Greenpaper©

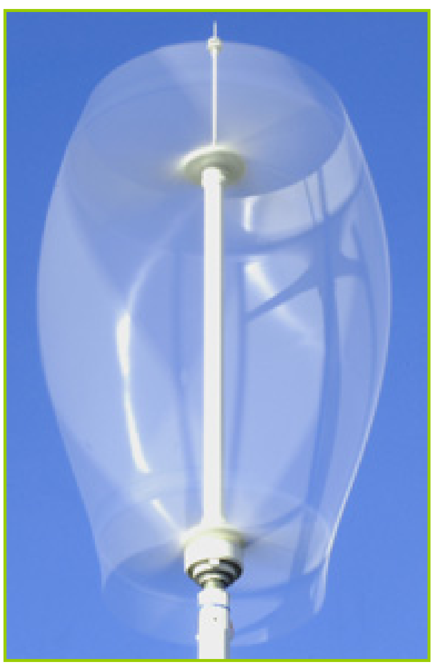
March 2009

Copyright © 2009 Glumac. All rights reserved.

Building Integrated Wind Turbines

Prepared For:
The Los Angeles Community College District

Horizontal Axis Wind Turbine



Vertical Axis Wind Turbine

DESCRIPTION OF TECHNOLOGY

A wind turbine is a rotating machine that converts the kinetic energy of wind into electric energy. In addition to large-scale wind power plants, there are a number of small-scale applications for wind turbines such as generating electricity for individual buildings or off-grid uses. Typical small turbines are from 7 to 25 feet diameter and produce 900 to 10,000 W at test wind speeds.

Vertical-Axis and Horizontal-Axis Wind Turbines

Wind turbines can be separated into two categories based on the axis around which the turbine rotates: horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT). The dominant models in the U.S. market are horizontal-axis wind turbines, although vertical-axis wind turbines are becoming more popular for building-integrated applications.

Horizontal-axis wind turbines have the main rotor and electrical generator at the top of a tower. HAWTs must be pointed into the wind. Small turbines weathervane by a simple wind vane/tail, while large turbines generally use a wind sensor coupled with a servo motor to yaw into the wind.

In comparison to HAWTs, the main disadvantage of vertical-axis wind turbines is that the output efficiency at steady flow conditions is typically lower. The lower efficiency results because some blades are always cutting against the wind as the turbine rotates. However, VAWTs have several advantages which make them more attractive for many situations, including building-integrated applications. Advantages of VAWTs include the following.

- VAWTs do not need to be pointed into the wind to be effective. This is important on or near buildings, which create local wind turbulence, or in other locations where the wind direction is highly variable.
- They typically can operate at lower wind speeds, so energy is produced more hours of the year.
- Many models may be safer for birds, since the turbine is viewed as a solid object by birds according to manufacturers.
- Vertical rotating objects are inherently more balanced, produce less noise, and transmit less vibration to supporting structures.
- The generator and gearbox can be placed near the base rather than on the top of the tower, so it is more accessible for maintenance.

Due to the advantages outlined above, vertical-axis wind turbines are typically more appropriate for building integrated applications, although exceptions do exist.

BuildLACCD

Example of a VAWT-Darrieus
Cleanfield Energy V3.5
Rated Power Output: 3.5 kW

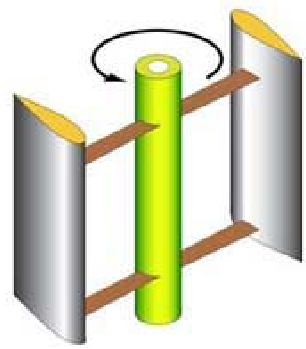
Example of a VAWT-Savonius
Pcon Windkraft S3-190
Rated Power Output: 0.7kW

Example of a VAWT-Hybrid
Ropatec WindRotor WRE.060
Rated Output Power 0.8kW

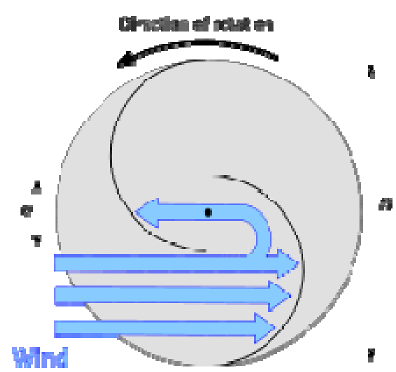
Vertical-Axis Darrieus and Savonius Wind Turbines

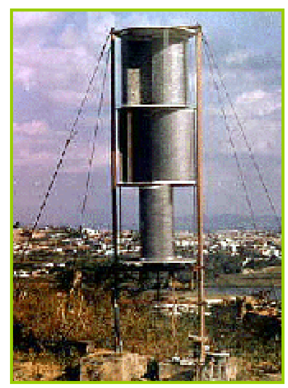
The vertical-axis wind turbines are further categorized into Darrieus and Savonius turbines.

The Darrieus turbines operate by lift. The blades are shaped like airfoils to create a pressure differential across the blades due to the Bernoulli effect. Darrieus blades are accelerated as they move against the wind much like a sailboat going upwind. The following pictures show typical Darrieus turbines.



The Savonius turbines operate by drag. The rotors are shaped like buckets or paddles to scoop incoming wind. The blades are accelerated as they move in the same direction with the wind, much like a sailboat going downwind.





A simple way of determining whether a VAWT design is based on drag or lift is to observe the movement of the tip of the blades relative to wind speed. Lift-type rotors have tips that move several times faster that incoming wind while drag-type rotors have tips that can only move as fast as the wind.

Because Darrieus turbines operate at higher speeds, they typically have higher power outputs and higher efficiencies. This makes Darrieus turbines more attractive for most wind turbine applications. Savonius or Darrieus-Savonius hybrid turbines have lower cut-in wind speeds and may be a better choice for locations with very low wind speeds.

Ropatec
Rated Power Output: 3 kW

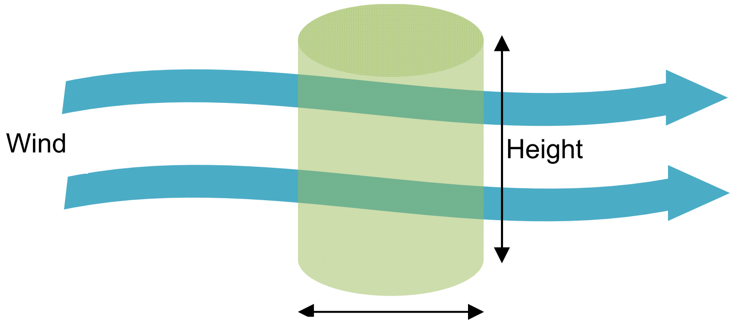
Quiet Revolution QR5
Rated Power Output: 6 kW

Aerovironment AVX1000
Rated Power Output: 1kW

Turbine Manufacturers

The emerging building integrated wind turbine market is still in the early stages of development. Therefore, care must be taken to evaluate the claims and performance data of different turbine manufacturers. There is currently no industry-wide 3rd party certification or testing agency, although the California Energy Commission is beginning to fill that role in California. All wind turbines must be CEC-certified to be eligible for state renewable energy incentives.

The Betz limit is a useful rule to evaluate turbine power curves. In 1926, the German wind energy pioneer Albert Betz published his book Wind-Energie, which contained a proof of Betz' Law. Using the basic rules of conservation of energy and conservation of mass, Betz proved that a wind turbine could convert no more than 16/27 of the wind energy into kinetic energy of the turbine. This limit of 59% became known as the Betz Limit.



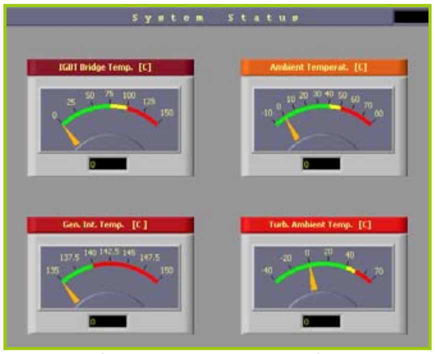
The power of the wind = $(½)\rho A v^3$

where,
ρ is the air density, roughly 1.2kg/m^3
A is the surface area facing incoming wind (HxD)
v is the velocity of wind

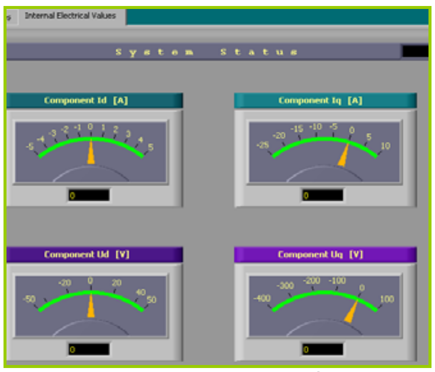
Therefore, the theoretical maximum turbine powerbased on the Betz Limit is given by $(0.59)(½)\rho A v^3$. Real-world turbines will produce less than this.

In addition to evaluating the power curves, it is important to gather additional information regarding any potential wind turbine manufacturer: The following questions are a few examples.

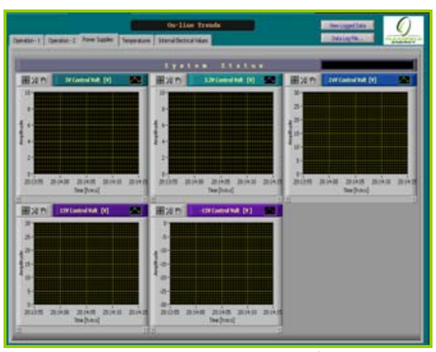
- How long has the company been in business?
- How many past projects have been installed?
- Are the turbines UL listed? This is required to be grid-connected or building-connected.
- Are the turbines CEC certified?
- Is noise and vibration data available?
- What type of monitoring and control software is available?
- What warranty is available?

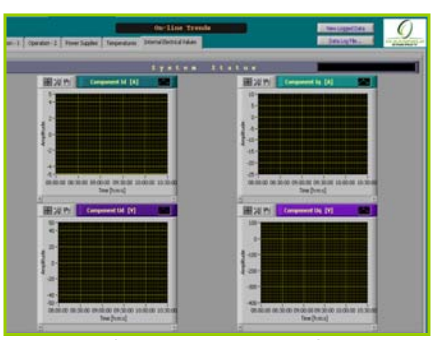


System Temperatures Screenshot



Internal Electrical Values Screenshot


Trendlines Analysis Screenshot


Past Performance Trendlines Screenshot

Wind Turbine Monitoring and Management

Some wind turbines manufacturers offer computerized monitoring systems for their turbines. The screenshots below show the graphical user's interface for Cleanfield's Remote Monitoring Option. With this option, each turbine inverter is connected to a building management computer and/or to a computer at Cleanfield's facility. Individual turbine performance data and conditions are logged and viewable real-time by turbine management staff.

The following are some examples of useful data from the Remote Monitoring Option,

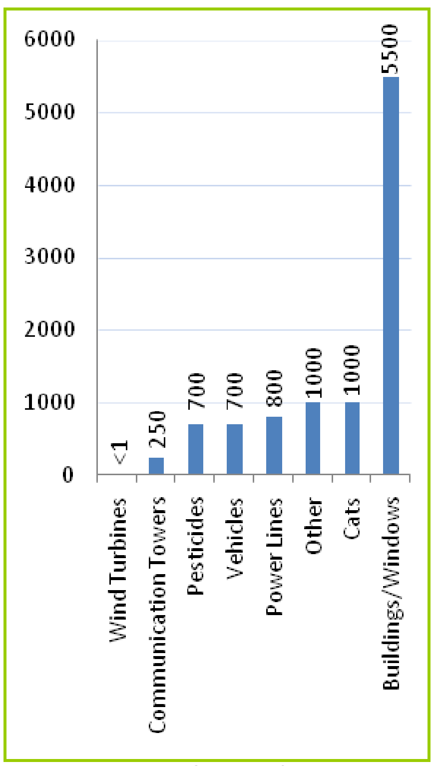
- Current wind speed for each turbine
- Current turbine's revolution per minute(rpm)
- Current rate of energy production
- Voltage and current changes within the turbine

When the wind speed goes above the maximum allowable safe wind speed recommended by the manufacturer, the turbines can be switched off either through the inverter or at the disconnect switches.

By monitoring turbine outputs and operating characteristics, turbine management staff can identify turbines which may not be operating properly, and preventative maintenance can be performed prior to a more serious problem occurring.

Sounds	SPL (dB)
Heavy Truck (45 ft), City Traffic	90
Alarm Clock (3 ft) Hair Dryer	80
Noisy Restaurant, Business Office	70
Air Conditioning Unit, Conversational Speech	60
Light Traffic (150 ft), Average Home	50
Living Room, Quiet Office	40
Soft Whisper (15 ft), Library	30
Rustling Leaves, Broadcasting Studio	20

Equivalency Chart
for Sound Pressure Levels (SPL) in dB



Causes of Bird Fatalities
Number per 10,000 Fatalities in the U.S.
Source: Erickson et al., 2002,"Summary of Anthropogenic Causes of Bird Mortality", International Partners in Flight Conference

Maintenance and Warranty

Typical maintenance requirements of small-scale wind turbines include periodic visual inspection and tightening of bolts. Most manufacturers recommend annual or semi-annual preventative maintenance.

Warranties vary by turbine manufacturers, but most include one year of parts and labor, plus several additional years of parts only. Given the developing nature of the technology, it is recommended to negotiate an extended warranty with whichever manufacturer is selected.

Noise and Vibration

In most wind turbines currently available in the market, the rotors are supported and separated from the main shaft by electro-magnetic forces. This keeps the physical contact between the moving elements to a minimum and thereby reduces noise and vibration.

Most manufacturers are in various stages of testing their products regarding noise and vibration, and in most cases independent test data is not yet available. Cleanfield is one of the more developed manufacturers, and the noise levels from their V3.5 turbine has been tested independently to be 50dbA in a 29mph wind at 8.9ft away from the rotor. This is equivalent to the noise level in an average home.

Impact on Birds

Several studies have concluded that significant bird fatalities caused by wind turbines are limited to large-scale wind farms located along bird migratory routes. A few well-publicized problems at these limited locations have created a public misperception about wind turbines and birds. Even when these cases are counted, there are many other more significant causes of human-caused bird fatalities. The most significant cause of bird deaths is tall buildings and windows. The chart at the left illustrates the relative magnitude of bird death causes. All wind turbines account for less than 0.01% of the total.

The National Audubon Society – California has publicly testified regarding the impacts of wind turbines on birds. The letter on the following page expresses Audubon's position on wind power.

The letter states that due to the differences in dimensions and operations between large-scale wind turbines used in wind farms and small-scale wind turbines, there is no significant threat to bird populations from small-scale wind turbines. The National Audubon Society supports the implementation of small-scale wind turbines.

Audubon CALIFORNIA

555 Audubon Place
Sacramento, CA 95825
Tel: 916-481-5332
Fax: 916-481-6228
www.audubon-ca.org

July 17, 2001

Assemblyman John Longville
Room 3123, State Capitol
Sacramento, CA 95814

Re: AB 1207: Support

Dear Assemblyman Longville:

The National Audubon Society–California is pleased to support your AB 1207 which requires cities and counties to consider the siting and operation of a small wind energy system as a "use by right" if it meets the specified requirements. We have been asked by your bill sponsors to comment on the potential significant effect of AB 1207 and small wind energy on bird populations in California.

Audubon's main objective is the protection of birds and other wildlife and their habitat. We are also interested in supporting legislation that helps California deal with its current energy crisis, and that supports renewable forms of energy.

Audubon has a long history of working with the wind power industry in an effort to study and minimize the impacts of wind power development on birds and wildlife habitat. It is true that there is a correlation between bird deaths and large wind turbine farms. For example, in a recent eleven month research on Altamont, they found that 95 birds died from the wind turbines.

Unlike large-scale wind turbine operations with hundreds or thousands of turbines, AB 1207 encourages the use of small-scale wind turbines that produce approximately 50 kilowatts versus 1 megawatt of energy produced by large-scale wind turbines.

Unlike large-scale wind turbines (100 meters tall), small-scale wind turbines (30 meters tall) are a lot shorter and will not be used in the construction of large wind farms in California. The problems associated with large-scale turbines are that they are often times in the height range of migrating birds. The turbine blades also move at very high speeds, which is hard to detect by birds moving along a traditional migratory route.

We cannot assure you that there will be no bird deaths from small-scale wind turbines, but the numbers will reflect a death toll similar to the deaths caused by other stationary objects that birds routinely fly into, not the large death tolls seen with large wind turbine farms.

We do not feel that there is any significant threat to bird populations from small-scale wind turbines, and are pleased to support your AB 1207.

Sincerely,

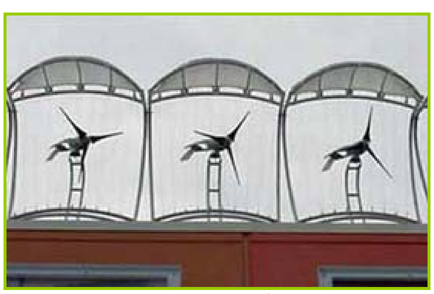
John McCaull
Legislative Director

recycled paper

Heos H-Series
Rated Output Power: 5kW

AeroVironment roof parapet turbine

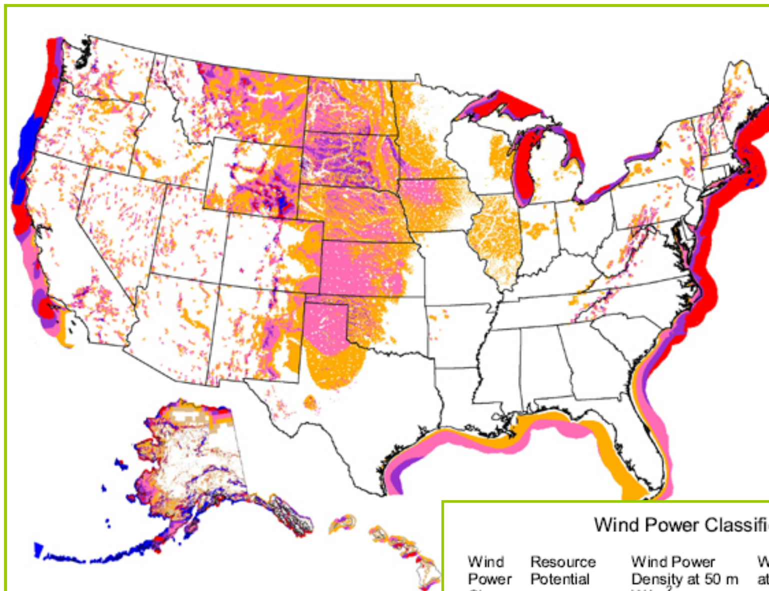
AeroVironment roof parapet turbine



AeroVironment roof parapet turbine

WIND ENERGY POTENTIAL

The energy that can be captured by wind turbines is highly dependent on the local wind speeds. Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain and some mountainous areas.



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

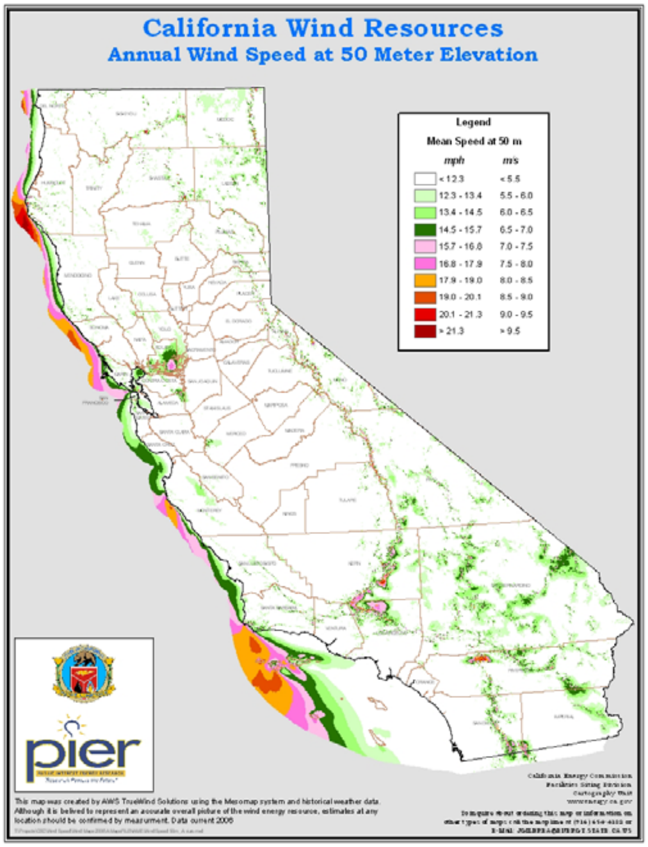
U.S. wind resources.
Source: www.eere.energy.gov

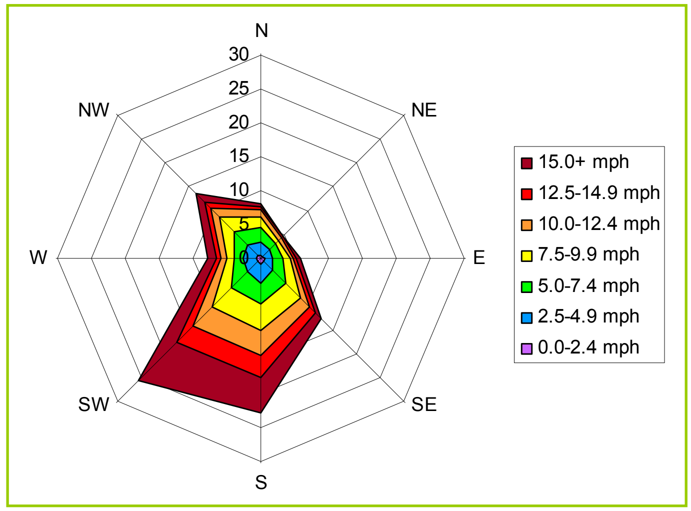
The State of California maintains maps of California indicating average wind speeds and wind power potential. Additional sources of data, including the National Renewable Energy Laboratory (NREL) and AWS Truewind, are also available.

The maps generally show that average wind speeds in the Los Angeles area are lower than typically recommended for wind power generation. If a wind turbine system is to be successfully implemented in the Los Angeles area, it must take advantage of the building architecture to funnel and accelerate the wind through the turbines to compensate for the low prevailing wind speeds.

When evaluating wind speed data, determine the height of the wind measurement and correct the data for the elevation of the proposed turbine. Wind speeds are slower near the ground and increase with greater elevation. Also, obstructions like adjacent buildings or trees will slow the wind and create turbulence.

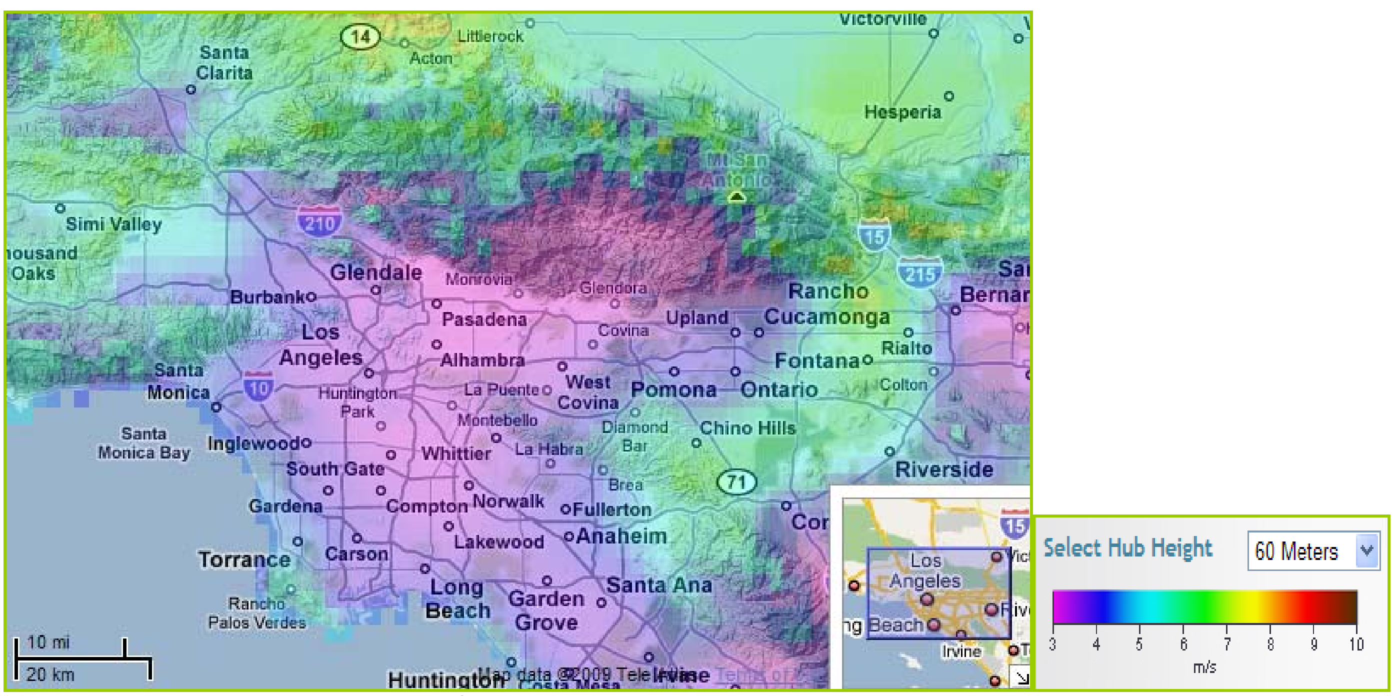
If a wind turbine system is to be pursued, on-site wind measurements should be made for an extended period to determine actual wind speeds and directions, including any local wind effects due to obstructions.



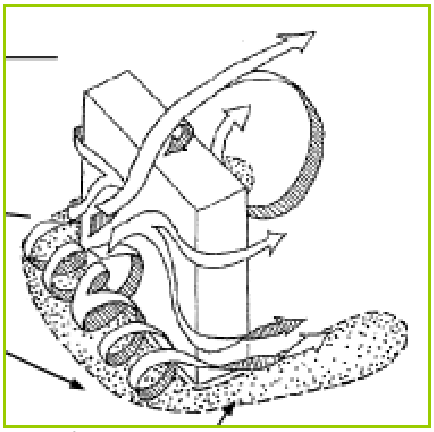


Example of a wind rose indicating frequency of wind directions and speeds.

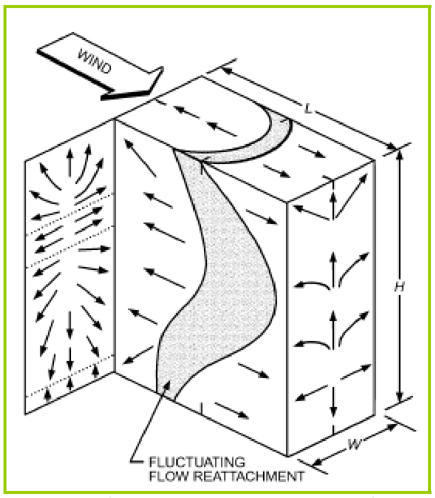
Average wind speeds potential in California. Source: www.energy.ca.gov/maps/wind.html



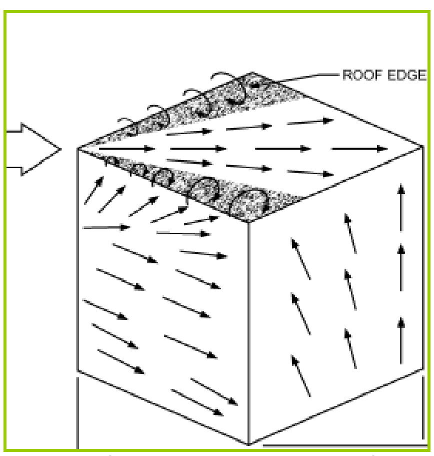
Average wind speeds in the Los Angeles area. Source: navigator.awstruewind.com



Airflow pattern around high-rise building
with wind direction perpendicular to façade



Airflow direction at building surfaces
with wind direction perpendicular to façade



Airflow direction at building surfaces
with wind direction 45 degrees to façade

BUILDING INTEGRATED WIND TURBINES

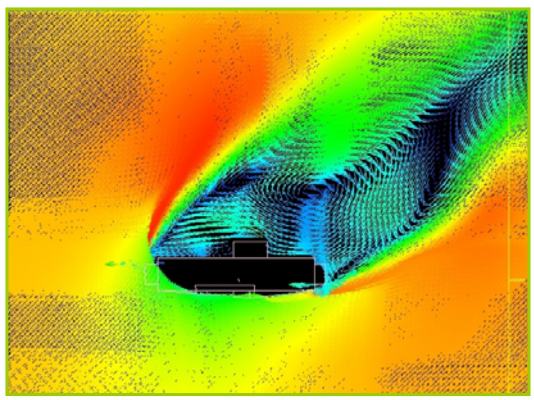
Wind turbines that are mounted on the roof or otherwise integrated into the architecture of a building present unique challenges and opportunities. Simply placing a turbine on the top of a flat-roofed building is likely to result in less energy production than a similar turbine on a tower of the same height. Wind turbulence and eddy currents on the roof can significantly reduce energy output. Horizontal-axis turbines are particularly susceptible to varying wind directions and low wind speeds.

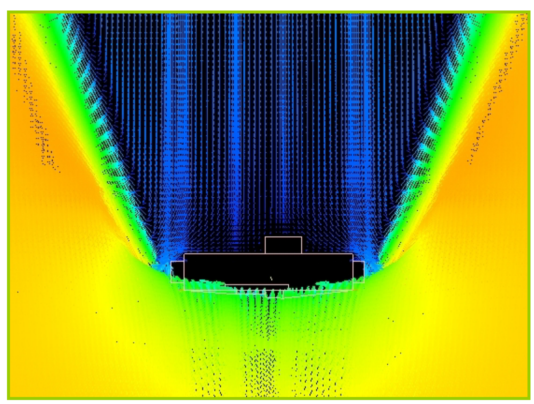
In urban or suburban locations, the effects of adjacent buildings result in unpredictable wind patterns, which make the implementation of wind turbines extremely difficult.

Despite these challenges, building integrated wind turbines provide opportunities that are not available for stand-alone turbines. The building architecture can be shaped to capture and funnel wind through the turbines, which can produce wind speeds through the turbines that are 1.5 or 2 times larger than the prevailing wind speed.

Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a powerful analysis tool that should be used to study the wind patterns around buildings and nearby obstructions. CFD modeling can be used to determine the optimum location for turbines and to calculate wind speeds at the turbines under various wind conditions.





CFD results for wind flow around a building with various wind conditions.
The color of the velocity vectors indicates speed. Red is fast, blue is slow.

Turby
Rated Power Output: 2.5kW

Windterra ECO-1200 turbine
Rated Power Output: 1000 W

Additional Resources

Government / Industry websites

- www.awea.org
- www.consumerenergycenter.org
- www.dsireusa.org
- www.energy.ca.gov/maps/wind.html
- www.cpuc.ca.gov
- www.eere.energy.gov
- www.nrel.gov/wind

Manufacturer websites

- www.abundantre.com
- www.avinc.com/wind.asp
- www.aerotecture.com
- www.cleanfieldenergy.com
- www.heos-energy.de
- www.mariahpower.com
- www.quietrevolution.co.uk
- www.windenergy.com
- www.windterra.com