Urban fallacy

In this new series, **Professor Doug King** examines aspects of environmental and sustainable design, addressing common areas of misunderstanding and answering some of the 'why' and 'how' questions that crop up in design reviews and team meetings. Part one looks at wind power and explains why we are better off designing low energy buildings and systems, and then investing in large-scale wind energy, rather than trying to offset excessive building energy consumption with small-scale, urban wind generation

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In order to generate electricity it is necessary to place your turbine in the wind. If it is sheltered by its surroundings it cannot perform.

To understand the importance of location and scale for wind power we need to start from first principles. The theoretical maximum power that can be extracted from the wind is given by the equation:

$$P = \frac{\rho A v^3}{2}$$

Where:

ρ = the density of air

A = the swept area of the turbine rotor normal to the wind direction

v = the velocity of the wind

Now, since area scales as the square of dimension, it can easily be seen that the theoretical power of a wind turbine scales as the square of its size and the cube of the wind speed. In simple terms, large turbines are much more efficient at converting the kinetic energy of the wind into usable power than small ones – and turbines in windy locations will generate far, far more energy overall than the same turbines in locations with poor wind resource.

However, the size of wind turbines actually has a much greater impact than the simple scaling of dimension, due to the boundary effect of wind close to the ground. Figure 1 indicates the typical depth of boundary layer in different locations. Within this boundary layer the wind velocity is reduced due to friction with the ground, which dissipates the wind energy, generating turbulence.

At around 100m in height, even large-scale wind turbines are well within the boundary layer and so it is tempting to simply ignore the effect. But we cannot. Due to the cubic scaling of power with velocity, even small differences in velocity can have a significant impact on generation. We need to look at the situation in more detail.

In Figure 2, the Suburban and Open Country boundary layer curves have been enlarged to the point at which we can overlay some typical turbine sizes. This is not 100 per cent accurate and should not be >

Figure 1: The effect of surface friction in reducing wind velocity near the ground is pronounced. Over a city centre, the boundary layer extends to twice the height that it does over open countryside, due to the increased surface roughness.

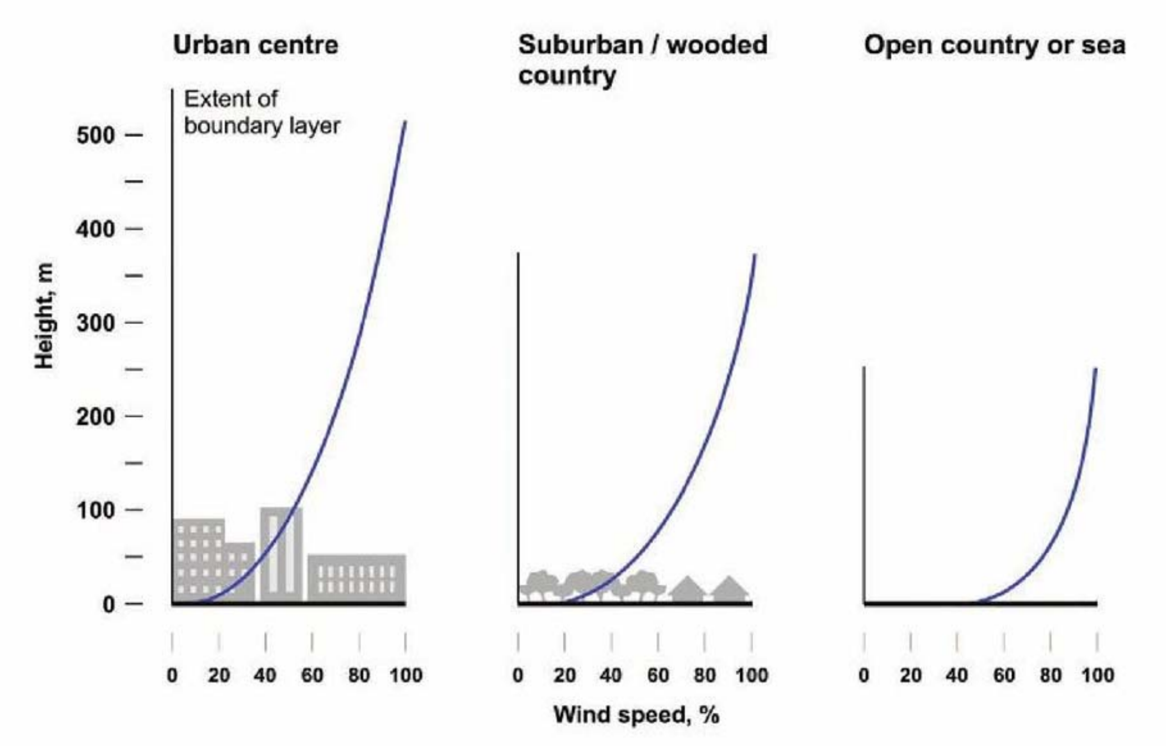
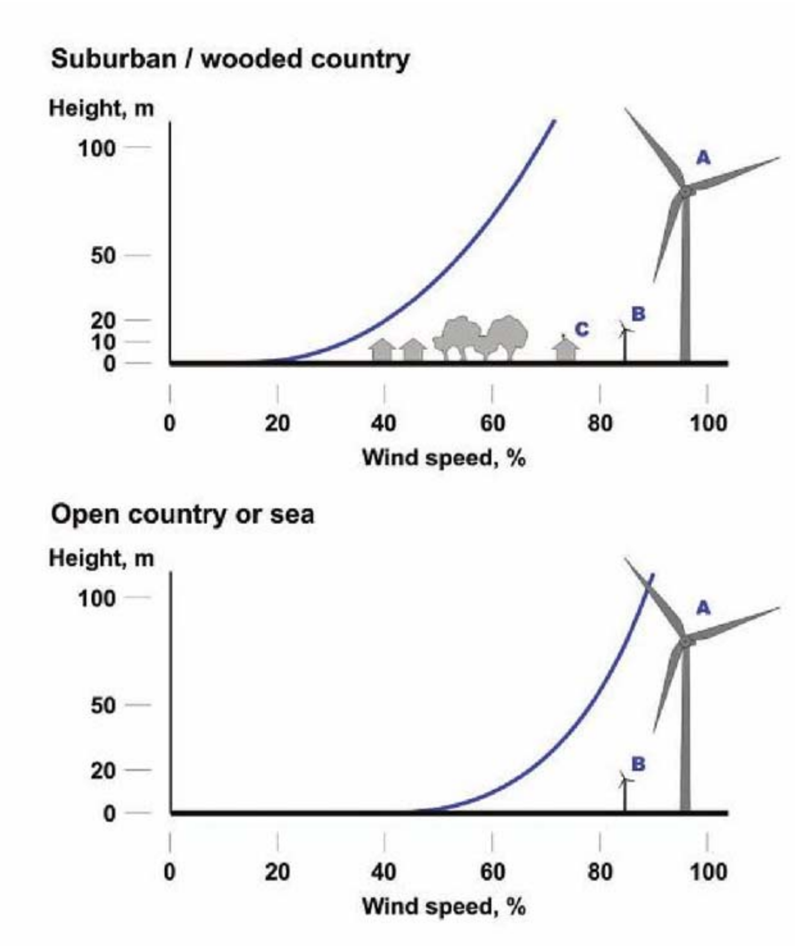


Figure 2: Within the boundary layer the wind power available is critically affected by both height and location.



used in calculations, but for now we simply want to gain an understanding of the principles. This approach is more than adequate to demonstrate the sensitivity to height and location.

The large-scale turbine (A) has a 70m diameter rotor and is typically mounted on masts around 80m high. This machine will generate 2MW at peak output. The small scale turbine (B) is 15m to the hub, has a 10m diameter rotor and is rated at 15kWp. A typical 1kW domestic micro turbine (C) has a rotor diameter of 1.75m, and mounted above the ridge on a typical house is at a similar height to the small-scale turbine. However, by definition, a building-mounted micro-turbine will only ever be found in the equivalent of an urban or suburban location. This is because the turbulence created by the building itself is typically of a scale equivalent to or larger than the turbine.

Now, the large turbine is just over seven times the size of the small scale one. Based on size alone, we would expect the output to be 50 times greater than the small turbine. However, in open country the velocity is about 25 per cent higher at 80m than it is at 15m, and therefore the power available is nearly twice as much due to the cubic scaling. Our scaling estimate therefore works out to 1.5MW – close to the 2MW peak output actually achieved. The remaining increase in peak power output is due to the higher maximum wind velocity for the larger machine.

Wind turbines do not always generate at their peak capacity, as this only occurs at the maximum rated wind velocity. We should therefore examine the situation in terms of the annual energy generation, to complete the picture.

To estimate the annual generation capacity of a wind turbine, we apply a capacity factor to account for the annual distribution of wind velocity. For open country locations with good wind resources, we can expect a

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Figure 3: Two identical Enercon E-70 turbines, operated by Ecotricity, are shown. The one at Shooters Bottom in Somerset (right), is generating 5,700,000 kWh a year. The other one, beside the M4 at Green Park near Reading, (left) produces just 3,500,000 kWh. The difference is accounted for by the wind energy dissipated through friction and turbulence as a result of the surrounding buildings and trees.

capacity factor of 30 per cent. So, in an unobstructed location, a typical small turbine could be expected to generate around 40,000kWh and the large turbine about 5,250,000kWh.

Let's consider the opposite scaling. The micro-turbine is about 20 per cent of the size of the small-scale one and is mounted at about the same height above ground. So, based on the size difference, we would expect the output from the micro-turbine to be around 3.5 per cent of our small one, or 1,400kWh. It was estimates like these that led to one micro-turbine manufacturer claiming that their product could meet 33 per cent of domestic electricity demand.

However, in order to complete the picture we need to look at the influence of location in Figure 2. Due to the increased surface friction, the wind velocity at any given height is reduced over suburban or wooded locations compared with open countryside. The difference becomes more pronounced the closer you get to the ground. The wind velocity at 15m elevation drops by half compared with open country, and at 80m it still drops by around 15 per cent.

We would therefore expect the capacity of the large turbine in a suburban location to be around 60 per cent of the open country condition, due to this reduction in wind velocity. Based on our earlier estimate for generation capacity in open country, we can estimate the suburban capacity to be around 3,150,000kWh. Figure 3 shows two such turbines in different locations which exhibit this capacity reduction almost exactly.

Now when we come down to 15m and below, the height of small and micro-scale generators, the wind velocity is reduced by 50 per cent compared with open countryside, which means that there is just 12.5 per cent of the wind power available. The situation is even worse in city centres. That, in a nutshell, is why wind turbines attached to buildings in urban locations achieve little more than decoration. Few people install small-scale turbines in urban or suburban locations because of this fact, as the generation capacity of around 5,000kWh or less could not possibly justify the installation cost. However, with the low cost of micro-generators, many are still tempted.

Applying the location factor for a suburban micro-turbine, you would expect an annual output in the region of just 175kWh. In fact, a recent survey by the Energy Savings Trust found no instance of a micro-turbine in an urban or suburban location that generated more than 200kWh per year. In some instances, the mains electricity consumed by the electronic control systems exceeded the annual generation from the wind. Micro-wind turbines are sold for around £1,500 to £2,000 and, in typical situations, may generate about four per cent of domestic electrical consumption. On commercial buildings, with their subsequently higher demands, micro-turbines are rarely justified.

Small-scale turbines of the size I have used as an example cost around £50,000 to £60,000 and, in a good location, will generate sufficient electricity to meet 100 per cent of annual demand for around six to eight homes. However, put them in an urban or suburban location and you will cripple them. Large turbines cost around £1.5m to £1.7m and can generate sufficient electricity for around 1,250 homes.

If you have cash to burn, buy a micro-turbine to make yourself feel good. But if you want to save carbon, invest in large-scale wind power or, even better, on energy efficient fabric and building services. ●

Doug King is principal of King Shaw Associates and visiting professor of building physics at Bath University. He was author of the Royal Academy of Engineering report, *Engineering a Low Carbon Built Environment.*