effects mentioned above, although they describe in a very simple way the wind flow around obstacles.

Until now, in Portugal, the wind potential assessment with the development of experimental measurements campaigns was a very onerous work being the associated costs, in most cases, more expensive than the turbines price. As result, most developers installed the small turbines without performing the wind energy potential estimations and assumed the risk of non profitability of this action. In other cases (most of them) the idea was simply abandoned when the risk was evaluated and proved to be larger than the acceptable.

Facing the lack of measurements in urban environments adequate to wind resource assessment, studies can be performed by using other sources of data. In what concerns the Portuguese case, there are already available national and regional atlas of the wind potential [5] that can be used as indicators of the existence of suitable wind for the installation of small wind turbines, but they are usually based in traditional microscale models as WA^{S}P coupled with mesoscale results which regardless their validity are not adapted to the urban environment. The first because it doesn't account for three dimensional effects of the wind flow over obstacles (buildings and urban structures) or separation effects, and the last because although these effects are taken in consideration, results are usually obtained for 1km x 1km minimum grid spacing which can't account for the detailed description of buildings and structures. In both applications, especially in the first case, always occurs an overestimation of the wind potential in the top of the buildings.

The use of CFD models to evaluate the wind behaviour around buildings is now state of the art. But although they are widely applied, some errors may occur due to the design of the geometric mesh of the structures and remaining environment, which is always very complex and computationally expensive. The time consuming and consequent cost of this kind of models is similar in practical terms and put the same limitations as the use of experimental campaigns.

The use of physical models of a city or parts of it in a wind aerodynamical tunnel are probably the most suitable solution to model the wind flow over urban areas. Errors are almost negligible and consequently results are accurate and trustfully. However, the construction of the 3D physical models and the use of wind tunnels with the possibility of simulating stratified atmosphere are also very expensive which sometimes leads to the selection of other types of modelling as the previously mentioned. When the economic issues are not a limit, these models are being used widely with very good results, but usually not for wind resource assessment.

Finally, a methodology to assess the sustainable wind potential of a given region or country was already developedwith the objective of contributing for the sitting of wind parks and assess the needs for grid reinforcement of of the Portuguese main windy regions [ref IEEE, under publication]. For microgeneration purpose, this kind of information is still not available. This type of study usually recurs to geographical information systems and a set of information is needed, such as municipality cartography, technology used, etc.

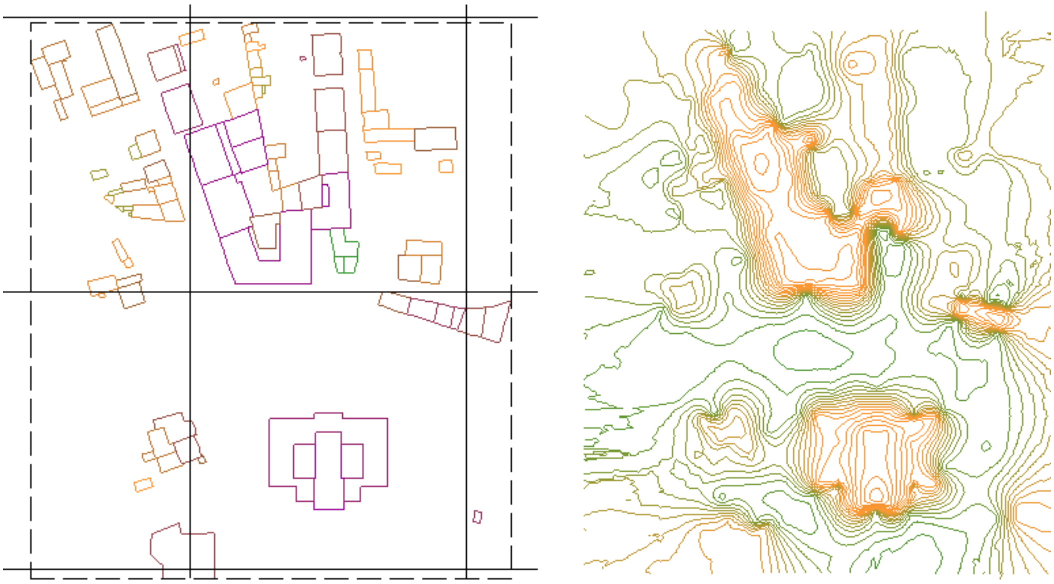
3. Methodology

The methodology here presented considers the construction of a surface evolving the urban environment so that the buildings area can be treated as a very complex topography map. This surface can easily be generated using as input the buildings description in form of a CAD map as long as the contours have height description values. These last are then subject to an interpolation method (in this case Kriging method [6]) to generate the surface. This method is useful since it saves time in what concerns mesh construction (e.g. for CFD models input) and can easily be inserted as input in almost all kinds of models – micro and mesoscale models, CFD and construction of 3D model for tunnel experiments in the use of physical models.

3.1. Construction of the surface

For the construction of the surface a CAD map is used and an example is represented in figure 3a. This map is inserted in MapEditor tool from WA^{S}P in order to perform quality control of the contours and corresponding heights of the buildings (other map editors can also be used). In this case, buildings are considered as being top plane as if they had terraces instead of roofs to make easier the methodology implementation. Future work will be performed considering roof inclination as in most of domestic cases of Portuguese traditional construction.

An ASCCI file is then generated with the coordinates and heights of the points representing the buildings in the CAD map (xyz file) and a Kriging interpolation method is applied to generate the surface (figure 3b). For small areas (few hundreds of meters) in order to improve the precision, a grid point spacing of 1 m is used, but for extensive areas, larger grid point spacing can be considered in order to reduce computational time.



(a) (b)

Figure 3 (a) – Buildings map representation. (b) Generated surface above the buildings area.

The generated surface is then completed by introducing a roughness value characteristic of urban areas. The final step is to insert the surface in a contour map representing the remaining surrounding region, although it can be done without this information if one is already considering a large area of a city (> 4-5 km).

3.2. Wind Potential Assessment

The methodology to perform wind potential assessment can use several model typologies and have as input the contour map shown above. In the case study here presented, a microscale model was used – WA^{S}P, being the wind data obtained from a Wind Potential Atlas for Mainland Portugal built with the application of mesoscale model MM5 [7]. As mentioned before wind flow in urban areas has complex characteristics which modelling is usually out of the standard simple microscale models envelope (WA^{S}P, WindPro among others), but in this paper the use of this methodology has as main objective to obtain results as a starting point for comparison with other more suitable models. In a near future a CFD model will be used in order to evaluate 3D effects of the wind flow. In this case a tetrahedral or resembling mesh will be built and initial and boundary conditions are currently under study.

A combined method using in a first phase a mesoscale model with large grid resolution (e.g. 1km x 1km) and then within the area of a cell apply CFD simulations considering the mesoscale results as input can be a possible alternative. This application is currently under study but unfortunately results weren't obtained in time to present in this paper. Experiences of this kind were already proposed by other authors using microscale models such as WA^{S}P instead of CFD [8]. This possibility, however, doesn't account for 3D effects once the simulations are performed in WA^{S}P and resembling models. With CFD, these effects can in fact be considered.

Also, the construction of a 3D model of the urban area is currently under consideration, although this kind of experiment is expensive. Simulations will be performed considering non-stratified and stratified atmosphere with a scale model of an area of a chosen city.

In order to test these methodologies, measurements can be used to validate results regarding the wind speed results obtained for given points of the map. At least two measurement sites are already under installation in public buildings in a city.

<u>3.3. Selection of suitable areas for small wind turbines installation</u>

In this work a study was performed in order to select suitable areas for small wind turbines installation. By this time only few variables were used – wind resource output and buildings height and available roof area. In order to do so, geographical information system (GIS) ArcGIS [9] was used. Results are presented in the case study presented bellow.

4. Case study

To test the methodology here presented an urban area was chosen in Torres Vedras city located in the western coastal zone of Portugal. In the region surrounding the city several wind parks are installed, and the municipality gently released the cartographic map of the city with adequate scale of detail (1:200 in the city historical centre and 1:2000 for the remaining urban area). Figure 4 represents a 3D view of the surface generated above the buildings.

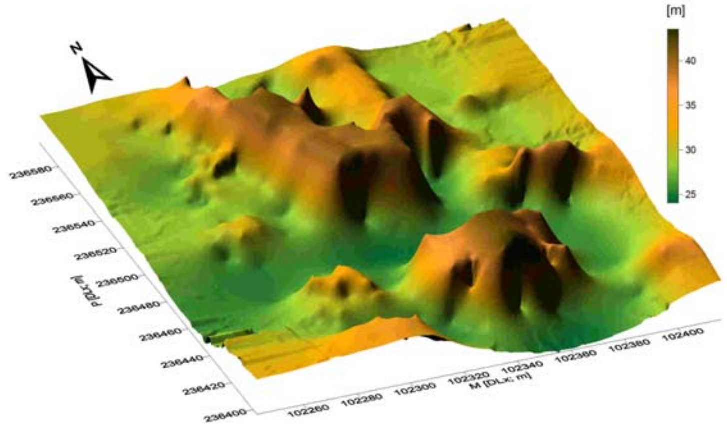


Figure 4 – 3D representation of the surface above the buildings.

Wind data series from the Wind Potential Atlas for Mainland Portugal was obtained for a grid point located in the selected urban area and wind potential assessment was performed with the help of WA^{S}P, for h=10m above the generated surface. Roughness information was introduced in the topography map being the z_0 value considered equal to the characteristic for urban areas according to the European Wind Atlas [10]. The obtained map is presented in figure 5.

It should be referred that the values here presented for the mean wind speed map may be overestimated due to the fact that simulations with the microscale model WA^{S}P cannot consider 3D effects and separation phenomena among other effects that were already exposed in the previous sections of this paper. Measurements in this area or experiments performed by using one of the methodologies presented above allow the evaluation of the uncertainties introduced in these results.

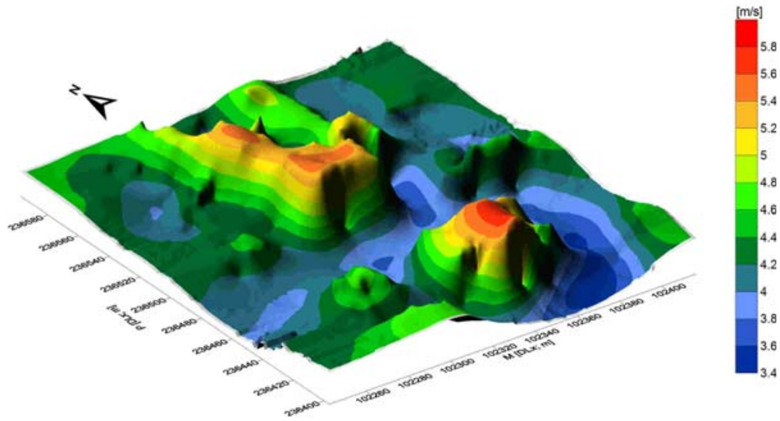


Figure 5 – Mean wind speed obtained by WA^{S}P for h=10 m above the generated surface.

After obtaining the mean wind speed map, selection of the suitable areas to install small wind turbines based on wind speed was performed in a GIS. In order to do so, mean wind speed map was used establishing as minimum value 4.5 m/s. Also it is important to filter the height and selected the highest buildings in order to avoid shelter and added 3D effects from neighbor buildings. As a result two areas were found (figure 6).

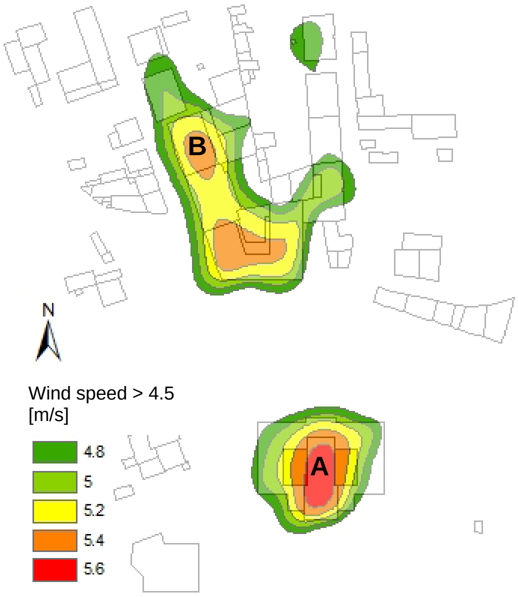


Figure 6 – Suitable areas for small wind turbines installation.

Considering the buildings height, the results should be centered at points A and B to install small wind turbines.

4. Concluding remarks

In this work a simple and strait forward ethodology to perform resource assessment in urban environment was drafted and applied to an actual case study to select suitable areas for small wind turbines installation. The method is based on the construction of a surface over a part of a city where the buildings description – limits and heights – was used. In this initial phase of the work the resource assessment was performed by using a microscale model – WA^{S}P and the selection of the suitable area by using a GIS platform.

The wind data used was obtained by the wind potential atlas for mainland Portugal since urban wind measurements were still not available at this time.

Several brainstorm simple cost-effective methods to estimate wind potential in urban environments were mentioned, being some of them currently under study and in implementation phase.

In what concerns wind resource assessment, the methodology presented needs further characterization and, eventually, calibration after the experimental phase of the work. Nevertheless, the surface is easily obtained from the buildings geometry may also be used as input for other models to calculate wind potential in urban regions, being them mesoscale or CFD. Also, these results can constitute a starting point to infer the differences between this approach and others more adequate as Physical (wind tunnel) and CFD, in order to establish suitable areas for small wind turbines installation. The presented method enables to overcome the lack of measurements and information about wind potential in the urban environment and to produce first estimates of urban wind resource for planning purposes. A measurements campaign is about to start as well as simulations with CFD and wind tunnel tests are programmed in order to establish the validity of this approach.

References

[1] Dec. – Law 363/2007, 2nd November, Diário da República, no 211, 1st serie, pp. 7978-7984.

[2] WASP Mortensen, N. G.; L. Landberg; I. Troen; E. L. Petersen, (1993). *Wind Atlas Analysis and Application Program (WAsP), Vol. 1: Getting Started*, Riso National Laboratory.

[3] E. Plate (ed), (1982), *Engineering Meteorology, Fundamentals of Meteorology and Their Application to Problems in Environmental and Civil Engineering*, Elsevier scientific publishing company.

[4] Estanqueiro, A. and F. Silva (1996). *Energia Eólica – Curso de Formação*, Altener program, INETI/DER,pp. 19-21.

[5] Costa P., P. Miranda, A. Estanqueiro (2006). *Development and Validation of the Portuguese Wind Atlas*, European Wind Energy Conference (EWEC2006), Athens.

[6] Burrough, P.A. (1986). *Principles of Geographical Information Systems for Land Resources Assessment*, Clarendon Press, Oxford. (Chapter 8).

[7] Grell, G. A., J. Dudhia, D. R. Stauffer (1995). *A description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5)*. NCAR Technical Note, NCAR/TN-398+STR.

[8] Landberg, L., L. Myllerup, O. Rathmann, E. Petersen, B. Jørgensen, J. Badger, N. Mortensen (2003). *Wind Resource Estimation – An Overview*, Wind Energy,6:261-271 (DOI: 10.1002/we.94), John Wiley and Sons.

[9] ArcGIS 9, (2006) ESRI.

[10] Troen, I. and E.L. Petersen (1989), *European Wind Atlas*, Riso National Laboratory, Denmark.

[11] Di Sabatino, S., E. Solazzo, P. Paradisi, R. Britter (2008), *A simple model for spatially-averaged wind profiles within and above the urban canopy,* Boundary Layer Meteorology, Springer, pp131-165.

[12] Smolarekiewics, P.K.,R. Sharman, J. Weil, S.G. Perry, D. Heist, G. Bowker, *Building resolving large-eddy simulations and comparison with wind tunnel experiments* (2007), Journal of computational physics, Elsevier, pp633-653.

[13] Coceal, C., T.G.Thomas, I.P.Castro, S.E. Belcher (2006), *Mean flow and turbulence statistics over groups of urban-like cubical obstacles,* Boundary-Layer Meteorology, Springer, pp491-519.