Wind Turbine Siting

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Outline

- Terrain roughness
- Escarpments
- Wind shear
- The roughness rose
- Variable winds
- Turbulence
- Wind obstacles
- Wind shade
- The park effect
- The hill effect
- Turbine siting
- Offshore winds
- Wind maps

Wind Farm Design

Download this freeware

http://awsopenwind.org
and
www.firstlook.3tier.com
(best use www.3tier.com)

Roughness

Introduction

- ✓ At high altitudes, the wind is hardly influenced by the surface of the earth
- ✓ At the lower layers of the atmosphere the wind speed is affected by the friction against the surface of the earth
- ✓ In the wind industry one distinguishes between the influence from the terrain roughness, obstacles, and the terrain contours (referred to as the *orography* of the area)
- ✓ Let's explore orography while investigating so called speed up effects, i.e., tunnel effects and hill effects

Roughness

- ✓ In general, the more rough the earth's surface is, the more the wind slows down
- ✓ Forests and large cities slow down the wind considerably, while concrete runways in airports slow the wind a little
- ✓ Water surfaces are smoother than concrete runways and barely impact the wind speed
- ✓ Long grass, shrubs, and bushes slow down the wind to some degree

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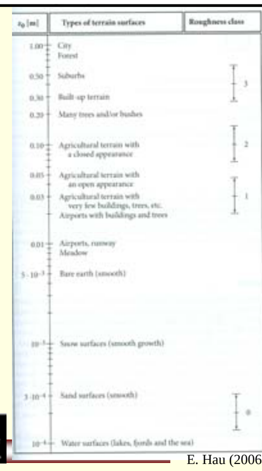
Roughness Classes (Lengths)



E. Hau (2006), p. 463

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Roughness Classes (Lengths)

- ✓ Roughness classes or lengths, are usually used to evaluate wind conditions at a landscape
- ✓ A high roughness class of 3 to 4 refers to landscapes with many trees and buildings, while a sea surface is in roughness class 0
- ✓ Concrete runways in airports are in roughness class 0.5. The same applies to the flat and open landscape

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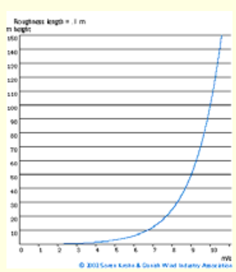
Wind Shear



- ✓ This graph shows how the wind speed varies in roughness class 2 (agricultural land with some houses and sheltering hedge rows at some 500 m intervals), assuming the wind speed of 10 m/s at a height of 100 meters
- ✓ *Wind shear* (wind gradient), is a difference in *wind speed* and *direction* over a relatively short distance in the atmosphere
- ✓ Wind shear can be broken down into vertical and horizontal components

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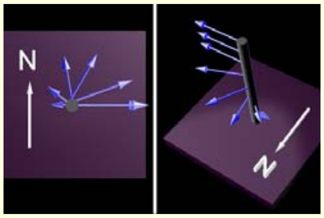
Directional vs Speed Shear



Speed shear: the wind speed increases with the height

Directional shear: a change in the wind direction with the height

http://ww2010.atmos.uiuc.edu/(Gh)/wwhlpr/modl_shear.rxml

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Wind Shear

- ✓ Wind shear is an important factor in the design of wind turbines
- ✓ Consider a wind turbine with a hub height of 40 meters and a rotor diameter of 40 meters (blade length = 20 m)
- ✓ The wind blows at 9.3 m/s when the tip of the blade is in its uppermost position, and only 7.7 m/s when the tip is in the bottom position
- ✓ This means that the forces acting on the rotor blade when it is in its top position are larger than when it is in its bottom position

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Wind Shear and Escarpments

- ✓ It is not correct to assume that the height of a cliff compensates for the height of the wind turbine tower, at least when the wind is coming from the sea
- ✓ The cliff creates turbulence and brakes the wind before it reaches the cliff
- ✓ This most likely reduces the turbine lifetime, due wear and tear caused by the turbulent air

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Wind Shear and Escarpments

- ✓ If one had a choice, one would select a rounded hill in the direction facing the sea, rather than the escarpments seen in the picture
- ✓ A speed up effect may occur at a rounded hill

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Wind

Main sources of wind data for wind farm siting

- ✓ Site specific data collection
- ✓ Wind map data
- ✓ Computational modeling
- ✓ Neighborhood wind farms

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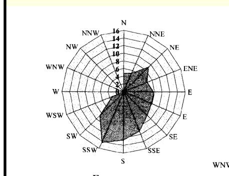
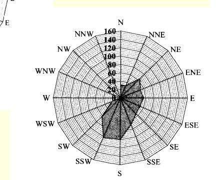
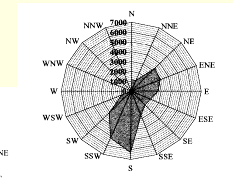
Wind Frequency/Velocity/Energy Rose


Frequency rose


Velocity rose


Energy rose

Spider diagram
Circular histogram

S. Mathew (2006)

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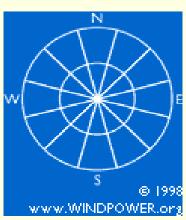
The Roughness Rose



- ✓ Similar to wind rose mapping wind energy coming from different directions, a roughness rose describes the roughness of the terrain in different directions from a prospective wind turbine site
- ✓ Normally, the compass is divided into 12 sectors of 30 degrees each, but other divisions are possible

Rose = Spider diagram

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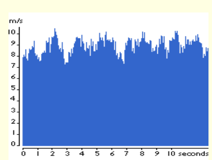
Wind Speed Variability

Short Term Variability of the Wind (second scale)



- ✓ The wind speed fluctuates and so does the energy content of the wind
- ✓ The wind variation depends both on the weather and local surface conditions and obstacles
- ✓ The most rapid variations are to some extent compensated by the inertia of the wind turbine rotor

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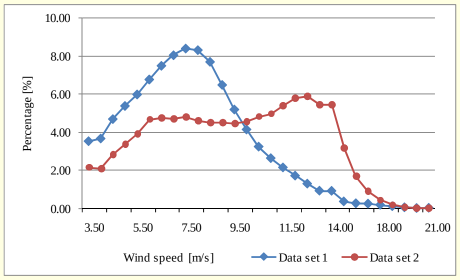
Wind Speed Variability



Distribution of 10-second data from two different months

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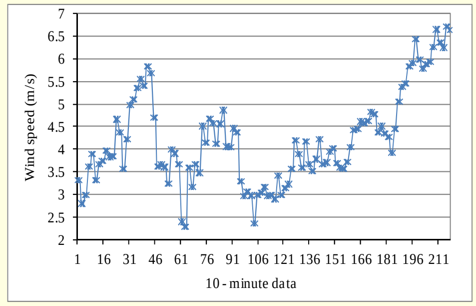
Wind Speed Variability



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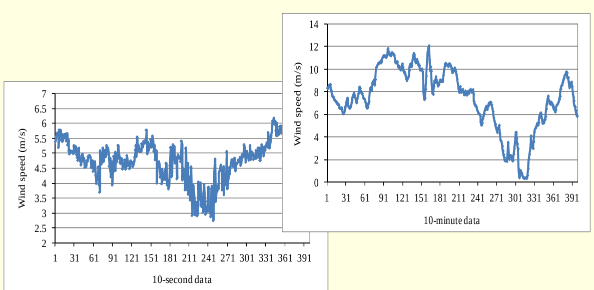
Wind Speed Variability



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Wind Speed Variability

Diurnal (Night and Day) Variations of the Wind

- ✓ At most locations around the globe it is more windy during the daytime than at night
- ✓ The graph shows how the wind speed at Beldringe, Denmark in by 3 hour intervals
- ✓ This variation is largely due to the fact that the temperature difference, e.g., between the sea surface and the land surface tends to be larger during the day than at night

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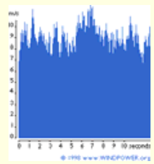
Wind Speed Variability

Diurnal (Night and Day) Variations of the Wind

- ✓ The wind is more turbulent and tends to change direction more frequently during the day than at night
- ✓ Electricity consumption is also higher during day time than at night
- ✓ Many power companies charge more for the electricity produced during the peak load hours of the day (shortage of generating capacity)



Turbulence

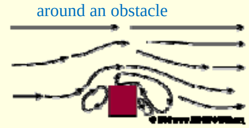
- ✓ Hailstorms and thunderstorms in particular, are associated with frequent gusts of wind which both change speed and direction
- ✓ In uneven terrain surface, and behind obstacles, e.g., buildings turbulence with irregular wind flows, whirls (vortexes) get created
- ✓ Turbulence decreases the efficiency of wind turbines
- ✓ It imposes more tear and wear on the turbine
- ✓ Wind turbine towers are usually made tall enough to avoid turbulence from the wind close to ground level

Accounting for Wind Obstacles

- ✓ For accurate predictions of wind power output it may be important to account for local wind obstacles in the prevailing wind direction near the turbine (closer than 1km or so)

Wind Obstacles

Side view of wind flow around an obstacle



- ✓ One would expect the turbine to the right (facing the wind directly) to be the one to start first when the wind starts blowing
- ✓ However, it does not start due to the small woods in front of the wind turbines which shelters the rightmost turbine in particular
- ✓ In this case, the annual production of energy is probably reduced on average by some 15% or more or the rightmost turbine

Wind Obstacles

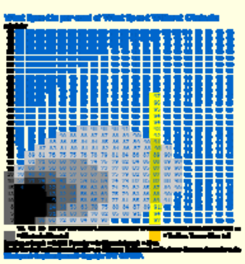
Top view of wind flow around an obstacle

- ✓ Obstacles to the wind, e.g., buildings, trees, rock formations can decrease wind speed and create turbulence
- ✓ The figure shows typical wind flow around an obstacle
- ✓ The turbulent zone may extend to some three time the height of the obstacle
- ✓ The turbulence is more pronounced behind the obstacle
- ✓ Avoiding major obstacles close to wind turbines in the prevailing wind direction recommended

Wind Obstacles

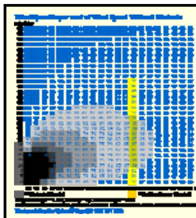
- ✓ The decrease in wind speed depends on the porosity of the obstacle (Porosity is defined as the open area divided by the total area of the object facing the wind)
- ✓ A building is obviously solid, and has no porosity, whereas a fairly open tree in winter (with no leaves) may let more than half of the wind through
- ✓ In the summer, however, the foliage may be very dense, thus reducing the porosity by, e.g., 30%

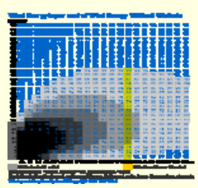
Wind Shade



- ✓ This graph provides an estimate on how wind speeds decrease behind a blunt obstacle (a seven story office building, 20 meters tall and 60 meters wide placed at a distance of 300 m from a wind turbine with a 50 m hub height
- ✓ The wind shade as different shades of grey
- ✓ The blue numbers indicate the wind speed in % of the wind speed without the obstacle

Wind Shade





- ✓ At the top of the yellow wind turbine tower the wind speed has decreased by 3% (is at 97%) of the speed without the obstacle
- ✓ The 3% of wind loss translates into some 10% of power

Wake effect from wind turbine
© Riso National Laboratory, Denmark

Wake Effect

- ✓ A wake behind the turbine, i.e., a trail of turbulent and slowed down air relative to the wind arriving in front of the turbine

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Wake Effect

- ✓ The expression wake is derived from the wake behind a ship
- ✓ Locating turbines as far apart as possible in the prevailing wind direction is desirable
- ✓ The land utilization and the cost of connecting wind turbines to the electrical grid call for placing them close to each other

Land utilization dilemma

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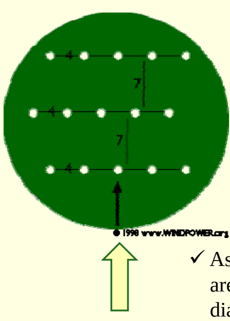
Park Layout



Prevailing wind direction

- ✓ As a rule of thumb, turbines in a wind park are usually spaced between 5 and 9 rotor diameters apart in the prevailing wind direction, and between 3 and 5 diameters apart in the direction perpendicular to the prevailing winds

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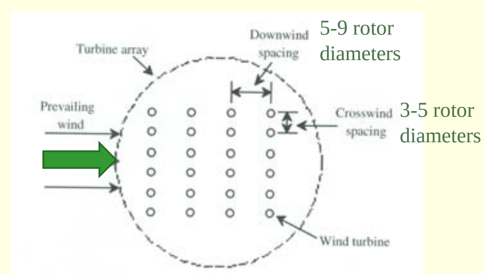
Park Layout



J. F. Manwell *et al.* (2002), p. 384

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Speed Up Effects: Tunnel Effect

- ✓ The air leaving the air pump nozzle moves much faster than the speed the cylinder is pushed
- ✓ The reason is that the nozzle is much narrower than the cylinder in the pump

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Tunnel Effect

- ✓ In a narrow mountain pass the air becomes compressed on the windy side of the mountain, and its speed increases considerably between the obstacles to the wind
- ✓ This is known as a "tunnel effect" (similar to the pump effect)
- ✓ For example, the wind speed in open terrain of 6 m/s, may result in 9 m/s in a natural "tunnel"
- ✓ Placing a turbine in such a tunnel offers advantages

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Speed Up Effects: Hill Effect

- ✓ A common way of siting turbines is to place them on hills or ridges overlooking the surrounding landscape
- ✓ It is always an advantage to have as wide a view as possible in the prevailing wind direction in the area
- ✓ On hills the wind speeds are higher than in the surrounding area
- ✓ This is due to the fact that the wind becomes compressed on the windy side of the hill, and once the air reaches the ridge it expands and soars down into the low pressure area on the lee side of the hill

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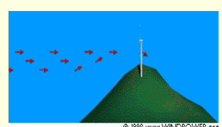

Hill Effect

- ✓ The wind in the picture starts bending before it reaches the hill, because the high pressure area actually extends some distance in front of the hill
- ✓ The wind becomes irregular, once it passes through the wind turbine rotor
- ✓ A hill that is too steep or has uneven surface may cause significant turbulence – thus negating the advantage of higher wind speeds

Software animation useful
www.emd.dk/WindPRO

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Selecting a Wind Turbine Site

Photograph Soren Krohn
© 1997 DWIA

Wind Conditions

- ✓ Looking at the nature itself is usually an excellent guide to finding a suitable wind turbine site
- ✓ Trees and shrubs provide clues about the prevailing wind directions as you do in the picture to the left
- ✓ Moving along a rugged coastline one may discover that centuries of erosion have worked in one particular direction
- ✓ Meteorology data, ideally in terms of a wind rose calculated over 30 years is probably the best guide, but these data are rarely collected directly at the site of interest

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Selecting a Wind Turbine Site

Wind Conditions

- ✓ If there are existing wind parks in the area, their production results are an excellent guide to local wind conditions
- ✓ In countries such as Denmark and Germany with a large number of turbines scattered around the countryside, manufacturers can often guarantee production rates on the basis of wind calculations made from the available data

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Selecting a Wind Turbine Site

Look for a view

- ✓ An ideal wind turbine site would be:
  - wide and open area in the prevailing wind direction
  - with few obstacles
  - low roughness in the prevailing wind direction
  - a rounded hill to place the turbines for a speed up effect

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Soil Conditions

- ✓ Both the feasibility of building foundations of the turbines, and road construction to reach the site with heavy trucks must be taken into account with any wind turbine project

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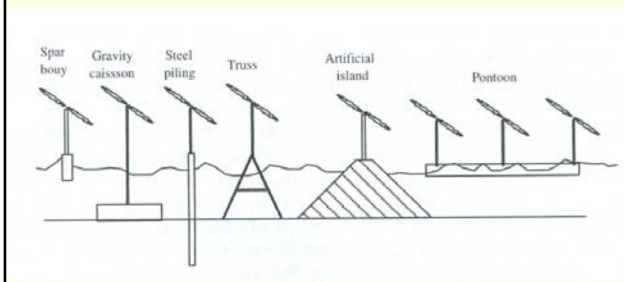
Offshore Foundations



Manwell *et al.* (2002), p. 407

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Small Wind

http://www.awea.org/smallwind/

I want to install a small wind turbine
http://www.awea.org/smallwind/toolbox2/drawer_1_installation.html

I want to promote small wind in my community
http://www.awea.org/smallwind/toolbox2/drawer_2_promotion.html

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Acknowledgement

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