3rd International Urban Design Conference

The Future of Wind Energy in The City

Damon Moloney

Umow Lai, Melbourne, Australia

damon.moloney@umowlai.com.au

ABSTRACT

A common depiction of the cities of the future is of modernistic buildings clad in solar collectors, adorned with foliage and topped with roof mounted wind turbines. Wind energy is certainly one of the fastest growing renewable sources currently being deployed, but what is the feasibility and the likely future of incorporating wind energy systems directly into our cities with building integrated wind turbines and can these help meet the energy demands of our future cities? This paper presents the author's recent endeavours to integrate wind turbines into both existing and new commercial buildings. Details are presented of the process and viability of incorporating wind energy in buildings and the engineering and commercial challenges faced in this renewables sector.

Keywords: wind turbines, windtunnel, renewable energy, building mounted.

Introduction

If we are to meet our collective commitment to lower the carbon dioxide emissions in Australia, the energy sources supplying our cities must increasingly come from renewable sources. While large scale wind, solar, tidal and geothermal power plants will no doubt play a role, a strong case exists for distributed generation and the use of localised supply sources to reduce transmission loses and increase the diversity of the grid supply. In the case of city buildings which account for a large fraction of our overall carbon footprint, many operators could gain a competitive advantage in the low carbon economy by harvesting their own power from renewable sources thereby improving their energy ratings and mitigating the effect of rising grid power prices.

One possibility for city buildings is to harvest energy from the wind, exploiting the high elevation of skyscrapers and the various aerodynamic amplifications found amongst city buildings.

The integration of wind turbines on buildings can involve detailed architecturally sculpted building forms designed to enhance wind flow onto a set of turbines or more simply by the installation of roof mounted turbines on a new or existing building. This is a relatively new proposition for modern buildings despite the first use of wind mills for electricity generation as far back as 1887.

Most recently we have seen an increasing number of vertical axis wind turbines populating the market; these are designed to perform in turbulent urban environments as an alternative to the traditional horizontal axis turbines installed in most modern wind farms. This paper explores the feasibility of using building integrated wind turbines to generate power within a commercial building. The future of this resource could change the landscape of the city.

The reasons to consider wind

Many property managers and building owners in cities around Australia are actively looking for ways to reduce the carbon footprint of their buildings. The reasons stem from the need to future proof the facility from rising electricity prices and to increase the competitiveness of the building under the pressure of mandatory disclosure. Moreover many businesses are demonstrating a commitment to make cuts in their net operational emissions if not from a cost management perspective then from marketability alone. The cost of not adapting their facilities for the broad and varied impacts of climate change could be devastating to their business.

With the National Australian Built Environment Rating Scheme (NABERS) building owners and operators are presented with a market incentive to maintain high energy efficiency in the operation of their buildings as star ratings are demonstrated to translate into increased rent. Under mandatory disclosure building ratings will not just be advantageous to the four and five star rated facilities but will have a similar impact across all classes of commercial buildings. There is therefore an onus on individual building owners to take low carbon strategies into their own hands rather than wait for technology such as clean coal, nuclear or large scale renewable power plants to reduce the carbon associated with grid electricity. Various government grants are also available to assist building owners to improve their energy efficiency. So while the Australian Government have clearly stated that renewables will form a key part of Australia’s low carbon future, it seems likely that the uptake of renewables will occur across the largest and smallest consumers from businesses to homes. Given the impetus to utilise wind as a resource in the city, how do designers determine the extent of the resource and the opportunities to best exploit it?

Where is the wind resource in a city?

Wind is driven across the planet due to differential heating of the earth’s surface which creates differences in air density and pressure near the surface, the air then flows to equalise those pressure differences. As wind flows over the surface of the Earth and over various natural and built forms it is disturbed by those obstacles and made more turbulent. At greater elevations above the surface the wind is less disturbed by obstructions, this gives rise to a velocity profile of increasing wind speed with height. Where there is little disturbance such as over water, the wind can reach strong and steady velocities at relatively low height and provide a high energy yield for off-shore wind turbines for example. Likewise the temperature differences between land and sea can drive the wind onto turbines at coastal locations. Local wind flow accelerations where air streams are compressed such as over a ridge or through a valley or canyon where wind is funnelled can provide an effective wind resource. While all these natural locations have among the highest wind speeds the power undergoes transmission loses when it is exported back to the grid.

For individual buildings to utilise their own wind resource in a city environment the aerodynamics of the city and buildings must be accounted for. Inner city wind flows can vary considerably between quiet sheltered spaces to exposed roof tops as well as strong gusty winds around the corners of buildings. In some city streets such as St Georges Terrace in Perth the wind is funnelled along the street by the tall buildings on either side. In Melbourne the Docklands area is a renowned windy location due to it’s open exposure to the bay. Wind speeds at the top of the Rialto in Melbourne have been recorded at 253km/h. In many cities tall buildings can deflect fast moving wind from upper elevations down to ground level creating problematic gust impacts on pedestrians. Buildings which are most exposed to wind effects usually include those that protrude a few stories higher than their immediate neighbours and those positioned on the perimeter of the city upwind of the prevailing wind direction. The wind exposure of these buildings provides an opportunity to harvest wind energy using building mounted turbines. The author has undertaken measurements and analysis of city buildings in Melbourne which show that at 10m above some high roof tops the wind speeds can reach an annual average of 6.5m/s. Some partially shielded locations show records of over 5m/s which still exceeds the turbine manufacturer’s typical recommendation of 4.5m/s average wind speeds.

Aerodynamics of buildings

The author's experience in building aerodynamics stems from a multitude of wind tunnel tests on model buildings. These include smoke flow visualisation studies, pressure testing to determine cladding loads and velocity measurements around buildings to determine pedestrian wind impacts. When wind encounters a tall building the flow is disrupted and distorted. A consequence of the increased magnitude of wind speed with height is that some of the wind at higher elevations tends to be deflected downwards by the building. Typically a stagnation point forms at about two-thirds the height of the building above which the wind tends to flow upwards and over the roof and below this point the wind can tend to be deflected downwards causing gust impacts on pedestrians. Wind also flows around the building from the high pressure upwind side to the low pressure lee side. Often the wind is compressed and accelerates around the upwind corners of the building as well as over the roof. When flowing around square edges of a building the momentum of the wind tends to make it separate from the building surface giving rise to vortices and a separation zone of relatively low wind speed or reversed wind flow. Streamlined shapes such as curved roof profiles exhibit more steady and consistently faster wind flows and the streamlining of building forms can be used to enhance wind flow onto carefully positioned wind turbines. The wind flow around buildings in a city environment is often more unsteady and gusty, this condition has necessitated the evolution of vertical axis wind turbines which can more easily cope with gusty conditions. The challenge for building integrated wind turbines is to position the turbines around a building where they will experience the fastest and most consistent winds and the highest energy yield.

Evaluation of the wind resource

A couple of tools exist to help define the extent of the wind resource in a city environment. For an existing building it is possible to undertake wind monitoring with an anemometer. The important aspect of on site monitoring is to position the anemometer correctly so that it provides a representative measurement of the wind resource on the roof top. Anemometers provide a single measurement location in space so it is important to move the anemometer around to different locations where time permits. The anemometer data should be compared and normalised against the local bureau of meteorology data. Measurements of on-site wind speeds can form a valuable addition to verify computational modelling or wind tunnel test data. In the author's experience often the site anemometer shows only a small component of the overall wind flow condition on the roof a building and if inadvertently located in a flow separation zone it can potentially miss areas of higher wind speed around other regions of the roof. By mapping out the wind speed distribution for all prevailing wind directions and utilising meteorological records to determine the wind speeds approaching the city it is possible to identify the prime locations on a roof for the installation of wind turbines. The most important aspect of maximising power from wind turbines is to realise that the power output is proportional to the cube of the wind speed. Therefore small improvements in wind speed can produce big gains in power output but missing the best winds on a roof top can be devastating to the energy yield.

Designing urban wind turbine Installations

On a medium to large commercial building the use of wind turbines as a renewable energy generator can be a viable proposal so long as it can be shown to meet certain design criteria. These usually relate not only to the power production and payback but also to the aesthetics and the overall environmental impact.

Wind turbines receive a mixed response within the community; there are those who find them an elegant symbol of clean energy and those who despise them as an unsightly addition to the local landscape. It seems that for wind energy systems to coexist with the population within a city they must do so inconspicuously and/or as gracefully as possible. The challenge remains in the small wind industry to adopt designs which will result in the least amount of objection. Councils seem generally supportive of wind energy systems in most capitals as proposals and installations continue to gain support in Sydney, Hobart, Melbourne, Adelaide and Perth. In New York Mayor Bloomberg has envisioned wind turbines on New York buildings as a useful mechanism to reduce carbon.

It is important for any new building venture let alone one faced with a degree of scepticism to approach the issue with a scientifically grounded approach in design and selection of the technology. The following performance criteria are recommended.

Engineering performance criteria include assessment of the power output, start-up speed and braking performance. These may be demonstrated by a power curve obtained through testing to a standard such as IEC 61400 or by windtunnel tests of the product. Structural wind loads should be obtained by measurement and should include both static and dynamic (resonant) components. To date there is little of this information available on most urban turbines and some building owners may choose to undertake their own tests prior to considering the integration of wind on their buildings. The small wind industry needs significant work in this area.

Servicing and maintenance criteria should be demonstrated by the provision of local support for the product and by specifying maintenance activities based on recent installation experience. The proximity of local suppliers and installers to the site is an advantage when installing new or unfamiliar technology.

Environmental Impacts of the turbines should be shown to have no adverse impacts in terms of fauna, noise or electromagnetic interference. Aesthetics may also be factored into the assessment of the various turbines.

Available Technology

Within the performance criteria discussed above a search of the available technology for this application can be undertaken. Generally the manufacturers of vertical axis turbines claim their products are more suited to a turbulent environment and produce noise levels more conducive to a suburban or city location. Some manufacturers of horizontal axis turbines state that their products are not suitable for roof top applications. The small wind turbine industry is growing and developing worldwide and while one or two manufacturers have several years experience of supply and service, there are many who are relatively new to the industry with limited data to verify their products. The market supply of vertical axis turbines suitable for urban environments is the least developed within the wind turbine industry. Many of these products lack adequate test data and there is an ever present danger of encountering those seeking to exploit the renewables market for their own short term gain by offering less well engineered products or products with a superfluous point of difference. More than one supplier contacted by the author expressed confusion when asked to see a power curve for their product and simply focused on the fact that the turbine could be painted in various colours. The standardisation of product testing in this category is particularly lacking but is improving. In the future more customers will demand higher levels of certification as product familiarity increases.

Two recent turbine installations of note include the Bahrain World Trade Centre (in Bahrain) and the Strata building in London, both of which chose to use established and tested technology for their building integrated turbines. Both are of the horizontal axis variety and include building forms designed to enhance the wind flow onto the turbines. These are noted to be directionally limited and may produce unfavourable noise levels, it will be interesting to observe their performance in coming years. At Logan airport in Boston a set of parapet mounted turbines have been installed and are designed to pick up the wind acceleration effects over the roof of the building. Such products work suitably well for a strongly unidirectional wind climate. Some products are designed to attach to the corners of buildings to pick up the acceleration of wind around the building edges, designers must consider that these turbines will produce little energy when they're on the downstream side of the building although they can still be a worthwhile installation.

Future Engineering Challenges

In order for the wind resource in cities to be exploited there needs to be further engineering of the available wind turbine products. Most of the urban turbines that exist on the market are designed for low rise residential applications with power outputs of up to 6kW. Larger vertical axis machines exist up to 200kW but only a few are available with capacities suited to a large commercial building in the range 30-50kW. For these products to be able to tap into the wind resource atop tall city buildings they need to be engineered and tested for such use. Structural safety is of paramount concern when installing these devices above a population centre. Turbines must be demonstrated to be capable of withstanding the fastest wind speeds recorded in cities as well as being resilient to fatigue and designed to resist dynamic loads across the whole wind velocity spectrum. Start up speeds must be reduced further so that the turbines can provide power in lighter winds. Simple methods for maintenance must be engineered into any wind turbine solution especially at the top of a 40 storey building.

Business Case

The business case for building mounted wind turbines is a function of the upfront capital cost and the on-going maintenance cost offset against the future avoided cost of electricity and other derived income such as renewable energy certificates (RECs). In the coming years electricity prices and RECs prices will be indirectly influenced by the price of carbon but a direct cost of carbon in the future should also be allowed for. The decoupling of domestic solar hot water RECs from commercial renewables in January 2010 will likely enable RECs to trade closer to their capped limit in coming years, this could provide a valuable income stream for wind energy generators.

The marketing benefits of a wind turbine installation are difficult to quantify as part of the business case however this could form part of the incentive for conscientious corporate organizations. Where wind turbines improve the overall building NABERS energy rating, the building may achieve greater rental when disclosing it's GHG emissions under mandatory disclosure.

The business case predominantly comes down to the extent to which this clean renewable energy will offset the cost of grid electricity into the future. Electricity prices will be influenced by a variety of both demand pull and cost push inflationary pressures over the next two to three decades as well as direct regulatory control. The retail price of electricity is a summation of wholesale electricity prices, distribution costs, network costs, retailer's supply costs and pressures associated with government policy such as emissions trading and renewable energy targets.

Modelling undertaken for the Garnaut review as part of the assessment on Australia's Low carbon future shows that a government scheme (modelled start date 2011) such as the Carbon Pollution Reduction scheme will likely lead to strong price rises in the first three years after the introduction of the scheme. In late 2009 the NSW Independent Pricing and Regulatory Tribunal (IPART) corroborated the findings of earlier studies and announced a 62-68% increase in electricity prices could be expected in the first three years after the introduction of the CPRS. Even without emissions trading they have stated that a 40% price increase is necessary to cover the cost of network upgrades. Other forecasters are suggesting a 100% price rise in the next 5 years. In Victoria SP Ausnet have proposed a 400% increase in the peak summer tariff charges as a means to discourage non-essential peak use and to manage the grid demand. In Australia the demand for electricity will also increase with our increasing population. The impact of all these influences is an upward push on electricity prices which must be accounted for when considering the business case for building integrated wind.

In January 2010 Australia's mandatory renewable energy target has been expanded from a target of 9500GWh to 45,000GWh. The RET specifically addresses the use of renewable energy in the pursuit of stabilising Australia's atmospheric CO_2 concentrations. Most commentators concede that renewable energy is a more expensive form of carbon reduction than other abatement measures (eg transport or agriculture reforms) but it is a desirable technology based initiative for our long term future. The expanded RET places greater pressure on costs within the economy and particularly the price of grid electricity because of the increased need of electricity retailers to purchase renewable energy certificates. Low, medium and high probability pricing models may be adopted when considering the business case for wind energy.

Future Systems

The short term future for wind energy systems will likely include numerous building mounted installations as the wind resource and business case can be demonstrated in a city environment. Designers will be able to appropriately locate the turbines to maximise the yield within the built environment considering the aerodynamics of the surrounding built forms. Importantly there will be fewer surprises in the performance and safety of the turbines as a result of increased testing to recognized standards.

The ever present issue of wind intermittency may be circumvented by intelligent energy management, where only essential services are operated by grid power and the wind energy is used to provide power supply that is not time critical such as making chilled water or hot water for later use. The power from wind energy can also be moderated by making hydrogen and combining the system with a fuel cell.

Intelligent control systems in turbines will enable products to tune themselves to the local built environment so they can more easily initiate their own start-up and can take advantage of certain site specific wind effects. Inverter and battery technology is also set to improve.

Wind turbines can also be used to control adverse wind gusts in complex built environments and could become an essential part of wind control in cities. By installing wind turbines around the edges of tall buildings they can dissipate wind energy and dampen the effects of tall buildings and mitigate the impact of gusts on pedestrians at street level. Vertical axis turbines positioned on certain street corners or across windy streets can have the same effect as a tree in subduing unpleasant wind effects.

Future wind energy systems in buildings may not necessarily be confined to a set of spinning blades. Future wind harvesting could come in the form of piezoelectric devices designed to capture energy from the motion of a building as it sways in the wind. These pressure sensitive devices can be installed in the foundations of the building or in the fabric to create a virtually invisible form of wind energy system.

Conclusions

Direct integration of wind energy systems into commercial buildings is already starting to gain increased interest and in the future we may expect more commercial buildings to be fitted with wind turbines. Some careful analysis and design is necessary before installing these wind energy systems in sufficient quantities to make a moderate difference to a building's operational carbon footprint. Turbines must be appropriately cited to take advantage of the fastest flowing winds around a building especially in the context of a built up city environment. Turbine manufacturers must be encouraged to demonstrate the operation of their products by testing to recognized standards. Finally a business case can be established including modelling of future electricity pricing and consideration of the value of a reduced carbon building.