WIND TURBINES IN THE URBAN ENVIRONMENT

3/10/2012

INTRODUCTION

In the European Community there exists a movement financially supported by the European Union (EU) for integrating wind turbines into existing structures and buildings including gas stations and apartment buildings.

They are being incorporated in architectural designs such as the World Trade Centre in Bahrain with tree wind turbines attached to bridges connecting two buildings.

In a rural environment, large wind turbines are usually located at least 500 meters from human dwellings. That is not the case in the urban environment if positioned on small structures; where they present the hazard of rotating machinery, vibrational dynamic loading, noise generation, and the possibility of collapse. In addition, they are subjected to turbulence, necessitating frequent repairs and to non-optimal wind conditions due to the presence of structures and trees.

In the USA, there was a proposal to integrate wind turbines into the Freedom Tower replacing the World Trade Center buildings. It was to have a 20 MW small turbine wind farm incorporated into the top 500 feet of its structure. New York mayor Michael R. Bloomberg proposed placing them atop the city's skyscrapers and bridges and offshore the coastline of Queens and Brooklyn. Wind turbines were used at some sites in New York City such as Battery Park City, 34th Street at the East River, at the Brooklyn Navy Yard site and at a commercial building in the Melrose section of the Bronx. The city of Boston installed wind turbines at City Hall, at four schools, at Logan International airport and the electrical workers union.

Universities in the USA have been emplacing them on top of their Engineering laboratories dampening their vibrations with spring loaded pads.

WIND TURBINES IN URBAN AREAS

Wind follows the path of least resistance by going around obstacles such as hills, mountain passes and buildings. Along the edges of these obstacles the wind speed and the density increase. If a wind turbine is capable to use this increase in speed and density its energy production can be up to two times higher than when standing in an undisturbed flow.

However, placed on the lee side of a large obstacle, the output will be reduced to half of the yield normally expected. Since wind turbines designed for urban areas are small, averaging does not diminish the phenomena that determine the power yield.

WIND STREAM ABOVE STRUCTURES

Computer simulations were undertaken to study the effect of an obstacle on the wind flow around it. **T**he first observation is that the deviations in the wind stream steadiness start long before the wind reaches the obstacle and continue far beyond it.

The wind stream passes at an upward angle of 30-40 degrees from the leading edge over the roof of the building. Underneath that line there is only turbulence and no wind.

Consequently the turbine must be placed on a mast of sufficient height to bring it above the turbulence.

Interestingly, a potential advantage arises since the wind speed directly above the turbulence layer is 20-40 percent higher than that prior to encountering the building.

This 20-40 percent higher wind speed raised to the third power according to Betz's law yields:

$$(1.20^3 - 1.40^3) = (2.197 - 2.744)$$

This provides a (2.2 - 2.7) times higher available power than the undisturbed horizontal wind flow. This is potentially very interesting, provided that the wind turbine can utilize the wind approaching from such an angle.

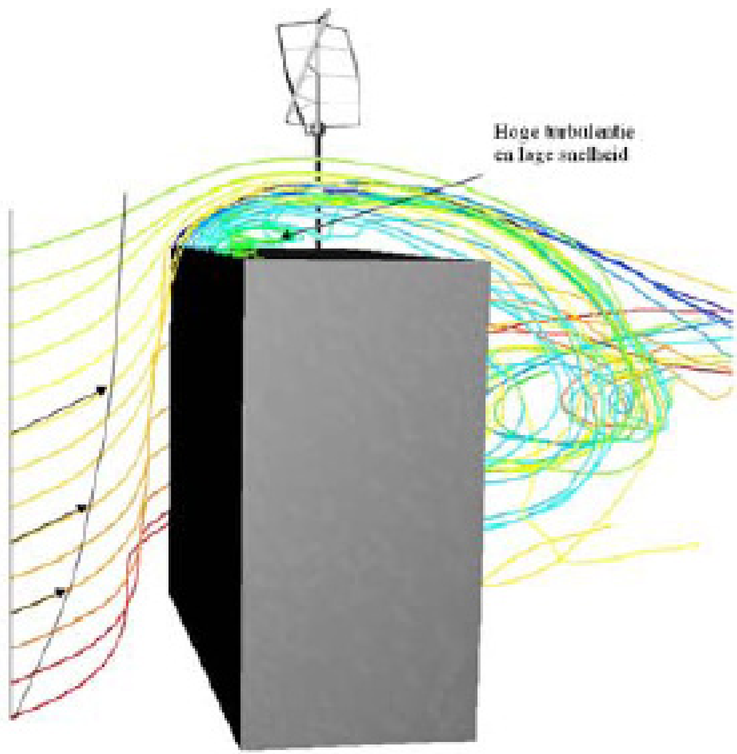

Figure 1. Wind turbulence attached to a tower above a building, above the turbulence zone.

OPTIMAL POSITIONING ATOP STRUCTURES

A wind turbine atop a roof should be placed above the turbulence layer. The closer a turbine is placed to the leading roof's edge for the prevailing wind, the lower the turbine can be emplaced. A lower height mast is advantageous from the perspective of costs and height restrictions.

This is true if the duration of the wind blowing from other directions than the prevailing one is negligible. However in Western Europe the percentage of time that the wind blows from the prevailing direction as compared with a uniform distribution is not that prominent.

Wind tunnel tests at the Delft University of Technology exploring the reaction of a wind turbine to winds approaching from an angle from below, just as it occurs over a building, were undertaken.

The results revealed that horizontal axis wind turbines reach their optimal output when the wind comes in perpendicularly to the rotor with the turbine emplaced closer to the edge facing the predominant wind direction. Vertical helical rotor wind turbines performed during these tests as if the wind came in perpendicularly at its full speed and showed an aerodynamic efficiency of about 40 percent.

Two explanations for this performance can be advanced:

1. Due to the helical shaped blades, an upward slanting wind passes the airfoil perpendicularly in a nearly ideal way.
2. As a consequence of the three dimensional nature of the rotor, such a wind hits the blades on the leeside at full speed delivering extra driving power.

The tests indicated that the energy yield may well be up to two or more times higher than expected from the swept area of the rotor. Horizontal axis wind turbines would be unsuitable since they cannot take advantage of an upwardly slanted incoming wind and suffer from the stronger forces on their rotors from such a wind.

DYNAMIC VIBRATIONAL LOADING

Wind turbines generate vibrations that are transmitted to the structure on which they are mounted.

Roof tops create turbulence that interferes with normal wind turbine operation. Even if sophisticated vibration dampening systems are added to the turbine to isolate it from the structure, these will not be able to affect the turbulence that reduces the power production as well as cause damage to the turbine. To avoid the rooftop turbulence, the wind turbines would have to be mounted on towers high above the roof. This negates any savings on the tower's costs, adding to the installation complexity, and reducing its safety.

Blade shedding, missile generation and turbine collapse are other hazards. An owner in upstate New York was reported to have found that his roof mounted runaway turbine fell apart on some dark stormy night and plunged down at the residence area through the fragile roof structure.

Reinforced concrete roofs may be able to absorb part of the loads created by the wind turbine and its tower. But this is not the case for the wooden or metallic roofs of most structures in the USA and Canada. An unoccupied structure may bear the dynamic loads and vibrations but an occupied structure such as an office building would be a at a disatvantage.

Figure 2. Tied down rotor on an inoperational Allgauer derivative wind turbine on top of a building at Holzhausen, Rheinland-Pfalz, 2005.

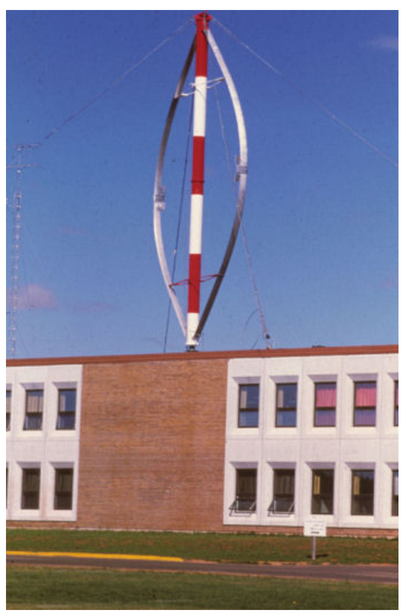

Figure 3. An Indal Darrieus vertical axis turbine built on a school roof in eastern Canada around 1980. The turbine was reported to be removed because of the damage it caused to the building. Source: NR Canada.

Figure 4. Wind turbine 40-ft tower collapse while being mounted at the playing field of the Fakenham High School, Norfolk, UK, 2009.

VIBRATIONS AND RESONANCE

Vibration and resonance remain an important consideration even if a wind turbine is dynamically balanced to a balance specification of G 6.3 or ISO 1940/I, and therefore to a large extent vibration free. Wind turbines are inherently dynamic systems that may introduce vibrations into the building that they are attached to.

This happens when the resonance frequency of the combination of mast and roof falls within the operating frequency range of the turbines such as 1-10 Hz.

In order to prevent adverse effects due to these dynamic phenomena, the mast type turbines are designed to have a resonance frequency just below 1 Hz.

The amplitude of a potential vibration of the support structure and building is in practice determined by the mass of the system.

A concrete roof does not pose problems since its resonance frequency is low and its mass high. A resonance, when occurring, will not be noticeable. This may be different with a roof using a steel skeleton or wood construction. It is complicated to calculate the occurring resonance frequencies for these roofs; measuring it is far simpler and cheaper.

Calculations show that at structure heights from 20 meters upwards, a good energy yield can be expected. Below that height the yield is uncertain. A three stories family house has a height of about 10 meters. Since a wind turbine must be situated above the turbulence layer, a mast of at least 5 meters in height is needed. The top of a wind turbine will be at least 8 meters above the roof, which, from an aesthetical point of view, is unacceptable for a family house.

In addition, the roof construction of family homes is in general too light to withstand the forces that extreme winds can exercise and the roof construction may not be suitable due to vibrations.

TESTING SITES

Small turbines testing should be done on university campuses or research laboratories in open areas without pedestrian traffic away from the main buildings.

There are numerous cases of small turbines shedding their blades. Missile generation from flying rotors or chunks of accumulated ice would be a hazard from unattended running turbines. There have been an account of a shed blade from a failed turbine that was built too close to a building that penetrated through the door and could have impaled the owner if he happened to be present at this location at the wrong time.

Upon completion of a test program, the turbines should be lowered to the roof as a safety precaution. On top of buildings there is enough turbulence anyway to invalidate the testing results for normal operation unless research is being done specifically on the effects of such turbulence.

If sited on top of buildings, only small machines can be used at less than 2.5 meters in diameter. The location and tower height must allow the turbine to fall off the building into a vacant or delimited empty lot in case of its structural collapse.

Figure 5. Inoperational small Bergey 1500 wind turbine on top of university building at Melbourne Australia, 2000. Photograph: Paul Gipe.

Figure 6. Roof wind turbines removed for repair.

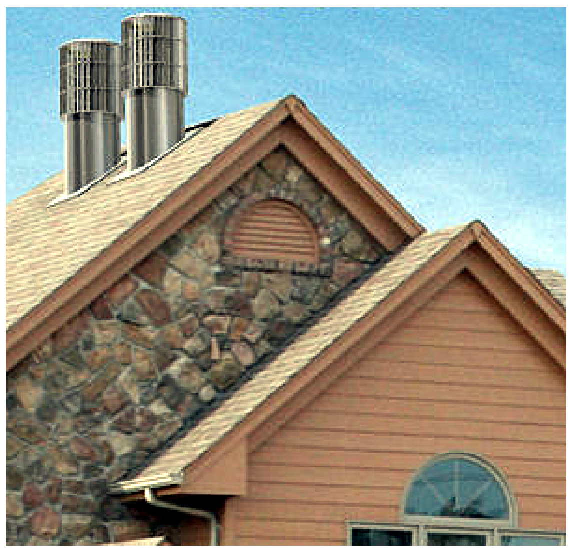

Figure 7. Roof-mounted vertical axis wind turbines.

WORLD TRADE CENTRE, BAHRAIN

An architectural trend exists in the design and construction of green buildings such as the 240 meters high twin tower World Trade Centre offices at the Bahrain Commercial Complex.

The new Bahrain World Trade Centre (BWTC) incorporates the first towers in the world to generate part of their own electricity using wind turbines. It harnesses wind power to produce about 35 percent of its requirements. Three wind turbines, each supported by a 30 meter bridge spanning between the two towers, were installed at a cost of one million Bahraini Dinars (BD).

The three massive turbines, measuring 29 meters in diameter, are supported by bridges spanning between the complex's two towers. Through its positioning and the unique aerodynamic design of the towers, the prevailing on-shore Gulf breeze is funneled into the path of the turbines, helping to create power generation efficiency.

The “wing” nozzle profile of the towers would channel the airflow through the turbines. Square buildings disrupt the smooth flow of air and create turbulence, which lowers wind turbines efficiency and can cause their premature failure. Thus structures that incorporate turbines need curved surfaces or ducts to keep the wind flowing smoothly towards the rotor. A wind turbine integrated into the space between the two towers can be 25 percent more efficient than a free standing device. The footprint of each tower forms an airfoil shape that accelerates air flow over the turbine and stops turbulence. By concentrating the wind, buildings can enhance the efficiency of wind turbines.

The BWTC became the first building of its kind in the world to integrate turbines with a commercial tower structure. Its unique architecture has been inspired by ancient traditional Arabian and Persian wind towers.

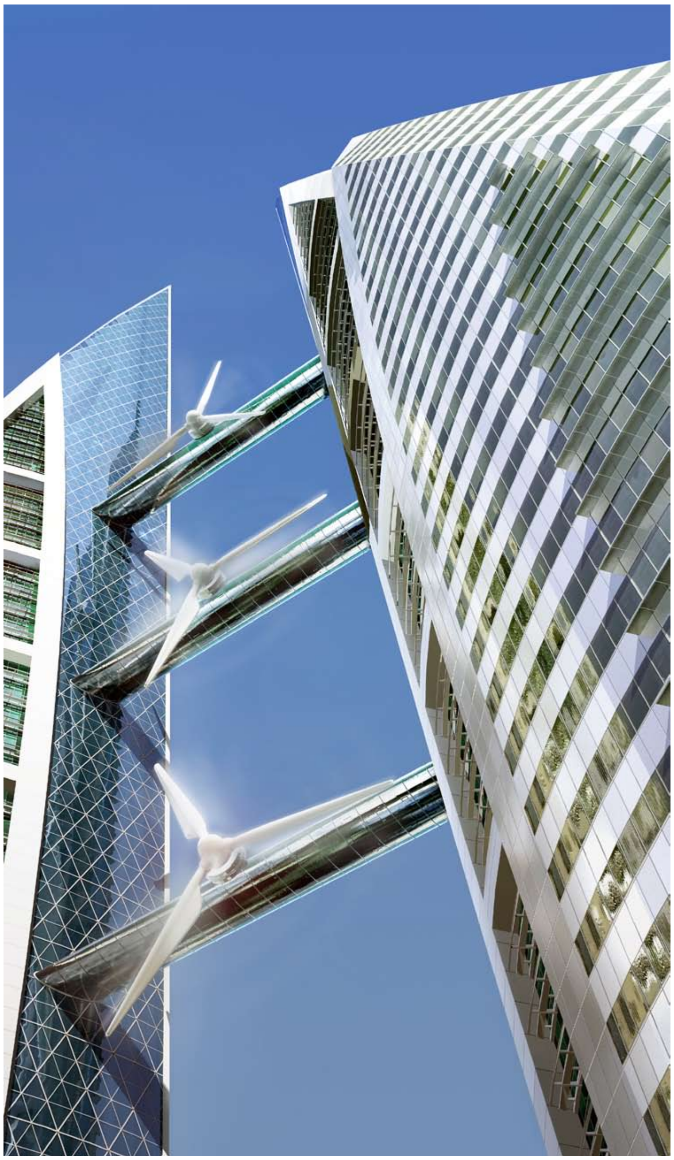

Figure 8. Three wind turbines at The World Trade Centre towers in Bahrain.

Figure 9. Wind turbine attached to a bridge at the Bahrain World Trade Center.

FREEDOM TOWER WIND TURBINES

The proposed Freedom Tower to be completed by 2015 will be one of the world's tallest buildings at the patriotic symbolic height of 1,776 feet or 545 meters, in reference to the year of American independence. Its capping spire is supposed to mirror the Statue of Liberty's upraised arm. That is still shorter than the 1,815 foot feet CN Tower, not strictly a building. In any case, taller buildings are already being planned; no building stays as the tallest building for too long.

In a cabled truss section starting above the 60th floor, wind turbines are proposed to power 20 percent of the building's energy needs with wind coming off the Hudson River.

Normally cities are not practical for wind turbines, since other high buildings create turbulence. But for such a tall building this becomes irrelevant. The turbines would produce electricity 40 percent of the time. That should cover the base power demand of the building, which reduces the amount of electricity received from the electrical grid. Battle McCarthy, the firm that helped to develop the tower's wind farm, suggested that enough energy to power a thousand homes would be available. The structure surrounding the turbines is designed to focus the wind and increase its speed by 30 percent.

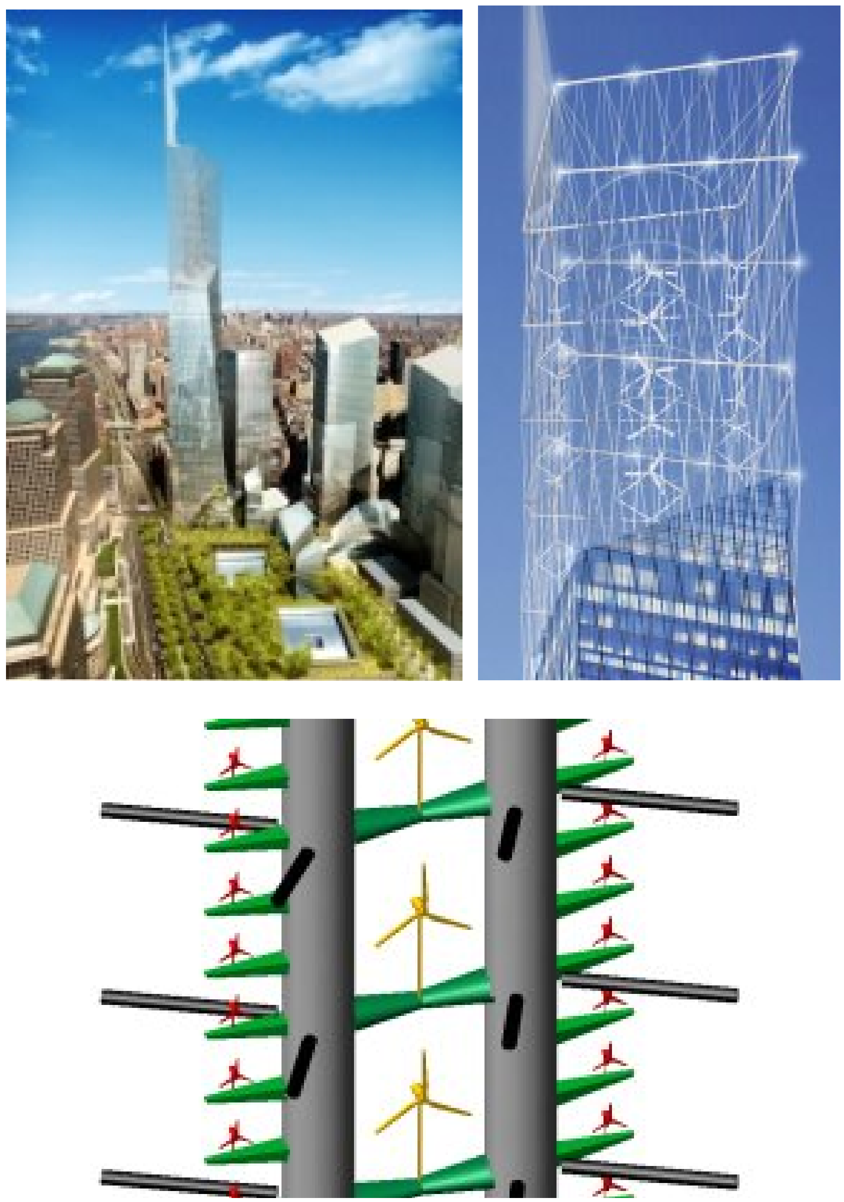

Figure 10. Proposed wind farm design atop the Freedom Tower, New York.

The Freedom Tower architects, Skidmore, Owings and Merrill, claimed that the open lattice work structure of the tower's upper section will allow air to flow unimpeded over the wind turbines. They also claimed that the building's shape twists to face the prevailing winds, although few details are given.

Eight vertical wind turbines were integral to the original design of the Freedom Tower, by Skidmore, Owings and Merrill. They would have been situated within an open air cable framed structure at the tower’s upper reaches, though they were never envisioned as a major power source. Governor George E. Pataki expressed concern about the danger the blades would pose to migrating birds, and others worried about them icing up and then shedding the ice as missiles. The New York Police Department raised objections to the tower's overall security provisions, compelling a redesign that abandoned the wind farm notion.

Critics note that large turbines in cities pose several problems, not least the danger to people and property in case of a blade ejection. Blades can weigh hundreds of kilograms, and tip speeds can exceed 100 km/hr, so an escaping blade fragment could do considerable damage.

Urban wind proponents say that such fears are unfounded. Modern turbines have safety features including speed control and blades that can be pitched edge on into the wind during storms stalling them.

Perhaps the biggest challenge for building mounted turbines is noise. Any slight imbalance in the blades is amplified by centrifugal forces, causing the turbine to vibrate when rotating. No rotating machinery is perfectly balanced and any imbalance shows up once per revolution, and there is nothing that can be done about it. The noise produced can vary from a regular thump to a low rumble. Should the turbine speed match the harmonic resonance frequency of the surrounding structure, such as a supporting beam, then the building itself can also vibrate, amplifying the sound.

If the turbine is part of the original design, as in the Freedom Tower, it should be possible to dampen vibrations by constructing heavy support structures. But that could be costly.

A solution to the vibrations problem is the choice of vertical axis wind turbines. Unlike traditional windmills with their propeller blades, vertical turbines have helical blades that are attached at both ends to a vertical shaft. They spin whatever the wind direction is.

Vertical turbines produce less vibration at a given rotation speed because the blades do not stick out so far and so exert less pull. To reduce the vibrations still further, the installation of 30 small, 100 kW turbines in the Freedom Tower, has been suggested rather than fewer large ones. Vertical turbines would automatically change speed if they approach the resonance frequencies of any components.

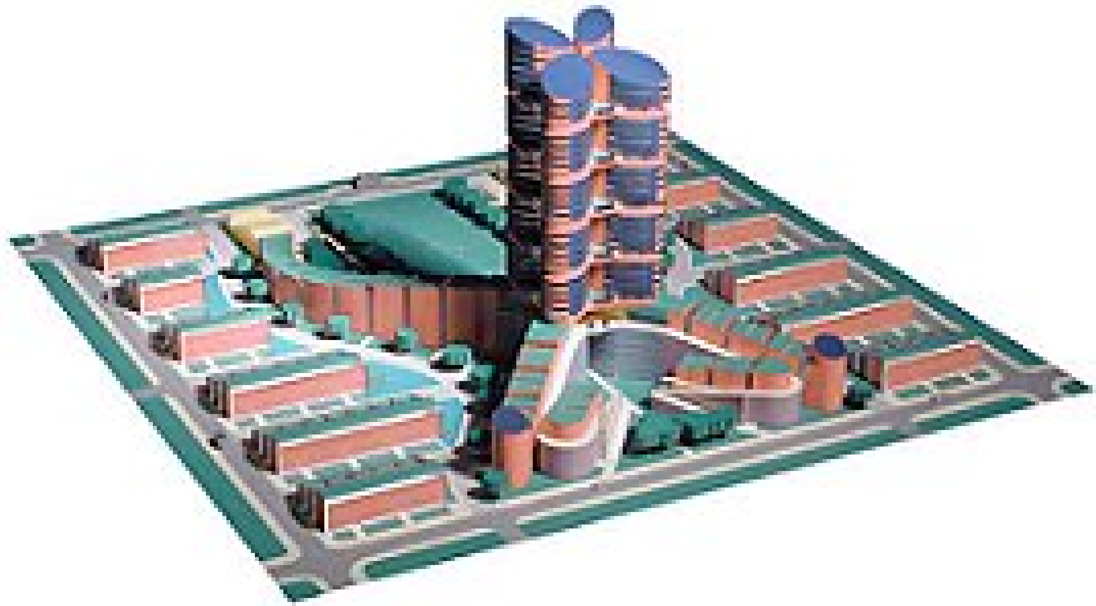

Figure 11. Flower Tower high rise building design uses vertical axis wind turbines.

Despite these advantages, vertical turbines have not been commercially successful. The few firms pursuing them in the 1970s and 1980s ran into financial problems, are reported by Robert Thresher, director of the National Wind Technology Center in Golden, Colorado.

Most low rise city buildings do not have room for 30 turbines, whatever their size, and suffer from weak and unreliable winds.

A design adding openings just below the roofline to channel air up through ducts, across turbine blades and out onto the roof is another possibility. Ducts offer several advantages. By channelling the wind, they reduce air turbulence before the air meets the rotor. They also allow the turbines to be hidden away, and prevent broken blades from escaping and causing damage.

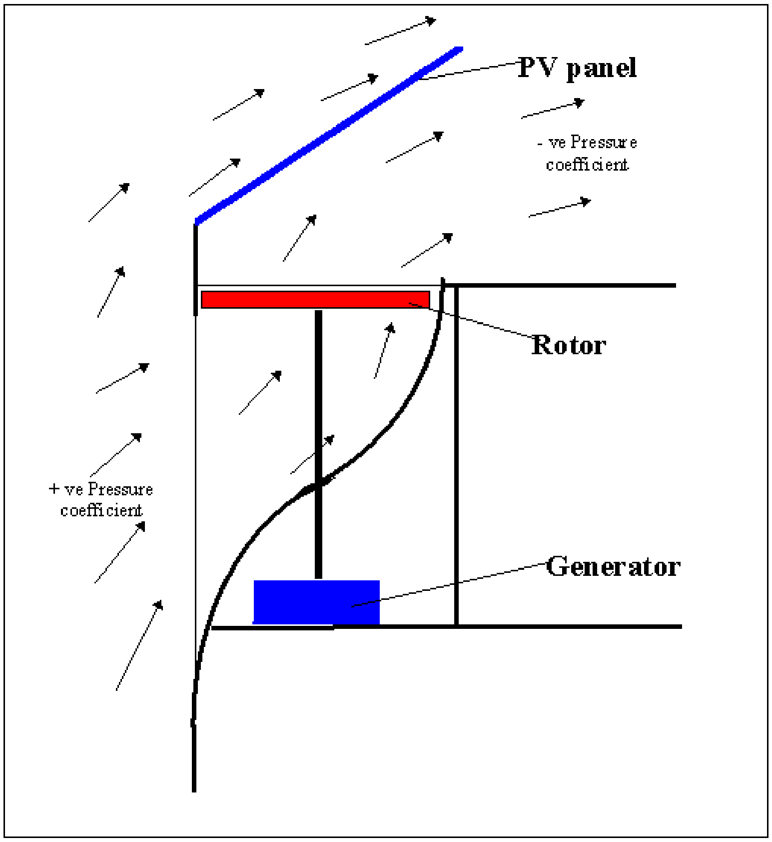

Figure 12. Conceptual ducted design vertical wind turbines for incorporation in urban structures in combination with solar Photo Voltaic (PV) panels.

Although no projects as ambitious as the Freedom Tower have yet been built, the number of small windmills is on the rise. In the Netherlands, dozens of them spin on rooftops at La Hague and Amsterdam. The Scottish government is funding a trial of small turbines on the roofs of primary schools in Fife.

URBINES: WIND TURBINES IN THE URBAN ENVIRONMENT

World Architectures News uses the neologism: Urbines for wind turbines built in the urban environment.

Architects have been integrating wind turbines into the design of tall buildings in such a way that the contours of the building envelope focus wind on to the turbine blades, much like the casing around a gas or water turbine.

This was applied at Castle house, a 43 stories, 408 units, apartment building at Elephant and Castle in Southwark, London. Three 9 m wind turbines integrated into the top of the building to generate sufficient power to drive the energy efficient lighting to the building, an integral part of the sustainable credentials for the building as a whole.

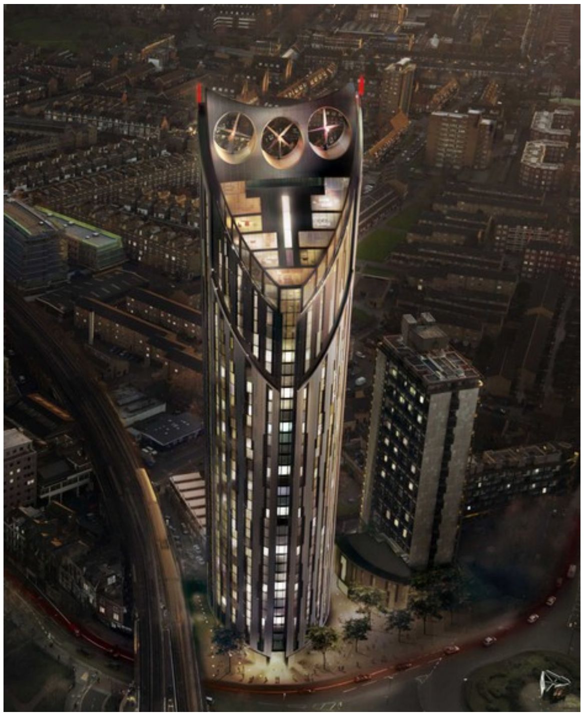

Figure 13. Apartment building at Elephant and Castle in Southwark, London, with three wind turbines integrated into the top of the building.

MICRO TURBINES ROOF BATTERIES

Researchers at Hong Kong University and Lucien Gambarota of Motorwave Ltd. suggested Motorwind, a battery of micro wind turbines connected along a horizontal axis. Motorwave’s micro wind turbines are light, compact of 25 cm rotor diameter, and can generate power with wind speeds as low as 2 meters/second.

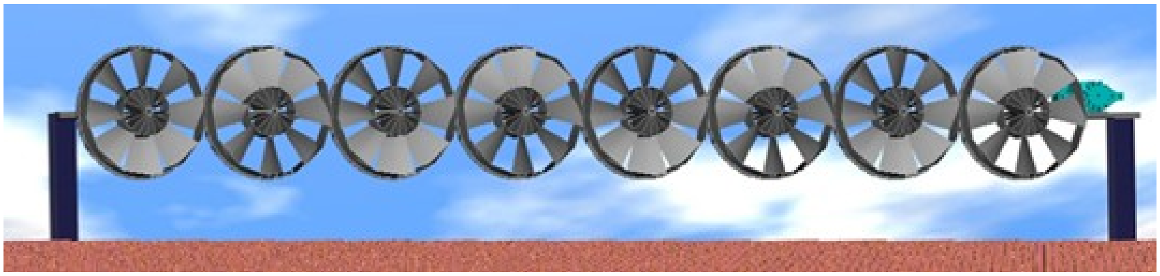

Figure 14. Battery of eight microturbines to be placed on a building roof.

According to tests, turbines arranged within a surface area of one square meter and a wind speed of 5 m/sec generate 131 kWh/yr. Plans are for the Hong Kong Sea School to install 360 micro turbines encompassing an area of 20 m^2.

AEROTECTURE ROOF TURBINES

Aerorotecture combines air turbines and solar photovoltaics to architectural design into wind turbines designed for urban settings. It is suggested that their helical turbines can be installed on existing rooftops or built into the architecture of new buildings to provide clean renewable electricity at its site of consumption.

Their Aeroturbines designs, developed at the University of Chicago, are advocated to be noise and vibration-free, safe for birds, able to utilize multi-directional and gusting winds, self-regulating with no overspeed protection required, low maintenance, and made from low-cost and readily available materials

Figure 15. Vertical 510V turbine with ballast.

The 510V Aeroturbine consists of a helical rotor and airfoils housed within a 6 ft. x 10 ft. steel cage and weighs approximately 450 lbs. with the alternator attached. It is intended for vertical mounting and can be either bolted or ballasted down. The standard overall height is 20 ft. tall. The base and caged rotor structures are both 10 ft. tall.

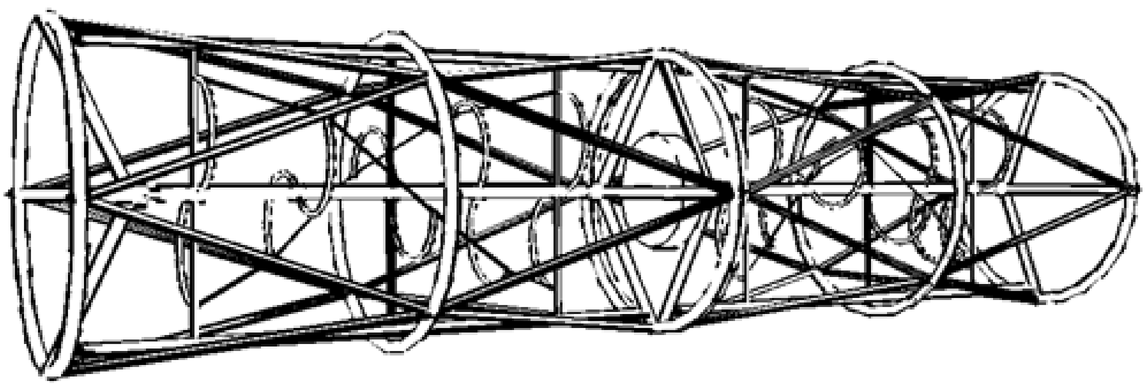

Figure 16. The horizontal helical 520H turbine.

The 520H Aeroturbine is composed of two 510V turbines joined horizontally by a shared alternator. The approximate weight is 750 lbs. which includes the alternator. It can be bolted or ballasted down horizontally and is stackable end-to-end. While the 510V works well in multi-directional winds, the 520H requires a dominant wind direction; for maximum efficiency, the rotational axis of the 520H must be oriented perpendicular to a location's dominant wind direction. The building must have a special shaped roof, a pitched roof is best for the wind to rise above and flow into the turbines, like a wind ramp. Flat roofs will not be suitable, because the wind will blow over the turbines instead of into them. It is 9 ft. tall and approximately 21 ft. long end to end. For efficient operation, they must be building attached and above or away from surrounding trees and other obstructions, and in an area with average wind speeds of at least 15 mph.

Figure 17. Hybrid wind and photovoltaic solar installation of vertical helical 610V2 turbines.

The 610V2 Hybrid Aeroturbine consists of twin helical rotors and airfoils housed within two 6 ft. x 10 ft. steel cages combined with a shelf of 12 photovoltaic solar panels. It weighs approximately 1400 lbs. including the alternators, without ballast. It is 20 ft. tall and the solar shelf spans 31 ft. The typical power rating for each of the 12 solar panels is 175 Watts for a total of 2,100 Watts. The 610V2 Hybrid is intended for vertical mounting and can be either bolted or ballasted down.

Figure 18. Ribbed helical rotors construction, transmission base and alternator detail of helical vertical turbine.

DISCUSSION

A small Jacobs wind charger was installed in the 1970s on a building in the Bronx as a challenge to the Consolidated Edison Company in New York City. It operated for a while, proved the point but had to be later removed.

The Arizona manufacturer of the small Air series turbines Southwest Windpower advocates installing them on building roofs as a competition to roof top solar collectors.

The topic remains a controversial one. There is no sufficient existing operational testing and experience on how these turbines perform under load or runaway conditions in extremely stormy or turbulent weather. Locating wind turbines away from the turbulence caused by buildings and trees is always worth the extra effort and cost.

According to Paul Gipe: “Mounting wind turbines, of any kind, on a building is a very bad idea. I have yet to see an application where this has worked or will likely work. In short, rooftop turbines will not do what their promoters claim and often will cause their owners no end of grief.”

Whereas some vertical wind turbine designs can be emplaced on structures on towers above the turbulence zone, the emplacement of both horizontal and vertical turbines atop residential and commercial wood and steel structures remains a topic for future research and testing.