Making Personal Wind Power Practical With Specialised Roof Designs

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Abstract

Due to the large space needed to build a practical wind turbine, personal wind power in residential areas can be hard to achieve. Furthermore, due to the abundance of buildings, wind speeds in residential and urban areas are often much slower than in rural areas. Due to these reasons, the majority of people who want their own source of renewable energy, can only access solar. This can restrict people who live in environments without long days and in climates less suitable to generating solar energy which leads to a reliance on traditional power from fossil fuels.

Making wind power a practical option for residential buildings will greatly improve the accessibility of renewable energy. Islam Abohela *et al*. showed that the power produced by a roof mounted wind turbine can be increased by nearly 50% with standard roof designs (Abohela *et al*., 2012). Ghulam Abbas Gohar *et al*. showed that by using a funnel system (INVELOX) that channels air through a smaller area they can produce a similar amount of energy from a much smaller wind turbine compared to a larger turbine without the funnel (Gohar *et al*., 2019). Combining these two ideas, a specialised roof design can be created that uses a two layer system to channel air into a smaller area in the middle of a roof to greatly improve the practicality of installing smaller wind turbines for personal use. The roof of the house can act as the bottom layer while an additional layer can be built above to capture and accelerate the between the two layers.

By making wind a practical source of personal renewable energy, the market place will become more diverse and renewable energy will be accessible to people in a variety of climates. Hybrid systems of solar and wind power could be a possibility to allow for the power generation in varied weather conditions..

Introduction

Currently solar energy dominates the market for household renewable energy. In 2016 according to the Global Wind Energy Council there was only 314,320 wind turbines functioning globally (Global Wind Energy Council, 2016), the majority of these are in wind farms or in rural areas. Australia alone had over 1.5 million solar panels installed on houses in 2016 (Australian Energy Council, 2016). Wind energy on its own is more efficient than solar energy. The most efficient solar panels only convert approximately 20% of the suns energy to electricity (Svarc, 2020), while average wind turbines can convert up to 50% of wind energy to (University of Michigan, 2019) electricity. The simplest reason why household wind turbines are less common than solar panels is due to the larger space required to install a wind turbine. Additionally, the high density of buildings in urban and suburban areas results in low wind speeds, making household wind turbines impractical.

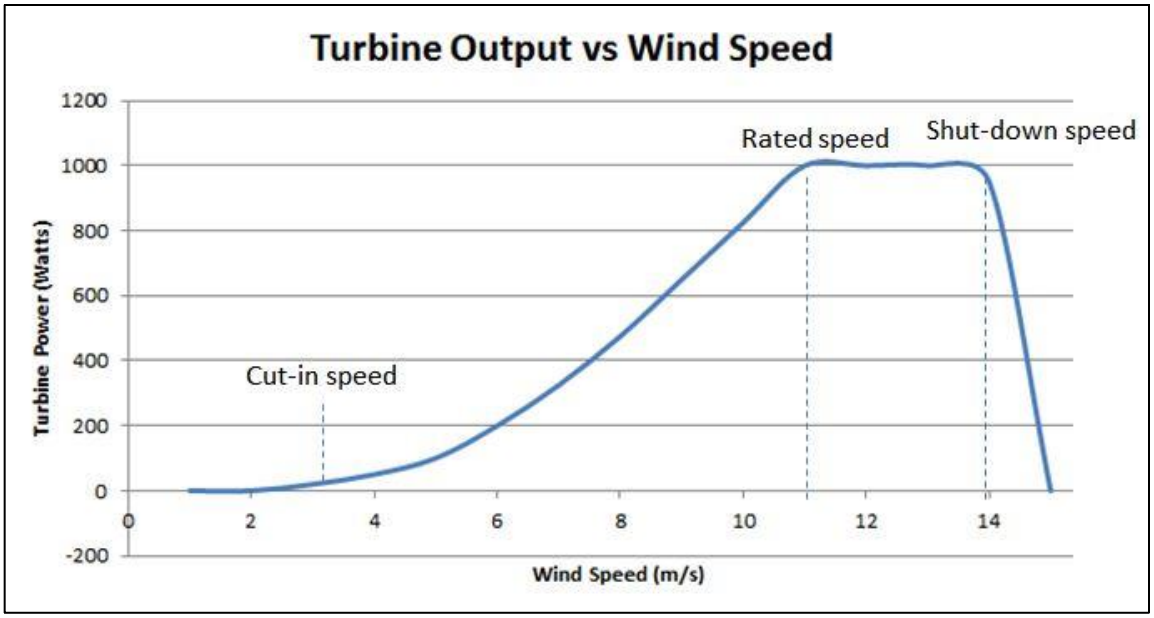


Figure 1: Wind Speed vs power curve for a 1kW wind turbine (Lombardo,2015)

Small household wind turbines are currently available, with an energy rating of several kilowatts, this energy rating refers only to the peak efficiency of the turbine. This peak efficiency is achieved when the wind speed is equal to the rated speed but below the shut-down speed. Wind turbines have a minimum wind speed, known as the cut-in speed, at which they can produce electricity and any lower speed will result in no electricity production. Until the rated speed is reached the wind turbine will only produce a fraction of its maximum power as represented by Figure 1, where an average 1kW turbine, which is readily available on the market, does not reach its maximum power until the wind reaches 39.6 km/h (11 m/s). In some urban areas the average wind speed fails to reach the cut-in speed due to the crowding of buildings. The average wind speed in Melbourne is 2.9-3.9m/s according to the Bureau of Meteorology (Bureau of Meteorology, 2020) and, as Figure 1 demonstrates this wind turbine in Melbourne would only occasionally produce any energy and it would be at a fraction of its rated output. It is for this reason that wind turbines typically require tall towers to be effective as the wind is faster at higher altitudes. Wind also tends to have less noise (or turbulence) at high altitudes as the effect of buildings and other obstructions is minimised as altitude increases. Not only does the presence of buildings lower the wind speed but it also creates high levels of turbulence which can stop wind turbines from functioning at their maximum efficiency. The loss in efficiency due to noise is especially high for traditional Horizontal Axis Wind Turbines (HAWTs) while Vertical Axis Wind Turbines (VAWTs) tend to be less efficient overall but function better when the wind has a lot of noise. VAWTs also tend to have a lower cut-in speed than HAWTs so for these two reasons VAWTs might prove to be a possible way forward for home wind power.

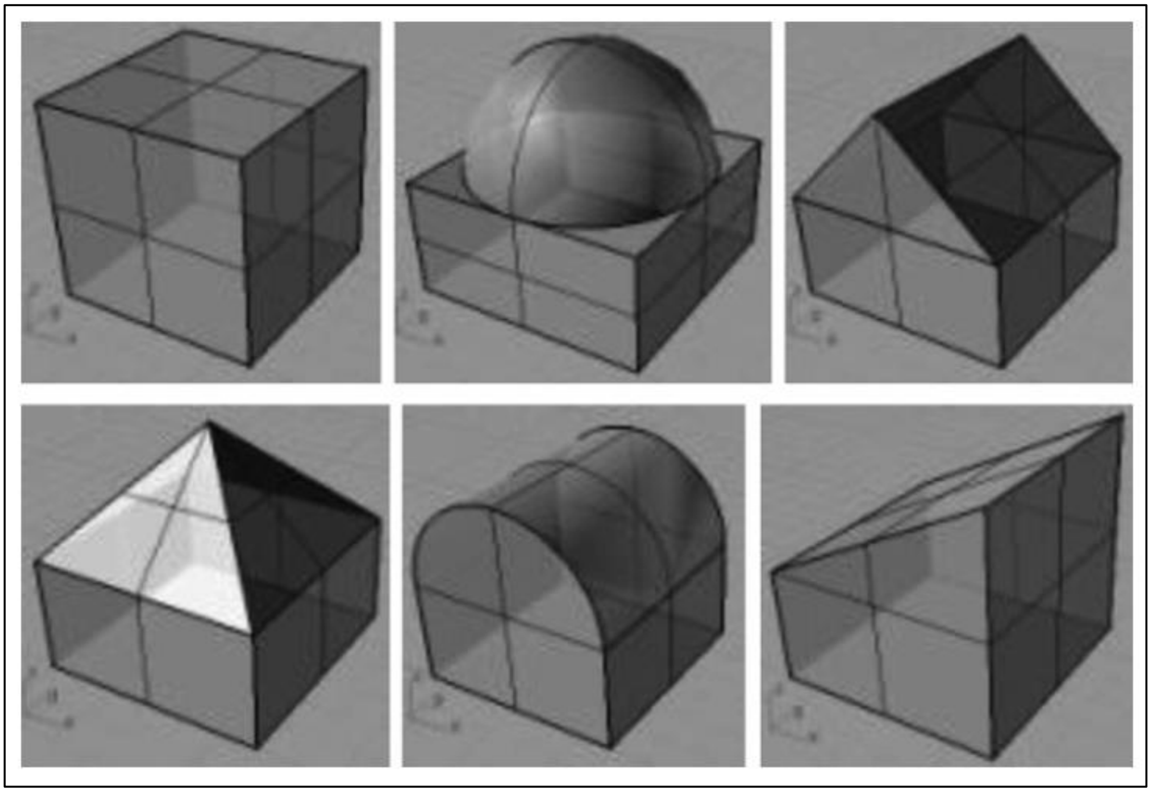


Figure 2: The 6 roof shapes tested by Abohela and his team
From Top Left: Flat, Domed,Gable, Pyramid, Barrel (Vaulted) and
Wedged (Abohela et al., 2012)

A study by Islam Abohela and his team from the School of Architecture, Planning and Landscape, Newcastle University investigated the effect the shape of a roof has on the wind speed as it passes over a house. They tested six different roof shapes on 6m by 6m by 6m houses as shown in Figure 2. The team found that the roof with the largest effect on wind speed (and by extension potential wind power) was the vaulted roof. The vaulted roof resulted in a velocity increase of 16% and wind power increase of 56% when the wind is in the same direction as the curve. They found that the direction of the wind had a considerable effect on the increase in power. The power increase drops to 48% if the wind is coming at a 45_o angle and to 27% when coming perpendicular to the side. Abohela's team also found that the wind direction had a strong effect on the optimal location to install the wind turbine for some roof shapes. Most notably the ideal height to install a wind turbine above the house drops from 9.6m when the wind is coming perpendicular to the angled side, to 7.8m when the wind is coming perpendicular to the flat side. The team further investigated how these values would change if the house was placed on an urban street. They found that the optimum height for the turbine is then increased to 15m due to the other buildings and the velocity increase was only a maximum of 7%. This significant change in location is another reason why rooftop wind turbines are usually inefficient as there is not always a single location where it can perform at its peak level. The impact on the velocity due to surrounding houses was minimised if the house was built much taller than the other houses on the street (Abohela *et al*., 2012).

Figure 3: Model of V-shaped roof guide (Hang Wang *et al*., 2016)

By adding a V-shaped roof guide above a traditional gable roof (shown in Figure 3) as part of their Eco-roof system, Xiao Hang Wang and his team were able to accelerate the wind by an additional 44% (Hang Wang *et al*., 2016). By increasing the wind speed by 44% as it passes over the roof of a house, the cut-in speed and rated speeds were effectively lowered by 31%. For their model they used VAWTs between the guide and the roof to harness the energy. Wind speed tends to have a cubic relationship to the energy produced by a wind turbine (Centre of Sustainable Systems, 2019), which means that doubling the wind speed can improve the energy produced by the turbine 8-fold, so this wind speed increase of 44% could result in could result in up to 3 times the amount of energy but the design is heavily reliant on wind direction. Due to the inclusion of solar panels in the construction, Hang Wang's design is a promising hybrid system, which would allow the harnessing of wind power and solar power simultaneously, obtaining the benefits of both. Arguably the biggest benefit of a hybrid system is that wind turbines work better during nights and winters while solar energy works better during summer and during the day allowing a complementary and therefore more stable source of electricity to be obtained.

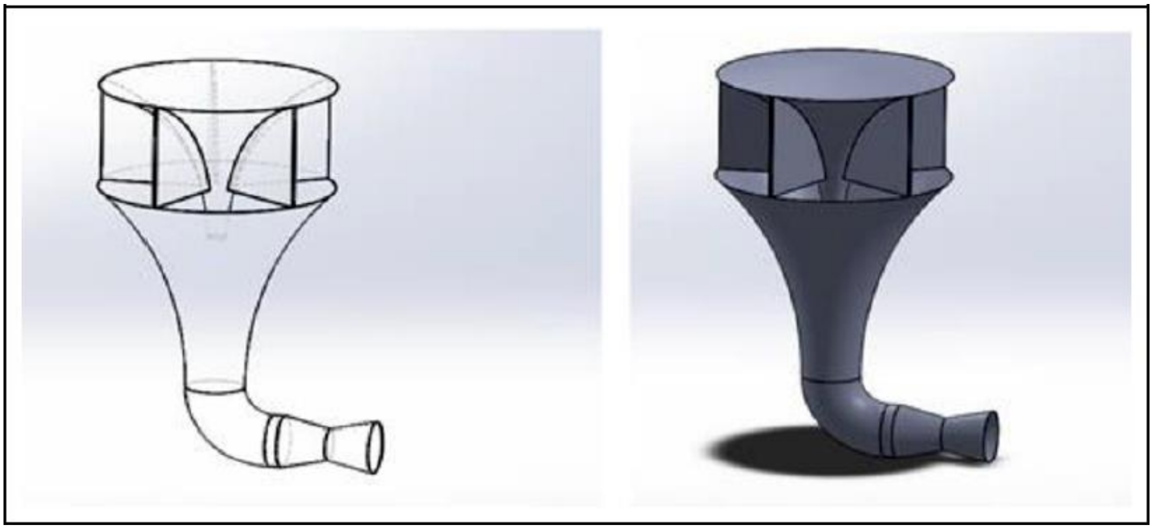


Figure 4: Model 1 of the INVELOX system (Gohar *et al*., 2019)

Another system that attempts to increase the speed of wind to harness energy is the INVELOX system (shown in Figure 4) developed by Ghulam Abbas Gohar and his team from the Department of Mechanical Engineering, COMSATS University Islamabad, Sahiwal, Pakistan and Energy Research Centre, COMSATS University Islamabad (Gohar *et al*., 2019). The INVELOX system allows smaller wind turbines without a tower to produce the same amount of energy as a larger wind turbine on a high tower. It works by capturing the fast wind at a high altitude and funnelling it down and through a smaller section of the tube to accelerate the wind speed. Gohar and his team also developed a second INVELOX model shown in Figure 5 that utilises a turbine system instead of the funnel to push the wind down the tube. With their INVELOX systems Gohar's *et al*. has been able to measure maximum windspeeds of 10.4m/s and 41.4m/s from model 1 and 2 respectively when starting with an initial windspeed of 6m/s (Gohar *et al*., 2019). There are three small wind turbines placed at the end of the tube which harness this energy with the first turbine harvesting the most energy followed by the second and then the third as the wind loses some velocity after each turbine it passes through.

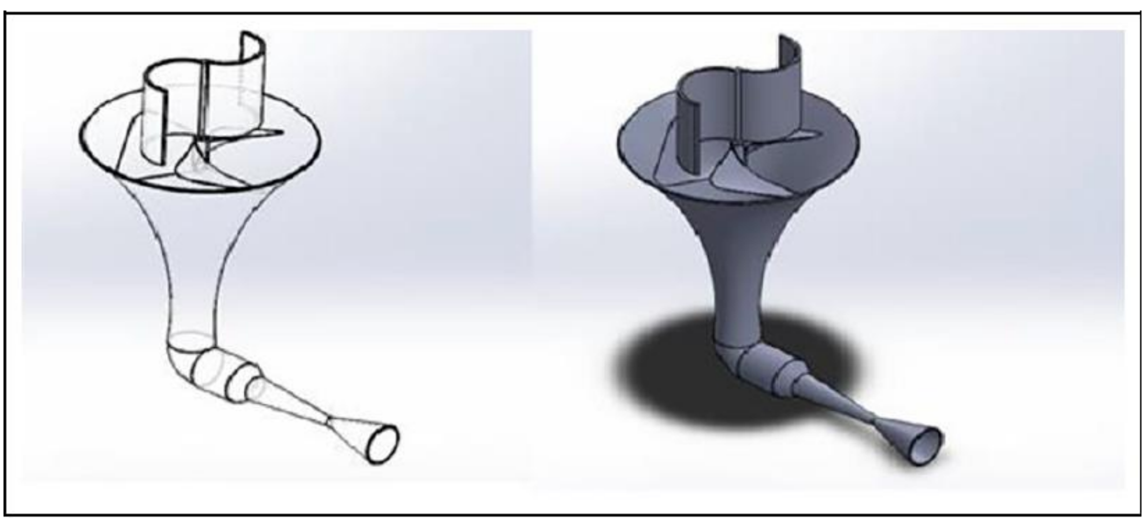


Figure 5: Model 2 of the INVELOX system (Gohar *et al*., 2019)

Methods and Results

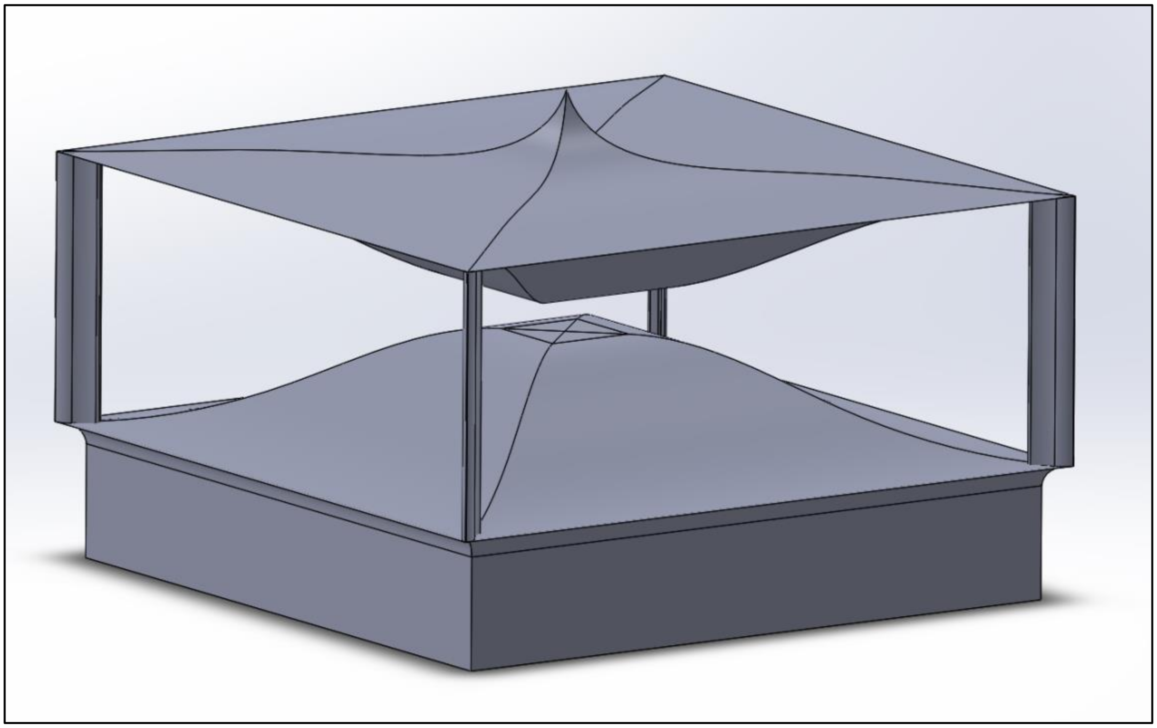


Figure 6: Final design of custom roof system

Models were designed using SolidWorks 2018 and the flow simulation add-in tool was used to determine the results. The basic house that this system was based on was 15m wide, 15m deep and 3m high. The design was identical from each of the four directions so that system efficiency did not depend on the wind direction. The final design for the system is shown in Figure 6. The roof is designed to function as a funnel to force air through a smaller area, thus increasing wind velocity. Four 4m diagonal walls were used in the corners of the roof to force the air inwards horizontally, and a second roof (wind guide) to force the air inwards vertically. The bottom of the wind guide had an identically mirrored shape to the top of the roof to minimise noise in the wind. The lowest point of the wind guide is 1m above the highest point on the roof since many small VAWTs are roughly 1m tall. The top of the roof has a 1m by 1m flat section at the peak to simplify the installation and maintenance of the wind turbines which can be installed in this area. The bottom of the roof guide is a 2m by 2m flat area. The shape of both the roof and wind guide were inspired by air foils and funnels as well as the systems of Abohela *et al*. and Hang Wang et al..

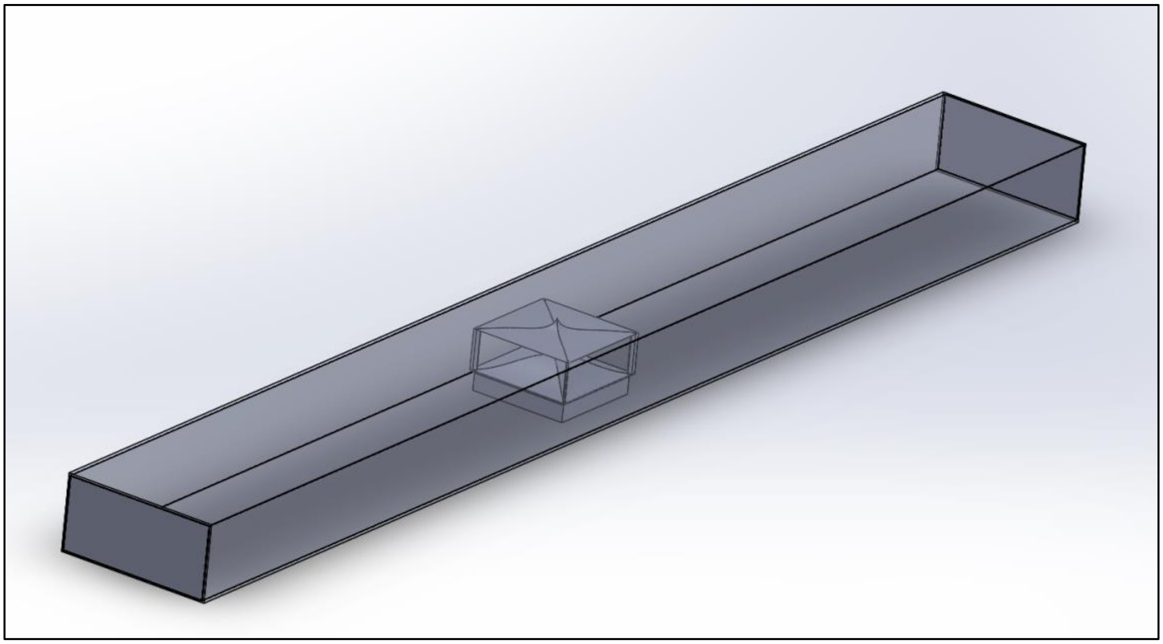


Figure 7: Final design of wind tunnel

To run the simulations a wind tunnel was assembled, shown in Figure 7 with dimensions of 24m wide, 11.5m tall and 200m long. The walls were 30cm thick except the two ends which were 5cm thick. To run the simulation the front end of the wind tunnel had 3 m/s boundary condition, while the two sides, the top and the far end were all treated to have environmental pressure (101 kPa) to simulate being in the open.

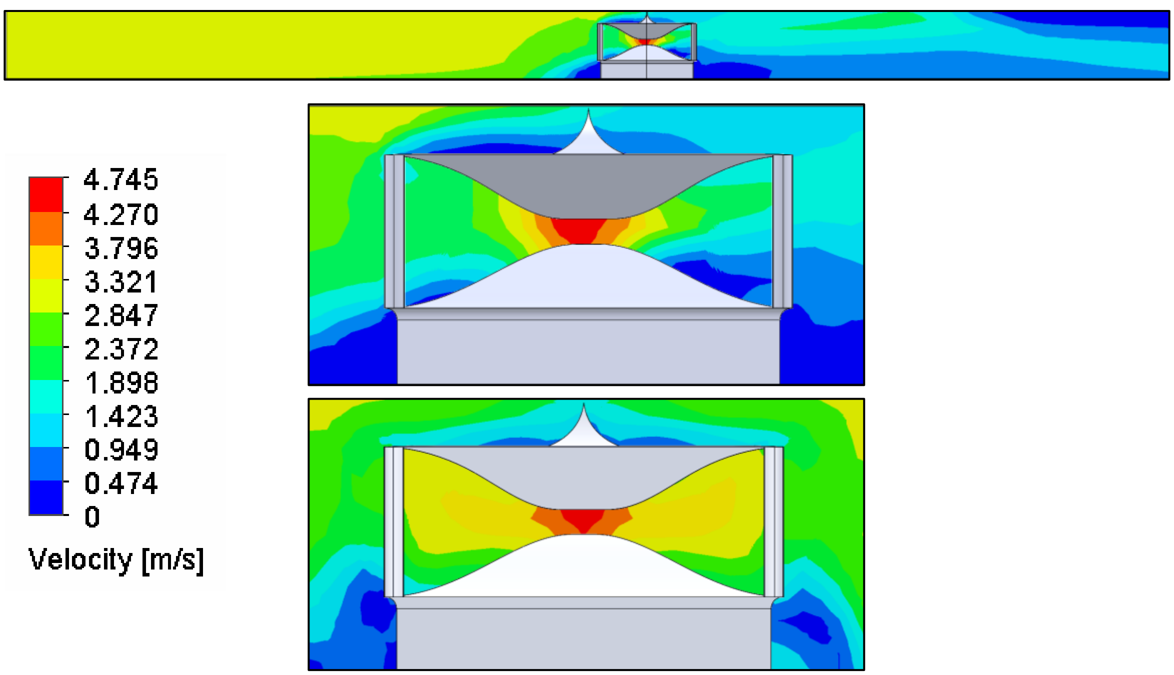
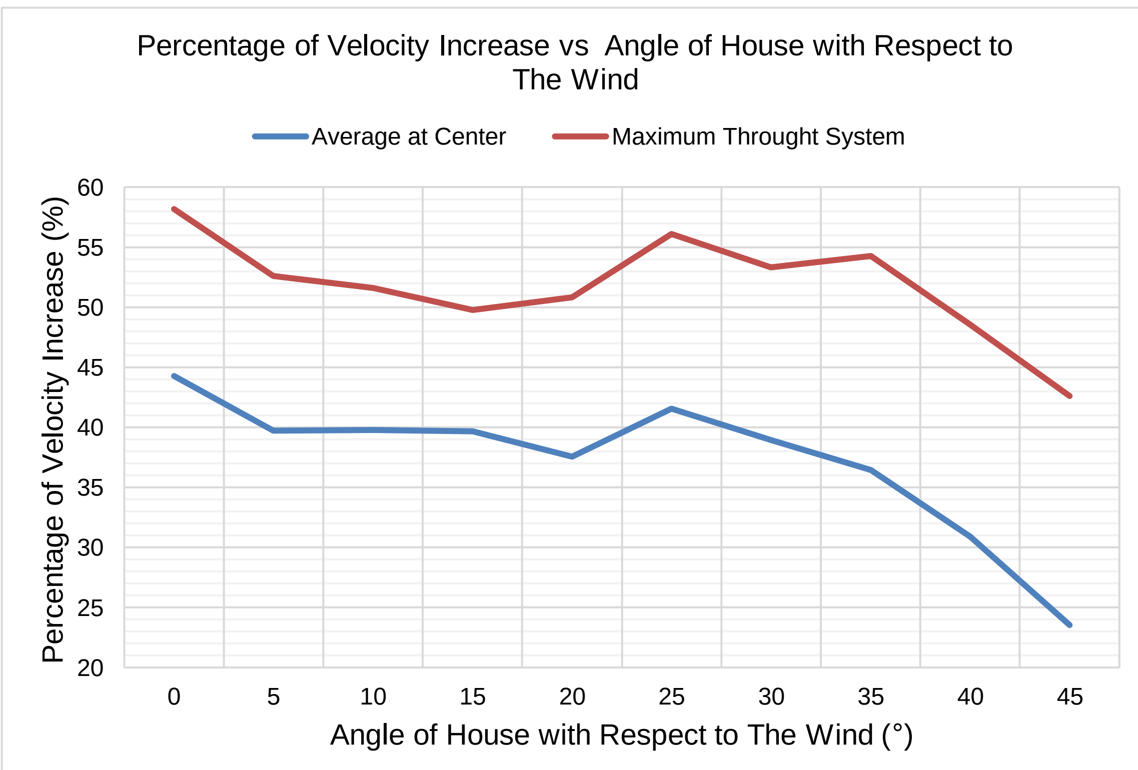


Figure 8: Velocity profile of flow simulation of the custom roof system.
Full length of the side profile (Top)
Close up of the side profile (Middle)
Front profile (Bottom)

The velocity profile of the flow simulation is shown in Figure 8. The maximum wind speed reached is 4.7m/s. This represents a 58% increase in speed. This could result in wind turbines efficiency being increased 4-fold. This would also result in the cut-in speed and rated speed dropping by 37%. However, the average speed within the 1m by 1m by 1m volume between the roof and the wind guide at the centre is 4.3m/s. This average speed was determined by creating a 1m by 1m by 1m volume goal in the Solidworks flow simulation tool. This average speed also represents a 44% increase in wind speed, meaning a wind turbine installed in the centre of the system will work approximately 3 times as efficiently as a wind turbine in the open. Furthermore, the cut-in speed and rated speed will also both drop by as much as 31%.

This system is most effective when the wind is perpendicular to one of the four sides, but, the system is still efficacious if the wind is coming from a direction in between the four sides. Further simulations were run, rotating the building in increments of 5_o from 0_o to 45_o and the maximum and average velocities were both recorded, and the results are shown in Figure 9.

Figure 9: Plot of maximum wind velocity throughout the whole system and average wind speed at the centre of the system depending on the angle of the building with respect to the wind



The average velocity drops significantly especially at high angles as the velocity profile is stretched horizontally, as shown in Figure 10. This is due to the walls no longer forming the 45_o angles allowing less air to be pushed inwards horizontally. However, the central area is still a location of high wind speed, meaning it would be a consistent position to install a wind turbine unlike aforementioned roof designs where the optimal position can move considerably (Abohela *et al*., 2012). The lowest average wind speed of 3.7m/s still represents an increase in speed by 24% which would result in a boost of almost double to the maximum efficiency of a wind turbine. The average speed at the 10 different angles is 4.1m/s which is a 37% increase over the inlet velocity of 3m/s. On average a wind turbine could work up to 2.6 times as efficiently as a wind turbine outside of the system, while the cut-in and rated speeds would also be lower by up to 27%.

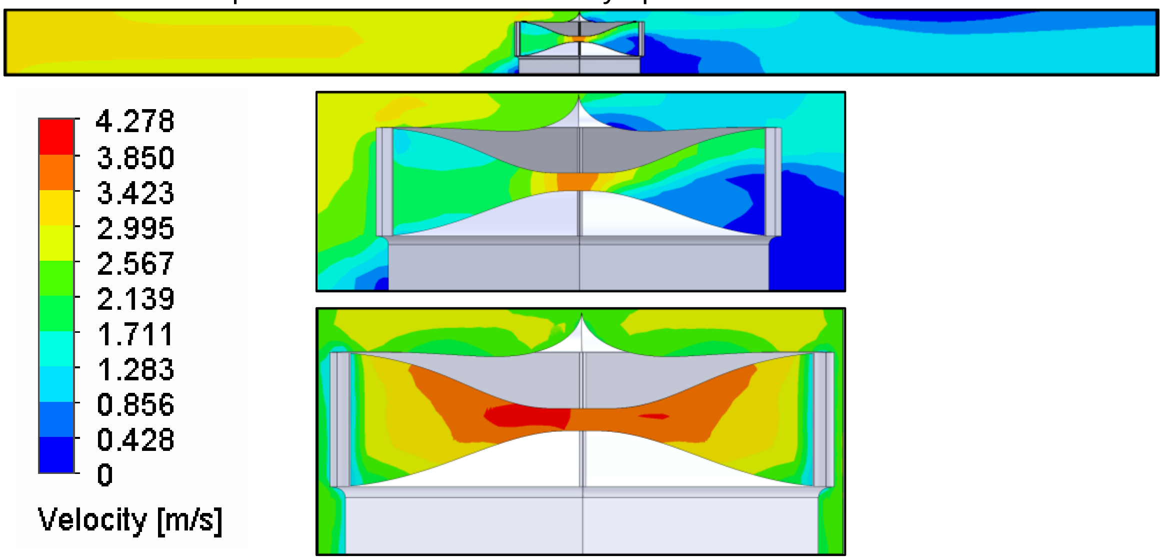


Figure 10: Velocity profile of flow simulation of the custom roof system rotated by 45_o to the wind.
Full length of the side profile (Top)
Close up of the side profile (Middle)
Front profile (Bottom)

Discussion

While this system may not close the gap in practicality between rooftop solar and rooftop wind power, it is a step in the right direction. In the majority of cases, a wind turbine installed in this system will still function below its rated level but it could be very useful in areas near to the poles where there are very short days during winter making solar energy an impractical year-round solution. The greatest potential of this technology lies in hybrid systems such as the one designed by Hang Wang *et al*. Due to the complementary nature of the seasonal biases of these two technologies there is considerable advantage to combining them, especially in the context of personal renewable energy.

By developing wind power into a feasible renewable energy option for homeowners, people in varied climates will be empowered to install their own source of renewable energy. Also, by removing the strong seasonal bias with the use of hybrid systems, homeowners will see renewable energy as a lower financial risk. Furthermore, the blockchain technology present across solar trading platforms can expand to also allow users to trade wind energy. This would allow for more fiscal engagement as customers would have the option to buy and sell electricity to their neighbours. An energy sharing scheme such as this would also give access to renewable energy to those unable to purchase solar panels or a wind turbine themselves, as they could buy it from their neighbours at an affordable price.

The biggest drawback to this system is the relatively large size of the roof compared to the rest of the house which could result in a high production cost. The large size could also be an unpopular addition aesthetically, especially considering the large shadows cast, which could hold people back from installing the system. The velocity profiles show that the wind has considerable levels of noise and while VAWTs are less effected by noise than HAWTs, they can still be less efficient when the air is noisy instead of a smooth laminar flow. Another problem is the scalability of this design as the wind leaving the system is very slow, this means that if multiple house in a close area install the system, they could have a detrimental effect on each other's efficiency.

This project still has many steps to go before it is ready for home installation. Larger simulations showing how the system would work when amongst other houses is crucial to investigate the practicality of the system as other structures will impact speed and direction. Creating different designs for different floor plans is also a crucial area of further investigation to make the system a more viable improvement for a variety of houses. For most floor plans that aren't square, the direction of wind will likely have a greater effect on the system. Running tests with scale models with wind turbines installed could also demonstrate how noisy the air and how much it improves the efficiency of the wind turbines. Taking inspiration from the INVELOX model 1 technology (Figure 4) in curving the air could also help with houses without a rectangular floor plan to still funnel the air into one location. Furthermore, testing for the optimal positioning of a multiple wind turbine arrangement would further allow the maximum potential of the system to be achieved. Interestingly, as the side profile in Figure 8 depicts, the wind speed is initially slowed down as it travels towards the house where it is then accelerated through the system. The initial slowing of the wind could be lessened by expanding the system so that the volume of the wind is shrunk more gradually. This could be achieved on large warehouses, industrial buildings or schools to provide them with a private source of energy.

Conclusion

Solar power is effectively the only choice for people who want to install their own source of renewable energy. Currently rooftop wind power is an impractical solution, due to low wind speeds and high levels of wind noise in suburban and urban areas. By customising rooves the wind speed can be accelerated to produce more energy with a wind turbine. On average the two-layer system increases windspeed by 37% which would result in an installed wind turbine working up to 2.6 times as efficiently as one outside the system. This increase in speed also effectively lowers the cut-in and rated speeds of a wind turbine by 27%. Further research should investigate designs for this system on houses with different floor plans as well as investigating the impact of other buildings on the efficiency of the system. While large scale sources of renewable energy are crucial lowering global carbon emissions, creating more options for homeowners to have access to a personal source of renewable energy is paramount to distributing the responsibility and maximise chances for success.

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