Turby - Sustainable urban wind power from the roof top

(Photo Corné Bastiaanse, DHV, Den Haag)

The town hall of The Hague with the House of Parliament in the back ground

Among the high-rise buildings of various government buildings, the roof of the town hall in The Hague carries a Turby. The eleven storey building, which was designed by American architect Richard Meier, is the latest location for Turby, a vertical axis wind turbine that can generate energy from the rapidly changing winds around high buildings.

If current trends are anything to go by, in future we will no longer produce all our electricity in large, central power stations. Small-scale local electricity generation will gain in importance. Sander Mertens, a post-doctoral student at TU Delft, developed the aerodynamic design of a wind turbine which is specifically suitable for built-up areas. Compact, mobile, low-noise, and vibration-free, it is the ideal alternative for use on top of high-rise office blocks, where wind speeds can easily reach twenty percent more than with the same height away from buildings. The electricity can be fed straight into the building's power system, saving on energy transport costs and losses, and producing high feed-in yields. Prototypes have already been installed on the town hall in The Hague (designed by Richard Meier), on an apartment block in Tilburg, on an office block in Breda, and on top of the Delft ChemTech faculty building. Interest has been generated in London and Leicester in the UK, New Mexico and New York in the USA, and in France and Canada.

by Bennie Mols

Windmills in a flat green landscape stretching to the horizon and beyond – the archetypical image of Holland. Windmills even provided the means of creating the Mondrianesque landscape with its straight cuts and dykes bordering rectangular sections of grassland. In the seventeenth century, windmills were the mainstay of the Dutch efforts to reclaim land from the sea and finally create a dry place to live in.

Say windmills, and everyone will instantly think of panoramic views with rows of rotating sails cutting through the air. The open country, where the wind can go as it pleases, is the windmill's natural habitat. Until recently, that is. In an overcrowded country like the Netherlands, space comes at a premium. Today, visual intrusion, environmental impact, and noise have become the hurdles to be surmounted before wind turbines can be installed in the open country.

These problems are an incentive to look for creative solutions for putting the wind's motional energy to good use. Of course, the wind can blow fiercely across the open Dutch landscape, but as anyone who has passed a high-rise building on foot or a bicycle on a windy day will tell you, conditions can be pretty blustery in built-up areas too. When moving air reaches a building, there are only two ways to clear the obstacle. It can go either around it, or over the top. In doing so, as we have all noticed, the wind picks up speed.

Dick Sidler wondered whether the wind in built-up areas could not be put to good use with a wind turbine designed specifically for use in such a location. Following his graduation as an electrical engineer at TU Delft he had taken a job elsewhere. In 1993 he started his own energy technology consultancy company, already convinced that decentralised power generation would become the thing of the future. Instead of getting all our electricity from large, central power stations, we would be using an increasing number of local power sources. Not just wind power, but also solar energy and total energy plants. Forty percent of our energy consumption can be attributed to buildings, in other words, room for improvement.

One thing he was certain of: the plan had to involve a wind turbine on a vertical axis rather than one on a horizontal axis like most wind turbines we see around us. The advantage of using a vertical axis in a wind turbine is that it will keep turning irrespective of the direction the wind. The classic windmill, with its horizontal axis and rotor blades turning in a vertical plane, needs some sort of guide vane or mechanism to yaw it in the right direction whenever the wind shifts. Dick Sidler realised that in a built-up environment, with the wind constantly, and often unpredictably, changing direction, it would pay to use a type of mill that would not need to waste energy by going in circles to follow the wind around. On top of that, a wind turbine with a vertical axis requires less maintenance since it has no mechanism to prevent cable twist and no system to turn it into the wind. However, first the drawbacks of existing vertical axis designs had to be tackled: the relatively low efficiency and high vibration and noise levels.

Whisk Sidler started by surveying the market for vertical-axis turbines, and he came up with two possible candidates, the Windside and the Catavent. The Windside was his first choice, but it proved too expensive. According to Sidler, experimental readings showed that the yield was only about 25% of the manufacturer's figure.

Sidler realised that he required much more than his own knowledge of aerodynamics if he were to conduct the necessary wind turbine experiments successfully. So he contacted Dr. Gerard van Bussel of the Wind Energy Section of the TU Delft faculty of Civil Engineering (which has now become part of the faculty of Aeronautical Engineering). At the time, Ir. Sander Mertens was working on his post-doctoral research into the use of wind energy in built-up areas. Sidler conducted some experiments on the Catavent at the test site of the Wind Energy Section. The Catavent is a Canadian design that looked like a large air scoop that could turn itself into the wind by means of a set of guide vanes. As the air hit the device, it was diverted by a hornlike device onto a horizontal drum. Both the wind scoop and the drum rotated around the same axis. The air flowed into the drum through its open top, and could only escape through holes in the side. Vanes mounted at right angles to the outside were shaped so that the airflow was diverted in a tangential direction. This would cause the wheel to turn, driving a generator through a belt system. The lower end of the wind scoop featured a type of wind deflector designed to prevent the wind striking the vanes directly, and in addition to create a form of suction.

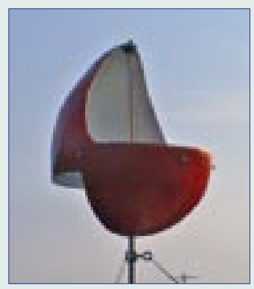
The Chelker-wind farm in Addingham, Ilkley, West-Yorkshire, Great Britain. Each wind turbine has a capacity of 300 kW/h.

Both the wind turbines of the past fifty years that are used to generate electricity and the traditional windmills that were used to pump land dry or grind wheat, use horizontal main axis, which means that both types require some sort of mechanism to yaw them into the wind.

Large horizontal-axis wind turbines often feature gearboxes that transfer the energy collected by the enormous rotor blades to a generator. As the wind shifts, so does the rotor, which means that some provision must be made to prevent a cable twist between the generator and the foot of the mast. Turbines fitted out with these mechanisms require regular maintenance.

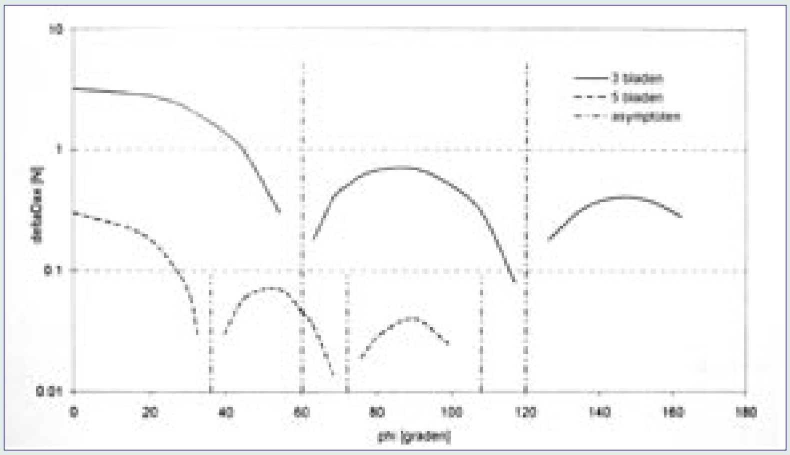
The Catavent is a Canadian designed wind turbine in which the wind flow is diverted by a horn-shaped duct and fed into a horizontal drum. As the air flows out of the drum past vanes mounted on the outside of the drum, the rotor is set in motion. Two screens fitted alongside the rotor protect the drum from the wind's onslaught and could also create a degree of suction.

One of the problems of the Catavent was that it would not stand stable in the wind, as field tests during the December 1999 - April 2000 period showed. Dick Sidler investigated whether a different casing design could improve matters. A series of model tests culminated in the Wind Egg, which yaws into the wind very stably without any problem. Yet, wind tunnel tests resulted in the finding that the wind flow through the turbine housing was turbulent with a strong swirl in the front, but the energy output was rather low

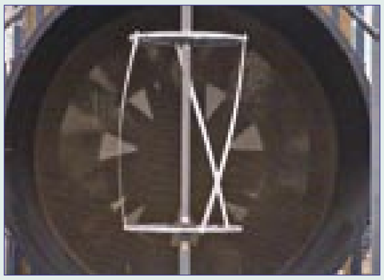


The drum-shaped rotor of the Catavent wind turbine showing the vanes fitted to the outside of the drum.

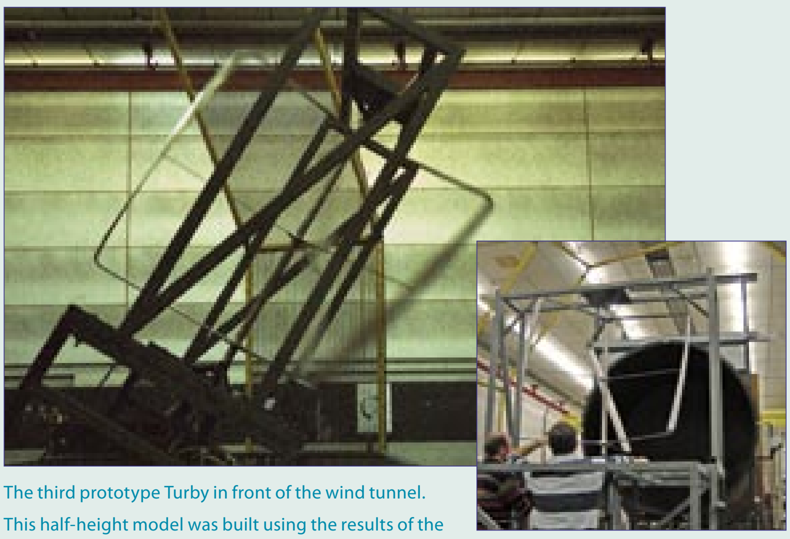
A Darrieus turbine is being transported to the wind tunnel of the Wind Energy section at TU Delft to be tested for the Eneco power company.



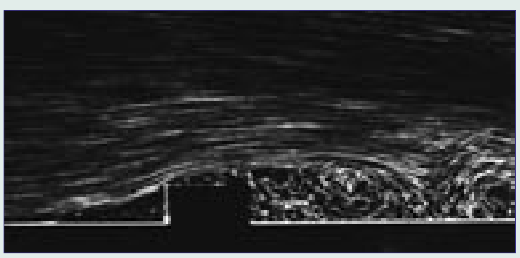
Graphic representation of the variation of the axial forces on the shaft as a function of the blade skew. The vertical dashed lines indicate the skew of the blades at which the variation in the axial force reaches zero on the shaft. Two graphs are shown. One shows the results of the theoretical model for a 3-bladed rotor, while the second gives the results of the theoretical model for a 5-bladed rotor.



The first prototype Turby in front of the wind tunnel of the Wind Energy section at TU Delft's Stevin Laboratory. It has racing bike wheels fitted with aerodynamic spokes at its top and bottom. The manufacturer of the first prototype thought the aerodynamic spokes would keep the drag figure down. However, the model disintegrated because the bolt used to secure the position of the two wheels broke under the strain of the centrifugal forces, causing the blades to bend outwards. A redesigned and stronger model, although it proved capable of coping with the centrifugal forces, required additional power to keep it in motion. It did show though that the required power input became less as the air speed increased. Apparently the model manage to extract energy from the wind, but this was too little to overcome the total drag. The readings obtained from tests on this model were used to determine the optimal aerodynamic dimensions.



The third prototype Turby in front of the wind tunnel. This half-height model was built using the results of the tests on the early prototypes. The model was to run under its own power, and run it did! The model — the largest size that could be accommodated in the wind tunnel — was used for all the wind tunnel tests and the final design of Turby was based on these measurements.



Visualisation of the air flow across the roof of a model building in a wind tunnel. The air flow path is made visible for photography by adding small particles. As can be clearly seen, the wind does not blow horizontally across the roof, but flows at an angle. The curly path of the particles close to the roof indicates that the local airflow constantly changes direction, in other words, it is turbulent.

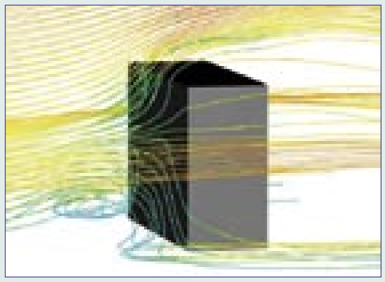
"Sidler's query most closely matched my research," Mertens says, "and so it became a useful excursion alongside my main subject of enquiry: wind energy in the build environment."
Most wind turbines use the lifting force that acts on the curved rotor blades, just like the lifting power that enables an aircraft to stay airborne. Both the Windside and the Catavent (and its successor, the Windports) are based on the principle of resistance encountered by an airflow striking a surface. The experiments conducted on the Catavent showed a very pour efficiency. After having searched the market Sidler concluded that there was no efficient vertical axis wind turbine available, so he asked Mertens to design one.
"We immediately started looking for a lift-generating device with a vertical axis," Mertens says, "and then you automatically end up at the Darrieus design." This device, which looks a bit like a whisk mounted on a vertical axis, was invented in 1931 by a Frenchman, Darrieus. The whisk comprises three blades with a wing-like section. The main drawbacks of the Darrieus generator are that the ends of the blades near the central axis contribute little to its generating capacity, while the blades produce unpleasant vibrations and noise.
"Bearing the original Darrieus design in mind, we set out to create a straight-bladed variant, shaped like the letter H. This could have performed a little better than the original design, but it had the same problem as the Darrieus: the blades, more so in a two-bladed design –simultaneously changed wind directions along their full length, producing considerable vibration levels, with alternating lift forces on the blades as well as an alternating torque. These all had to be overcome, and so the basis of the new turbine was found in an odd number of inclined blades equidistant from the axis along their full length, producing a helical shape."

Rotor blade accelerations up to 200 times g Mertens became responsible for the aerodynamics of the machine. He combined analytical flow calculations with data from the wind tunnel (using a computational fluid dynamics program) to continually improve the design.
"I was able to calculate how high and how wide the rotor blades had to be. This resulted in a wind turbine with three inclined rotor blades, the whole assembly being three metres high and two metres wide. The chord of the blades is ten centimetres. A wind turbine of this size will produce 2.5 kilowatts."
This became the basis for the wind turbine that was to be named Turby.
An extra complication for the design was that the wind turbine has to produce as little noise as possible. After all, it was to be operated in an urban environment, not in the open country.
Mertens: "Keeping the noise level low means keeping the rotational speed down. The number characterising the rotation of the rotor blades is the tip speed ratio, which gives the ratio of the rotor blade tip speed over the wind speed. While for Turby the ratio sits at the relatively low value of 3, a propeller turbine in the open country can have a tip speed ratio of 9. The requirement for low-noise power production significantly reduces Turby's tip speed ratio. As a result the Reynolds Number, that typifies the type of airflow, is relatively low, which makes model simulation harder to do. In addition, the lifting power acting on the rotor blades becomes more difficult to model, so the model simulation results could not be more than a guideline. We had to go on to testing models in a wind tunnel."
When the initial prototype of Turby was built, the company constructing the wind turbine underestimated the centrifugal forces acting on the blades, Since these can reach up to 200 times g, the blades must be securely fixed. As this was not the case in the first prototype, a second had to be built. This time the device was strong enough, but refused to turn. The third attempt proved to be better. After some fine-tuning and scaling up the dimensions, the result was the present prototype Turby, which consists of three inclined, elongated and curved rotor blades arranged around a virtual cylinder two metres in diameter and three metres high. The rotor blades are made of a lightweight, strong, and rigid carbon-fibre composite material, resulting in a weight of only 4 kg per blade. The weight of the entire turbine is 135 kg. Turby's small diameter and the open nature of the rotor make it less intrusive than a normal wind turbine in an open field. Thanks to its lightweight construction, Turby can be installed without a lifting crane.
"Each Turby located on the roof of a high-rise building in a town generates power exactly where it is needed, without transport losses," Mertens says,

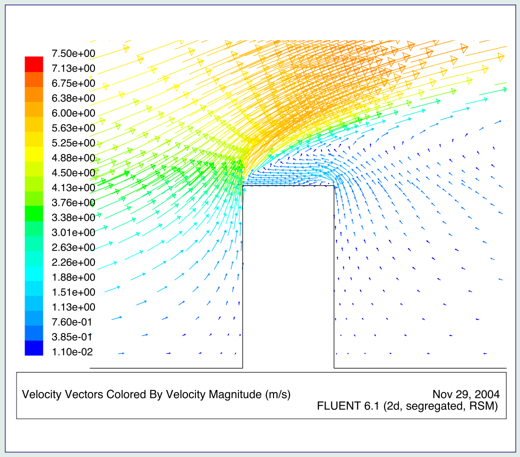
"That's the beauty of the system. Turby is connected to the building's power system behind the public utility meter. The power goes straight into the building, reimbursing the owner at full kilowatt hour rate. Whereas owners of wind turbines in the Dutch countryside have to go begging to a power company to offload their output. The power company, pays them only one third of the amount consumers are charged for a kilowatt-hour.
In a reasonable wind location, not too close to the coastline, nor stuck between other high-rise blocks, a single Turby will provide about 3000 kilowatt-hours, enough to cover the power consumption of an average family. Turby prototypes have now been installed on the roof of an apartment building in Tilburg (the first installation dates from May 2004), on an apartment building in Breda, on the town hall in The Hague, and on the ChemTech faculty building of TU Delft. The only noise to be heard from the generators, and only along the top access gallery of the building, is a light whizzing sound as the wind gusts. Nothing is to be heard inside. These are all still single Turby installations, but Mertens is already thinking of roof-top wind turbine parks for the future.
The Dutch Ministry of Transport has also installed a single Turby, along the A50 motorway. It supplements a pair of German-made wind turbines, whose purpose is to provide power for the matrix information signs and the street lighting along the road. At least, that is the idea. Mertens is not convinced that Turby is suitable for the purpose: "It was really designed to be used in a built-up environment, sitting on a high roof. Other types of turbine work much better along the motorway."

More power from angled flows Turby has a number of unique features. It produces little noise and can handle all the changes in wind direction the built-up environment can throw at it, thanks to its vertical shaft layout.
"We were a little surprised by something else though," Mertens recalls. "As the wind crosses the roof of a high-rise building, it flows at an angle, typically twenty degrees, to the flat roof-top. This angle varies with the wind speed, sometimes a little higher, at other times a little lower. As the angle of flow increases, the yield of a normal wind turbine will start to drop as the useful wind component decreases. Turby on the other hand can get more energy from the wind as the angle of flow increases, up to a certain maximum, of course. This was new to us. We had never before heard of a wind turbine managing such a feat, and I have found no previous reports of the phenomenon. As the angle of the wind flow increases, the surface area of the unhindered wind reaching Turby also increases. That is the secret of the design."
Mertens also drew up a number of rules of thumb to indicate how high the rotor should protrude above the roof. Typical values range from 5 to 7.5 metres above the roof-top, where the wind speed is about twenty percent higher than the unhindered wind speed at the same height in the open field. Mertens conclusion is that wind energy offers a viable alternative if you can make use of the highest buildings in a built-up area.
"You have to be careful where you put the turbine, though. In Tokyo they once put a set of turbines just above the roof-top. That does not work. They really have to be up in the accelerated, angled airflow."
A normal wind turbine in the open field carries its own wind speed counter. Turby can do without. In fact it constantly measures the wind speed.
Mertens: "At low wind speeds, the rotor blades will start to turn, but they will go too slowly to generate sufficient lifting power on the blades. This is also too slow to generate power. The initial movement is detected and a signal is sent to the generator which briefly acts as a motor, increasing the speed of the rotor blades to the point where they have sufficient airspeed to generate the required lifting force on the blades. At that point the rotor takes over and the turbine continues to rotate on wind power alone like any other wind turbine."
So it needs extra energy to get started? Sounds like a major drawback. Mertens: "It takes only very little energy, since the rotor is relatively light. What's more, the system is monitored by a protocol to ensure that it does not get kick-started too often."

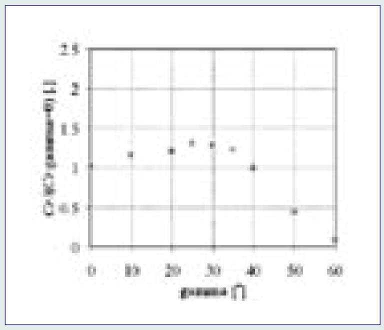
Wind turbine-integrated buildings The generator used by Turby is a compact direct-drive system, i.e. one without a gearbox, designed by Dr. Ir. Henk Polinder of TU Delft. The rotor drives the generator directly without the intervention of a gearbox. A gearbox generator would have been cheaper, but the



Visualisation of the air flow around a model building using a simulation program (Computational Fluid Dynamics calculation). This shows only the average tracks of small particles that were released in the undisturbed upwind airflow. As can be seen, the main flow passes on either side of the building and does not come close to the roof.



Speeds above the roof of a model building, obtained by means of a simulation (Computational Fluid Dynamics calculation). The speeds are colour-tagged (from high to low speed: red, yellow, green, blue. This clearly shows that Turby is located in an area with increased speed (yellow) relative to the undisturbed wind speed at roof top level (green/blue).



Test results of a measure for increase in power (vertical axis) of an H-Darrieus wind turbine (a wind turbine with an operating principle analogue to that of Turby) as a function of the angle of incidence of the flow (horizontal axis). The graph shows that the H-Darrieus turbine produces 30 percent more power at an angle of incidence of 25 degrees.

The final prototype of Turby on the test field of the Wind Energy section on the TU Delft campus. This is where the wind generator is tested under field conditions, such as gusting wind, start-up at low wind speeds, and high wind speed cutout.

Prototype Turby on the roof of a block of flats in the university town of Tilburg in the south of the Netherlands

Turby at the Q8 gas terminal on the North Sea coast near Velsen, where it is being tested for possible use on offshore platforms.

The generator of a Turby is fully integrated in the wind turbine and consists of an external magnetic rotor (the ring bearing the name) that rotates around the stator. The generator does not have any bearings of its own.

Interior view of the rotor with permanent magnets. These magnets have been fitted at a slight angle in order to reduce the adhesion forces that would hold the rotor in a preferred position, requiring an extra force to set the rotor in motion.

The generator stator is fixed to the stationary axis of the turbine, so no provisions are needed to prevent cable twist. The generator was designed to be highly efficient not only at full power, but also at lower power levels (at which it usually operates).

Since Turby is not self-starting Sidler developed a 'dedicated' converter. It is a four-quadrant system, which handles not only the start-up function of the synchronous generator as a drive motor, but also the turbine control and safety functions and the conversion of the variable voltage and frequency generated by the generator to the correct voltage and frequency so the wind-generated electrical power can be fed into the local grid.

direct-drive system requires less maintenance, which was a design prerequisite. According to Sidler the maintenance-free period is about twenty years.
The ring of permanent magnets forms part of the rotor. The motional energy is transformed into electrical energy, which is then electronically converted into alternating current of the same voltage and frequency as supplied by the mains grid. The generator not only handles the start-up sequence, but also acts as a brake and a safety monitor on the rotating turbine.
Dick Sidler has had the first prototypes of Turby made through his company Turby B.V.. Interested parties from all over Europe and as far away as China, Japan, Australia, New Zealand and the U.S. have already been enquiring about the sustainable urban roof-top wind power system.
Sander Mertens now works for the construction and industry section of DHV Engineering Consultants in The Hague.
"Having done all this research, I can now advise others on what can be done with wind power in a built-up area, all the way from wind nuisance to wind usage. Architects come to consult me about the integration of wind turbines in between buildings and on top of them. I advise them about the shape of buildings, and discuss the kind of yield they can expect."
Wind power in a built-up area can be used in three fundamentally different ways, as explained by Mertens in his Ph.D. thesis, due to be published within a few months. Firstly there are wind turbines inside or on top of existing buildings, like Turby. For future use, Mertens is also contemplating buildings with integrated wind turbines inside a duct that connects the high-pressure and low-pressure sides of a building. A third option is to have wing-shaped buildings.
Mertens: "Whereas a rectangular building produces an increase in wind speed at roof-top level of about twenty percent, a high cylindrical building could theoretically generate up to 200 percent along the sides of the building. The ultimate goal is to work with architects to devise a building that will enable a wind turbine to produce power as often as possible and as efficiently as possible. Unfortunately, many aerodynamic designs are not very practical as buildings, so the challenge will be to find the right balance of innovation between optimum aerodynamics and practical applicability."
Meanwhile at the Wind Energy Section of Dr Gerard van Bussel at Delft University another post-doctoral student is to continue the research into the aerodynamics of Turby-like generators for the built-up areas.

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Turby specifications

Operating range		
Wind speed:	4-14 m/s	
Survivable wind speed:	55 m/s	

Turbine		
Rotor diameter:	1.99 m	
Rotor height:	3.0 m	
Weight:	136 kg	
Nominal capacity:	2.5 kW at 14 m/s wind speed	

Mast	**Standard**	**Extended**
Height	6.0 m	7.5 m
Plinth distance	4.0 m	4.0 m
Cross-brace	1.5 m	2.3 m
Approx. weight:	240 kg	300 kg

Converter		
Output type:	single phase	
Nominal capacity	2.5 kW	
Peak capacity:	3.0 kW	

(Source: www.turby.nl)