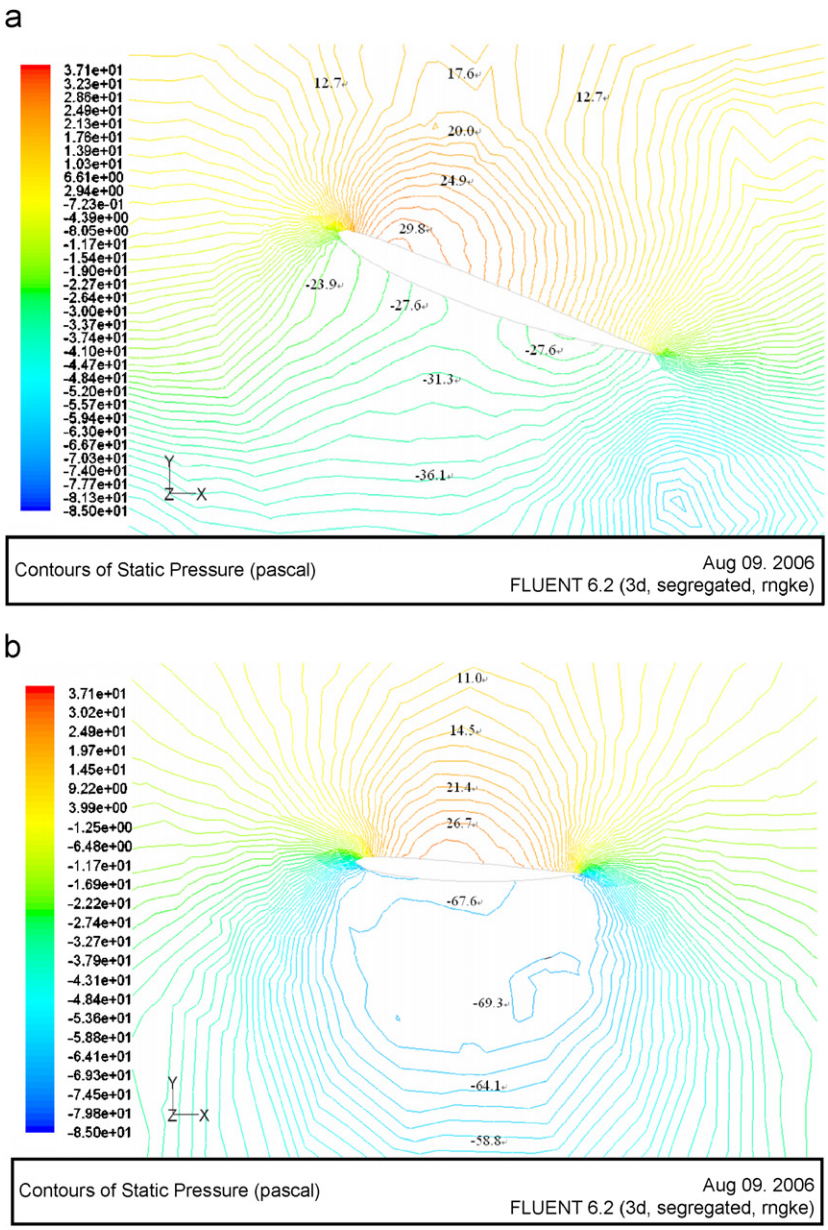


Fig. 12. Pressure contours on two planes across the chord of the blade. (a) On the across section near the root of the blade. (b) On the across section near the tip of the blade.

swept area, which would generate 726 kWh and 558 kWh, respectively, with the real wind resource.

Interestingly using Weibull functions, the calculated annual power yields are rather different. Using the standard method the power outputs are significantly larger than that using real wind data, even two times of the predicted results using best Weibull fitting (Fig. 14). One of the main reason could be the unsmooth probability curve for the location. The real wind data in the plot show two very high probabilities of occurrence for the wind speeds lower than 1.0 m s^{-1}. These two high probabilities at low speeds also made the average wind speed that derived by Weibull fitting lower than what people normally experienced. The standard Weibull method, on the other hand gave a more reasonable curve (the dashed line in Fig. 14). This method produced an average of wind speed about 5.7 m s^{-1}, which was very close to the figure of 5.1 m s^{-1} provided by Department of Trade and Industry Website for an open suburban terrain.

Even though the predicted electricity yield was not as good as what has been expected: significant increase in power output due to the add on scoop. As the reasons are unclear, further studies are needed.

Another aspect which needs further study is the assumption of instant response to wind changes. This assumption is acceptable and used in large wind turbines for one obvious reason: wind at open space and higher level are much more stable than that in a built up area. A large rotor experiences much less changes in wind conditions. Small wind turbine exposes to much turbulent airflow, even

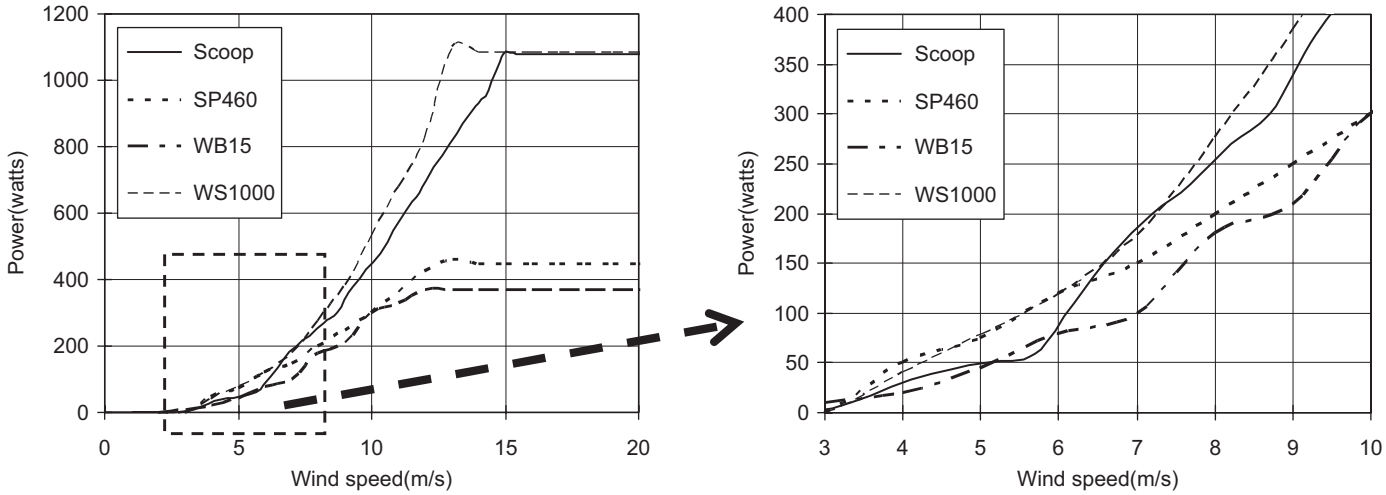


Fig. 13. Calculated power curve of the final design compared with other turbines of similar swept area.

Table 3
Annual energy yield (kWh) for the wind turbine and other two of similar swept area (the details of the three wind turbines are in [31])

Wind turbine	Swept area m^2	Actual data	Weibull fitted	Weibull standard
With scoop	1.77 (of the scoop)	872.2	467.3	952.6
WS1000	2.40	980.5	552.2	1119.5
SP460	1.77	725.6	426.1	827.0
WP15	1.77	558.2	319.5	635.1

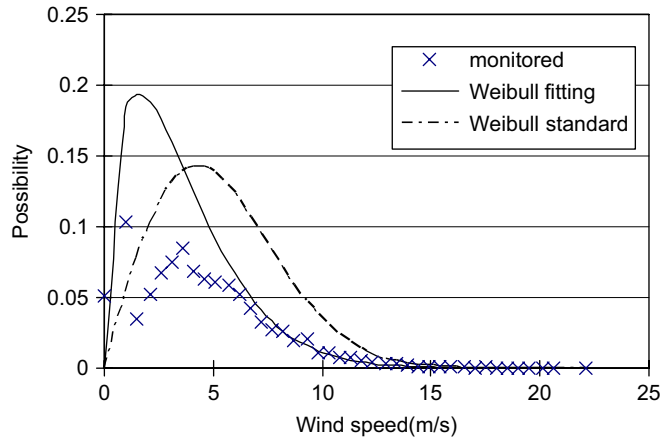


Fig. 14. The wind speed distribution of Edinburgh.

for a good vine device yawing is bound to reduce in power generation. Therefore a close monitoring of a real small wind turbine in a typical built environment would be a good opportunity to investigate the effects of turbulent wind on turbine yaw and rotor responses, and consequently the power yield.

4. Conclusions

This paper along with the previous one reports a systematic study on development of a small domestic wind turbine for built up areas. Like many other studies for such wind turbines, it focused at utilising more efficiently the slow and turbulent wind in built up areas using a scoop as a device of wind augmentation. As an outcome of this study, a small wind turbine with scoop was designed, tested and optimised using the methodology combining the theoretical, physical and computational (CFD) methods. The blades were created by a FORTRAN code based on the BEM theory, by which the chord and blade angle distribution along the radius were obtained. CFD method was employed as a virtual wind tunnel to investigate the performance of the selected design options, including both of the scoop and the rotor. The design options covered various shapes, detailed dimensions and configurations. The criteria used for assessment were primarily wind energy captured with a given wind capture area, and the final assessment was based on the cumulated mechanical power outputs calculated using real wind data.

The effects of the scoop on the airflow passing through the rotor remain unknown. As it has altered the velocity distribution radial direction and enhanced the airflow to drive the tips of the rotor, the rotor design, namely the chord and twist angle should take this into account accordingly. This can be an interesting research for future.

The conclusions drawn from this paper are in two folds: firstly the findings on aerodynamics of the rotor with the scoop, and secondly the limitation of this study which leads to suggestions for future studies.

In the computations, CFD results reveal that the connection methods of the element of blade have little

influence on the performance of the rotor, and the volume of the nacelle in the scoop should be keep as small as possible to obtain the highest power, and position of the wind turbine in the scoop should be placed near the inlet of the scoop to attain the highest performance. After the products were finalised, the power curves were predicted using CFD method and annual power output was predicted using the new proposed method.

The BEM theory which the design based on did not take into account of the effects of the scoop, which is believed to have significant effects on the flows around the blades, and consequently it would also affect the optimal design. It would be surely a rather interesting area for further studies. Additionally the air foil is developed for high Reynolds number flows, therefore the coefficients used in this research were all derived from such conditions. That surely results in some errors in the design and may open up a new way for further study.

Another rather important assumption made in this study was that the wind was stable. During a considerable period of time, its speed and direction do not change. This assumption is acceptable to large wind turbines, which are most likely be in the airflow of constant speed and direction for long enough for the turbine to gear up to a working state. Such unperturbed airflow behaves very differently from the actual ones in a built environment and consequently drives the turbine in a different way from a stable unperturbed flow. In a built-up environment, airflow is much unpredictable: varying in speed and direction. In response to this a turbine has to response to such fluctuation in airflow constantly, which changes the yaw systems and acceleration behaviours of the rotor. This will significantly reduce the power output for a small wind turbine in a built environment, if assessed using the normal methods developed for large wind turbines working in more stable winds.

In addition to the need for a proper method to estimate the actual electricity yield for the wind turbines working in built up areas, there are more work to be done. As all design has been based on unperturbed flow assumption, the final results here are still not yet to be seen as "fully optimised" for the use near buildings. Many aerodynamic issues need further investigation, such as the response to the changes in airflow speed due to the inertia of the rotor, the response to the change in wind directions due to the inertial of the whole machine, the frequency and amplitude of the changes that depend on the ground features characterised by building dimensions and streets sizes and many others.

Furthermore, the whole study focused only on the aerodynamic aspects of the wind turbine and the criteria for assessment was only on its power output. Many other aspects of a real product were not included due to the scope of the study. If the wind turbine is to be set up at a real site and start to produce useful electricity, there are many essential aspects to be examined, including mechanical stability of the stand to support the heavy head of the scoop and turbine, the materials for making the scoop, electric engineering for the generator connected to the rotor and mechanism of tuning the head towards the wind. All of these along with other general issues applicable to all wind turbines need to be properly addressed.

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