Indonesian Journal of Innovation Studies
Vol. 26 No. 4 (2025): October
DOI: 10.21070/ijins.v26i4.1675

Experimental Analysis of the Performance of Savonius VAWT with Different Numbers of Blades on Roofs

Jeremi Francisco — Mechanical Engineering Department, Faculty of Engineering, Universitas Pembangunan Nasional Veteran Jakarta, Depok
Damora Rhakasywi — Mechanical Engineering Department, Faculty of Engineering, Universitas Pembangunan Nasional Veteran Jakarta, Depok
Fahrudin Fahrudin — Mechanical Engineering Department, Faculty of Engineering, Universitas Pembangunan Nasional Veteran Jakarta, Depok

General Background: Renewable energy is increasingly vital for sustainable development, with wind energy offering significant potential in urban settings where land availability is limited. **Specific Background:** Vertical axis wind turbines (VAWTs), particularly Savonius types, are promising for rooftop applications but remain underexplored compared to horizontal axis turbines. **Knowledge Gap:** Limited studies have systematically examined how variations in blade number affect VAWT performance under low wind speed conditions typical of urban environments. **Aim:** This study investigates the performance of Savonius VAWTs with 3, 4, and 6 blades to determine the optimal configuration for efficient energy generation on building roofs. **Results:** Experimental testing over 24 hours at an average wind speed of 2 m/s revealed that the 3-blade turbine achieved the best performance, with a tip speed ratio (0.94), coefficient of power (0.242), and voltage output (14.41 V), outperforming the 4-blade and 6-blade designs. **Novelty:** This work demonstrates that reducing blade count can enhance efficiency in low-speed, rooftop urban wind applications, challenging the assumption that more blades inherently improve performance. **Implications:** The findings provide insights for optimizing small-scale renewable energy systems in urban areas, contributing to sustainable energy strategies and supporting national renewable energy targets.

Highlights:

- Three-blade Savonius turbine shows highest efficiency at low wind speeds.
- Blade number directly affects TSR, CP, and voltage output.
- Rooftop VAWT offers practical solution for small-scale urban energy.

Keywords: Wind, Wind Turbine, Tip Speed Ratio, Energy, Green Energy

Indonesian Journal of Innovation Studies
Vol. 26 No. 4 (2025): October
DOI: 10.21070/ijins.v26i4.1675

Introduction

Fossil energy is not the only source of energy available today. The world needs reliable and cost-effective renewable energy for a sustainable and cleaner[1]. New renewable energy (NRE) has been growing rapidly, making it a replacement solution for non-renewable fossil energy. With abundant solar energy on the equator that shines throughout the year, solar energy can be easily utilized in Indonesia. Likewise, wind energy is one of the most promising new renewable energies for power generation[2], [3].

Wind is a movement of air caused by differential heating of the atmosphere by the sun, planetary rotation, and irregularities in the Earth's surface[4]. Wind also blows continuously for 24 hours, something that the sun cannot do, as it only shines during the day. In general, wind energy is harnessed to generate electricity through wind turbines [5], [6]. A wind turbine is an electromechanical device that converts the kinetic energy of wind into electrical energy. The process is explained in two stages: the conversion of kinetic energy into rotational mechanical energy by the turbine blades, which is then converted into electrical energy by the generator[7].

Wind turbines are generally divided into two types: horizontal axis wind turbines and vertical axis wind turbines[7]. Horizontal Axis Wind Turbines (HAWT) are the most common type of wind turbine configuration, where the axis of rotation is parallel to the ground and the direction of the wind. Its high efficiency is a key feature, but it requires a mechanism to continuously face the wind and a tall tower to access more stable wind flows[8]. In contrast, Vertical Axis Wind Turbines (VAWT) are characterized by their vertically oriented rotor shafts. These wind turbines do not require strong winds to operate[9].

Indonesia's 2023 energy mix heavily relied on fossil fuels, with coal (40.46%), petroleum (30.18%), and natural gas (16.28%) making up the bulk. While renewable energy (EBT) saw a slight increase to 13.09%, this was still short of the 17.87% target. The government aims to boost EBT's contribution to 19.49% by 2024 and an ambitious 23% by 2025. To achieve this, Indonesia is committed to developing more renewable energy, particularly harnessing its significant wind energy potential. Regions like Sidrap and Jeneponto in South Sulawesi, for instance, could generate over 200 MW of wind power; they currently host wind farms with capacities of 75 MW and 72 MW respectively. According to the ministry of energy and mineral resources of Indonesia in 2024 [10].

VAWT (Vertical Axis Wind Turbine) is not as popular as HAWT (Horizontal Axis Wind Turbine), there are still many people who do not know the existence of VAWT let alone use it. Even though the use of VAWT on the rooftop of houses, apartments to office buildings can help produce clean electrical energy. Especially in people's homes, the use of VAWT can ease the burden of electricity they bear[11], [12],[13].

One of the important elements in wind turbines is the wind turbine blade. To determine the wind turbine blade, there are several factors that need to be considered, such as Coefficient Power (CP) and Tip Speed Ratio (TSR). The higher the Coefficient Power value, the more efficient the wind turbine blade and the higher the ability to obtain energy. Meanwhile, the Tip Speed Ratio is the ratio of the speed of the tip of the blade to the wind speed, so the higher the TSR value, the higher the rotational speed of the blade [14], [15].

Method

This research was conducted using an experimental method, testing a modified Savonius-type vertical axis wind turbine that had been flattened and had bends at the ends of its blades. The wind turbine had dimensions of 60 cm in height and 40 cm in diameter. There were three blade variations in this study: 3 blades, 4 blades, and 6 blades, as shown in the figure.

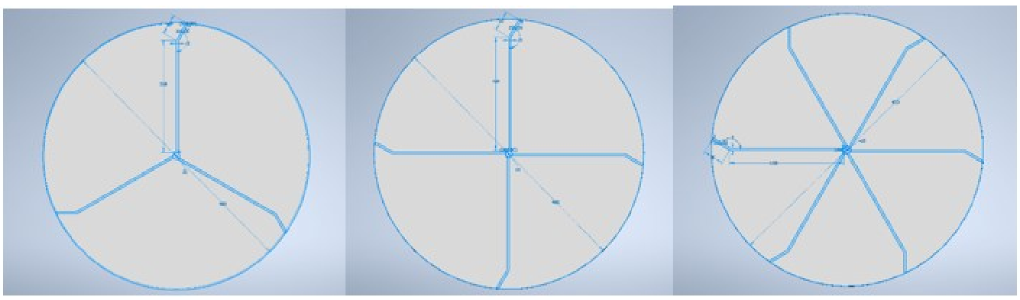

Figure 1. Top view of the VAWT design

DOI: 10.21070/ijins.v26i4.1675

Figure 2. The VAWT design

Data collection was conducted over a 24-hour period for each variation, with measurements taken every hour. Data collection was conducted on the roof of the UNPVJ Faculty of Engineering building, located in Limo, Depok. The data collected included the Tip Speed Ratio (TSR) of the wind turbine, the average Power Coefficient (CP) of the wind turbine every hour, and the electrical voltage generated by the wind turbine. Data collection was assisted by an ESP-32 using an anemometer sensor, a tachometer sensor, and an INA219 (current + voltage) sensor.

The material used for this wind turbine is PVC board. PVC board was chosen because of its lightweight nature and greater strength compared to plywood. The generator used is a 12V DC motor. The storage device used is a 12V 10A battery.

Wind turbines require wind energy, which is then converted by the turbine into mechanical energy. The amount of power obtained by the turbine can be calculated using the following formula:

$$Pw = \frac{1}{2} . \rho . A . V \qquad (1)$$

The cross-sectional area of a wind turbine is calculated as follows:

$$A = L . H$$

$$A = (2D - b - 2x)\, H \qquad (2)$$

After processing the measurement results of the wind turbine, we can begin to calculate the Coefficient of Power (CP), starting with determining the actual power of the turbine, which can be calculated using the formula:

$$PT = TD . \omega \qquad (3)$$

The required torque is calculated using the formula:

$$TD = F . r \qquad (4)$$

The force acting on the turbine shaft is calculated using the formula:

$$F = (m - s) . g \qquad (5)$$

The rotational speed of the Savonius wind turbine can be found using the formula

$$\omega = \frac{2.\pi.n}{60} \qquad (6)$$

Then the Moment Coefficient (CM) can be obtained using the formula:

$$CM = \frac{4\ .TD}{\rho\ .A\ .V\ 2.L} \qquad (7)$$

Additionally, the Tip Speed Ratio, which is the ratio between the turbine rotation speed and wind speed, is calculated using the formula:

$$TSR = \frac{\omega\ .R}{V} \qquad (8)$$

The Coefficient of Power (CP) is the ratio between the mechanical power generated by the wind turbine blades and the power generated by the drag force of the airflow. Therefore, it can be formulated as:

$$CP = \frac{PT}{PW} \quad (9)$$

Nomenclature:

Pw = Wind Power (W)

ρ = Wind Density $\left({}^{kg}/_{m^3}\right)$

A = Turbine Cross-sectional Area (m^2)

V = Wind Speed $({}^{m}/_{s})$

D = Wind Turbine Blade Diameter(m)

R = Wind Turbine Radius (m)

b = *Overlap Shaft Diameter*(m)

H = Wind Turbine Height (m)

PT = Actual Power of the Wind Turbine (Watt)

TD = Dynamic Torque of the Turbine measured in the study(Nm)

ω = Rotational Speed of the Wind Turbine $\left({}^{rad}/_{s}\right)$

F = Force (N)

m = Mass of the Weight(kg)

s = Spring (kg)

g = Gravity $\left({}^{m}/_{s^2}\right)$

n = Rotational Speed of the Turbine Turbin (rpm)

Results and Discussion

The results of this experiment are presented based on variations in the number of blades of wind turbines at low wind speeds, as discussed in the following sections. Keep in mind that wind speed during experimental testing varies considerably, with an average wind speed of 2 m/s.

A. Tip Speed Ratio (TSR) of a VAWT

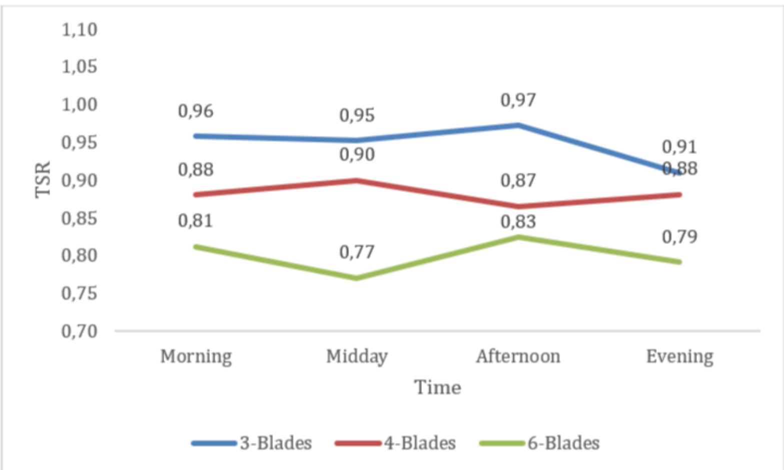

Figure 3. TSR Chart

Vol. 26 No. 4 (2025): October
DOI: 10.21070/ijins.v26i4.1675

As is known, because this is an outdoor experiment with unstable wind speeds, the data fluctuates. However, from the data obtained, it can be concluded that wind speeds are more stable at night than during the day, when they tend to vary.

From the results of the 24-hour experiment, data was obtained showing that the TSR value for 3 blades (with an average of 0.94) was higher than that for 4 blades (with an average of 0.88) and 6 blades (with an average of 0.80). At all times of the day (morning, midday, afternoon, and evening), the VAWT with 3 blades outperformed the others.

As shown in the graph, there were variations in TSR across each blade at the four time points. For instance, in the morning, the VAWT with 3 blades outperformed the 3-blade VAWT in the midday.In contrast, for the 4-blade configuration, the midday performance was superior to that of the 4-blade VAWT in the morning.

B. Coefficient Power (CP) of a VAWT

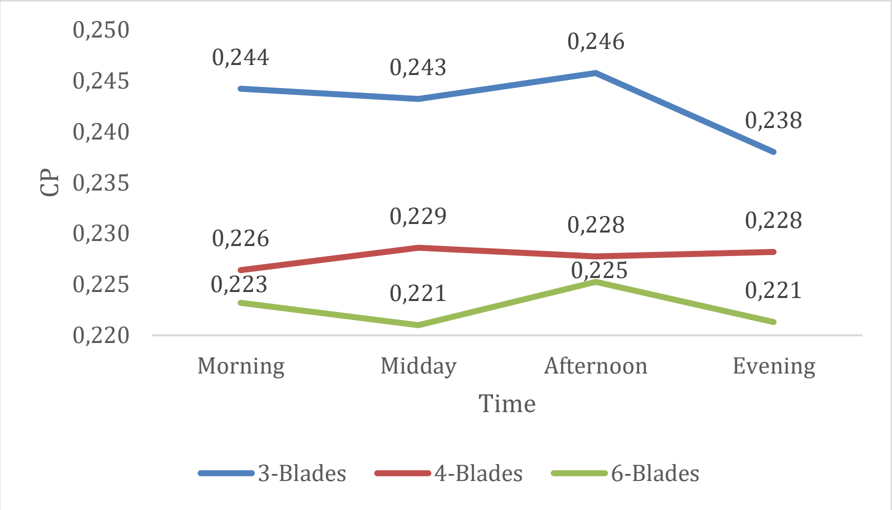

Figure 4. CP Chart

From the results of a 24-hour experiment, data was obtained showing that the CP in 3 blades (with an average of 0,242) was higher than in 4 blades (with an average of 0,228) and 6 blades (with an average of 0,222). Similarly to TSR, VAWT with 3 blades outperformed the other two in terms of CP. The highest CP was obtained from the 3-blade VAWT in the afternoon, and the lowest was obtained from the 6-blade VAWT in the midday and evening.

C. Voltage Generated by VAWT

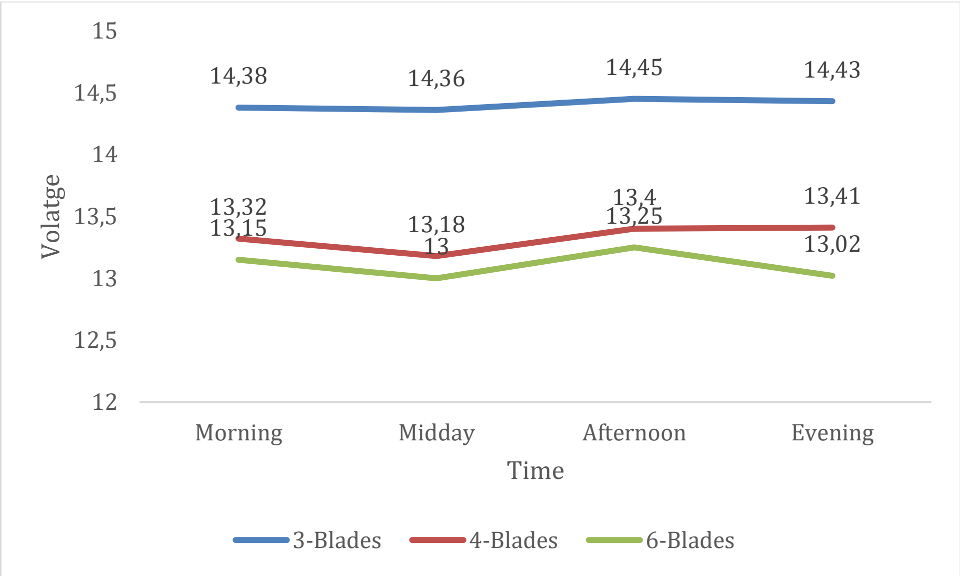

Figure 5. Voltage Chart

From the results of a 24-hour experiment, data was obtained showing that the Voltage in 3 blades (with an average of 14.41V) was higher than in 4 blades (with an average of 13.34V) and 6 blades (with an average of 13.08V). The highest voltage was recorded at the 3-blade VAWT at 14.45 V in the afternoon, and the lowest at the 6-blade VAWT at 13 V in the morning.

D. CP vs TSR

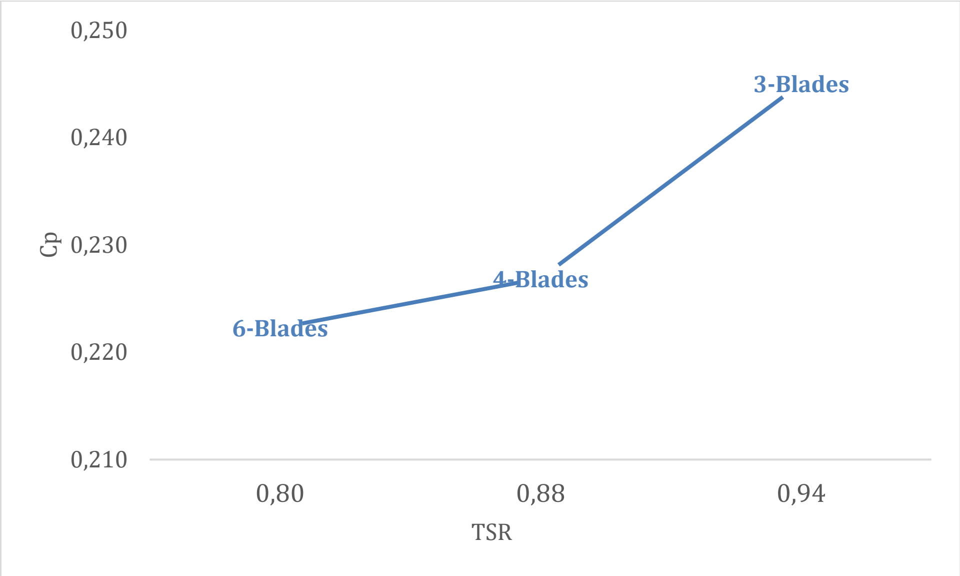

Figure 6. CP vs TSR

As can be seen, the highest average CP is found in 3 blades, while there is little difference between 4 blades and 6 blades.

Conclusion

From the results of the experiments conducted, several findings were obtained. At a wind speed of 2 m/s, the 3-bladed wind turbine was more efficient than the 4-bladed and 6-bladed wind turbines. The 3-bladed wind turbine produced an average tip speed ratio (TSR) of 0.94 and a coefficient of power (CP) of 0.242. Meanwhile, the 4-blade and 6-blade wind turbines produced TSR values of 0.88 and 0.80, respectively, with CP values of 0.228 and 0.222. Additionally, the 3-blade wind turbine produced an average electrical voltage of 14.41 V. Meanwhile, the 4-blade and 6-blade wind turbines produced electrical voltages of 13.48 V and 13.01 V, respectively.

Acknowledgments

Acknowledgments to supervisors and colleagues who have provided direct or indirect assistance. To the staff of UPNVJ for facilitating access to available facilities. To the Research and Community Service Office (LPPM) of the University of National Veterans' Development Jakarta for funding this research with the Chancellor's decision number: 977/UN61/HK.03.01/2024 (Project number: 118/UN61.4/LIT.RISCOP/2024).

References

[1] K. Rashid, S. M. Safdarnejad, and K. M. Powell, "Dynamic Simulation, Control, and Performance Evaluation of a Synergistic Solar and Natural Gas Hybrid Power Plant," Energy Conversion and Management, vol. 179, pp. 270–285, Jan. 2019, doi: 10.1016/j.enconman.2018.10.054.
[2] R. Kumar, K. Raahemifar, and A. S. Fung, "A Critical Review of Vertical Axis Wind Turbines for Urban Applications," Renewable and Sustainable Energy Reviews, Jun. 2018, doi: 10.1016/j.rser.2018.03.033.
[3] M. K. G. Deshmukh, M. Sameeroddin, D. Abdul, and M. Abdul Sattar, "Renewable Energy in the 21st Century: A Review," Materials Today: Proceedings, vol. 80, pp. 1756–1759, Jan. 2023, doi: 10.1016/j.matpr.2021.05.501.
[4] National Geographic, "Wind," National Geographic, Aug. 23, 2025. [Online]. Available: https://education.nationalgeographic.org/resource/wind/

[5] T. Zhang, B. Tian, D. Sengupta, L. Zhang, and Y. Si, "Global Offshore Wind Turbine Dataset," Scientific Data, vol. 8, no. 1, Dec. 2021, doi: 10.1038/s41597-021-00982-z.
[6] H. J. Wagner, "Introduction to Wind Energy Systems," in EPJ Web of Conferences, EDP Sciences, Oct. 2018, doi: 10.1051/epjconf/201818900005.
[7] F. Porté-Agel, M. Bastankhah, and S. Shamsoddin, "Wind-Turbine and Wind-Farm Flows: A Review," Boundary-Layer Meteorology, vol. 174, no. 1, pp. 1–59, Jan. 2020, doi: 10.1007/s10546-019-00473-0.
[8] D. A. Umar, C. T. Yaw, S. P. Koh, S. K. Tiong, A. A. Alkahtani, and T. Yusaf, "Design and Optimization of a Small-Scale Horizontal Axis Wind Turbine Blade for Energy Harvesting at Low Wind Profile Areas," Energies, vol. 15, no. 9, May 2022, doi: 10.3390/en15093033.
[9] D. H. Didane, M. R. Behery, M. Al-Ghriybah, and B. Manshoor, "Recent Progress in Design and Performance Analysis of Vertical-Axis Wind Turbines—A Comprehensive Review," Processes, Jun. 2024, doi: 10.3390/pr12061094.
[10] N. A. Pambudi, D. K. Ulfa, I. R. Nanda, I. M. Gandidi, A. Wiyono, M. K. Biddinika, et al., "The Future of Wind Power Plants in Indonesia: Potential, Challenges, and Policies," Sustainability, vol. 17, no. 3, p. 1312, 2025, doi: 10.3390/su17031312.
[11] M. K. Johari, M. A. A. Jalil, and M. F. M. Shariff, "Comparison of Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT)," International Journal of Engineering and Technology (UAE), vol. 7, no. 4, pp. 74–80, 2018, doi: 10.14419/ijet.v7i4.13.21333.
[12] K. A. H. Al-Gburi, F. B. I. Alnaimi, B. A. J. Al-Quraishi, E. S. Tan, and A. K. Kareem, "Enhancing Savonius Vertical Axis Wind Turbine Performance: A Comprehensive Approach with Numerical Analysis and Experimental Investigations," Energies, vol. 16, no. 10, May 2023, doi: 10.3390/en16104204.
[13] A. S. Saad, I. I. El-Sharkawy, S. Ookawara, and M. Ahmed, "Performance Enhancement of Twisted-Bladed Savonius Vertical Axis Wind Turbines," Energy Conversion and Management, vol. 209, Apr. 2020, doi: 10.1016/j.enconman.2020.112673.
[14] H. R. N. Ramadhan, A. R. Firmansyah, W. S. Adi, and T. R. Mulyadi, "Analisis Pengaruh Kecepatan Angin dan Overlap Ratio Terhadap Kinerja Turbin Angin Savonius Tipe-U," JTRAIN: Jurnal Teknologi Rekayasa Teknik Mesin, vol. 6, no. 1, pp. 1–7, 2025.
[15] S. Mahmud, W. Hardi, and B. Tjiroso, "Pengaruh Sudut Blade Terhadap Tip Speed Ratio (TSR) dan Coefficient of Power (Cp) pada Turbin Angin Savonius Type V," Prosiding Seminar Nasional Teknik Mesin, Badan Kerjasama Teknik Mesin Indonesia, pp. 303–309, Feb. 2025, doi: 10.71452/590801.