

# Wind turbine for urban application

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## ABSTRACT

*Rapid urbanization and increasing energy demand have intensified the need for clean and decentralized power solutions within cities. Urban wind turbines present a promising approach to harness renewable energy in built environments, where conventional large-scale wind farms are impractical. These systems are specifically designed to operate under complex urban wind conditions characterized by turbulence, low wind speeds, and multidirectional airflow.*

*Urban wind turbines are broadly classified into horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). Among these, VAWTs are more suitable for city applications due to their ability to capture wind from any direction, lower noise levels, and compact design. Additionally, innovations such as building-integrated wind turbines (BIWTs) enable seamless incorporation into architectural structures, enhancing both energy efficiency and aesthetic appeal.*

*Despite their advantages, urban wind turbines face challenges including lower efficiency, high installation costs, and regulatory constraints. Their power output is generally limited, making them more suitable as supplementary energy sources rather than primary power providers. However, when combined with other renewable technologies such as solar photovoltaics, they contribute significantly to hybrid energy systems.*

### Keywords:

*Urban wind turbines, renewable energy, sustainable energy generation, urbanization, decentralized power, built environment, wind energy, vertical axis wind turbines (VAWTs), horizontal axis wind turbines (HAWTs), building-integrated wind turbines (BIWTs).*

## I. INTRODUCTION

The rapid growth of urban populations and the corresponding increase in energy demand have created significant challenges for sustainable development. Cities, being major consumers of energy, are also key contributors to greenhouse gas emissions and environmental degradation. In response, there is a growing emphasis on integrating renewable energy technologies within urban environments to reduce dependence on fossil fuels and promote cleaner energy solutions. Among the various renewable sources, wind energy has emerged as a viable option, and its adaptation to urban settings has led to the development of urban wind turbines.

Urban wind turbines are specifically designed to operate efficiently within the complex and constrained conditions of cities. Unlike conventional wind turbines installed in open and rural areas, urban turbines must function in environments characterized by low wind speeds, high turbulence, and multidirectional airflow caused by surrounding buildings and structures. To address these challenges, innovative designs such as vertical axis wind turbines (VAWTs) and building-integrated wind turbines (BIWTs) have been developed, offering improved adaptability, reduced noise, and enhanced safety for urban deployment.

The integration of wind turbines into urban infrastructure not only contributes to decentralized energy generation but also supports the concept of smart and sustainable cities. These systems can be installed on rooftops, along building facades, or incorporated directly into architectural designs, thereby utilizing otherwise untapped wind resources. Although the energy output of urban wind turbines is relatively lower compared to large-scale wind farms, they play an important role as supplementary energy sources, particularly when combined with other renewable technologies such as solar photovoltaic systems.

Despite their potential, urban wind turbines face several challenges, including economic feasibility, regulatory constraints, and performance limitations due to variable wind conditions. Nevertheless, ongoing advancements in technology, materials, and urban planning strategies continue to improve their efficiency and practicality. This study explores the design, application, and potential of urban wind turbines as a sustainable solution for meeting the growing energy demands of modern cities while minimizing environmental impact.



FIG: 1 Vertical Axis Wind Turbines (VAWTs)

## II. PROBLEM IDENTIFICATION

The implementation of wind turbines in urban environments presents several technical, economic, and environmental challenges that limit their widespread adoption and efficiency. Unlike rural or offshore areas, cities are characterized by highly irregular wind patterns caused by the presence of buildings, trees, and other obstacles. This results in turbulent, low-speed, and multidirectional wind flows, which significantly reduce the performance and reliability of conventional wind turbine systems.

One of the primary problems is the low efficiency of energy generation in urban settings. Due to inconsistent wind speeds, turbines often fail to operate at their optimal capacity, leading to reduced power output. Additionally, improper placement of turbines on rooftops or within dense building clusters further diminishes their effectiveness by exposing them to wind shadows and eddies.

Another major concern is **noise and vibration**, which can affect the comfort and well-being of residents. Horizontal axis wind turbines, in particular, may generate noticeable sound and structural vibrations, making them less suitable for residential areas. Safety issues, such as blade failure or structural instability, also pose risks in densely populated environments.

The high initial cost and maintenance requirements of urban wind turbines present economic challenges. The return on investment is often uncertain due to variable energy production, making it less attractive for individuals and organizations. Furthermore, regulatory and zoning restrictions in urban areas can complicate installation, requiring compliance with building codes, height limitations, and safety standards.

Aesthetic concerns also play a role in limiting adoption, as urban residents and planners may resist installations that disrupt the visual appeal of city landscapes. In addition, there is a lack of awareness and technical expertise regarding the design and integration of efficient urban wind systems.

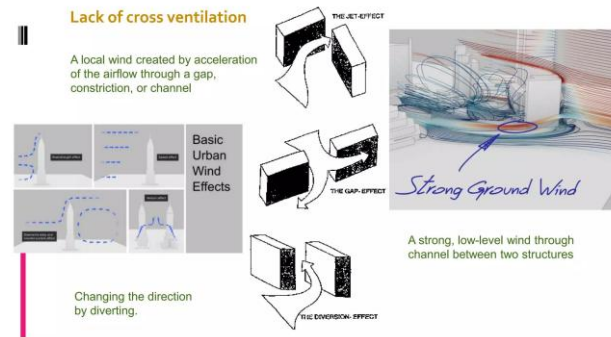


FIG: 2 – LACK OF CROSS VENTILATION WIND

### III. LITERATURE SURVEY

#### a) Literature Review:

The study of urban wind turbines has gained significant attention in recent years due to the increasing demand for decentralized and sustainable energy solutions. Various researchers have explored different aspects of urban wind energy, including aerodynamics, turbine design, performance optimization, and integration within built environments.

Early research primarily focused on the aerodynamic challenges associated with urban wind conditions. According to Micallef and Van Bussel (2018), the complex airflow in cities—characterized by turbulence, multidirectional wind, and flow separation around buildings—poses a major limitation to the efficient operation of wind turbines. These studies emphasize that understanding urban wind behaviour is crucial for improving turbine performance and placement strategies.

Several studies have identified Vertical Axis Wind Turbines (VAWTs) as more suitable for urban applications compared to Horizontal Axis Wind Turbines (HAWTs). VAWTs can operate independently of wind direction and perform better under low and unstable wind conditions, making them ideal for built environments. Recent research also highlights that VAWTs offer advantages such as low noise, enhanced safety, and better adaptability for rooftop installations.

Advancements in computational modelling and simulation techniques, particularly Computational Fluid Dynamics (CFD), have significantly contributed to the analysis and optimization of urban wind turbines. CFD-based studies demonstrate that turbine performance is highly dependent on placement, surrounding structures, and wind flow patterns. Improper siting can lead to significant discrepancies between predicted and actual energy output.

Recent literature also focuses on performance enhancement and hybrid systems. Bibliometric analyses indicate a growing trend in integrating wind turbines with solar energy systems to form hybrid renewable solutions for urban environments. Additionally, studies on rooftop installations highlight the importance of assessing building aerodynamics, wind resource availability, and turbine design parameters to maximize efficiency.

Furthermore, research on building-integrated wind energy systems (BIWTs) demonstrates the potential of incorporating turbines into architectural designs to improve energy utilization without requiring additional land. Experimental studies on residential buildings show that small-scale wind turbines can contribute to reducing dependence on conventional energy sources when properly designed and installed.

Despite these advancements, the literature consistently identifies several research gaps, including the need for real-world performance validation, cost optimization, and improved turbine designs capable of operating efficiently in highly turbulent urban conditions. Overall, existing studies indicate that while urban wind turbines hold promise, further interdisciplinary research is required to enhance their feasibility and large-scale adoption.

In summary, the literature reveals that urban wind energy systems are evolving through innovations in turbine design, simulation techniques, and hybrid integration, but challenges related to efficiency, cost, and environmental conditions remain key areas for future research.

## b) Literature Summary

The reviewed literature indicates that urban wind turbines have emerged as a promising solution for decentralized and sustainable energy generation in cities. Researchers have extensively studied the impact of complex urban wind conditions, highlighting challenges such as turbulence, low wind speeds, and multidirectional airflow. Among various turbine designs, Vertical Axis Wind Turbines (VAWTs) are consistently identified as more suitable for urban environments due to their ability to operate efficiently under variable wind directions and their lower noise levels.

Advanced tools such as Computational Fluid Dynamics (CFD) have been widely used to analyse wind flow patterns around buildings and optimize turbine placement. Studies also emphasize the importance of proper siting, as turbine performance in urban areas is highly dependent on location and surrounding structures. Furthermore, the integration of wind turbines into buildings, known as Building-Integrated Wind Turbines (BIWTs), has shown potential in enhancing energy generation while maintaining architectural aesthetics.

## c) Research Gap:

Despite significant progress, several gaps remain in the existing research on urban wind turbines. One of the major gaps is the lack of real-world performance data, as many studies rely heavily on simulations rather than long-term field experiments. This creates uncertainty in predicting actual energy output and system reliability in diverse urban conditions.

Another key gap is the limited focus on cost-effectiveness and economic feasibility. While technical performance has been widely studied, fewer studies address affordability, return on investment, and lifecycle costs, which are critical for practical implementation. Additionally, there is a need for improved turbine designs that can operate efficiently in highly turbulent and low-speed wind environments typical of dense urban areas.

Research is also lacking in standardized guidelines for turbine placement, safety measures, and integration with existing infrastructure. Social and regulatory aspects, including public acceptance, noise concerns, and urban policies, are not sufficiently explored. Moreover, the potential of smart technologies and real-time monitoring systems for optimizing turbine performance remains underdeveloped.

Therefore, future research should focus on developing efficient, cost-effective, and adaptive urban wind turbine systems supported by real-world validation, interdisciplinary approaches, and integration with smart city frameworks to ensure sustainable urban energy solutions.

## IV. RESEARCH METHODOLOGY

The research methodology for this study incorporates both simulation and experimental approaches, supported by the development of a 3D-printed prototype model as shown in the provided figure. The model represents a small-scale urban wind turbine system designed and fabricated to evaluate performance under controlled conditions.

### 1. Design and 3D Modelling:

The turbine components, including blades and supporting structure, were first designed using CAD software. Special attention was given to blade geometry to ensure suitability for low-speed and turbulent urban wind conditions. The design was optimized for fabrication using additive manufacturing techniques.

### 2. Prototype Fabrication using 3D Printing:

The finalized design was manufactured using a 3D printer, allowing precise construction of complex blade shapes and lightweight structures. The use of 3D printing enables rapid prototyping, cost efficiency, and easy modification of design parameters for experimental testing.

### 3. Experimental Setup:

The fabricated turbine model was mounted on a test platform, as visible in the image, along with essential components such as:

- A small DC generator
- Support stands for stability
- Electrical connections and measurement devices (digital display for voltage/current)

This setup allows real-time monitoring of turbine performance.

#### 4. Wind Input and Testing:

Artificial wind flow (using a fan or controlled airflow source) was directed towards the turbine to simulate urban wind conditions. Different wind speeds and directions were tested to analyze turbine behavior under variable conditions.

#### 5. Data Collection:

Key performance parameters were recorded, including:

- Rotational speed (RPM)
- Voltage and current output
- Power generation efficiency

The digital measuring unit in the setup was used to capture electrical output data accurately.

#### 6. Performance Analysis:

The collected data was analysed to evaluate the efficiency of the turbine design. The results were compared with theoretical expectations and simulation outputs to validate the effectiveness of the prototype.

#### 7. Design Optimization:

Based on the experimental results, modifications can be made to blade design, orientation, and structure to improve performance. The flexibility of 3D printing allows iterative improvements in the prototype.

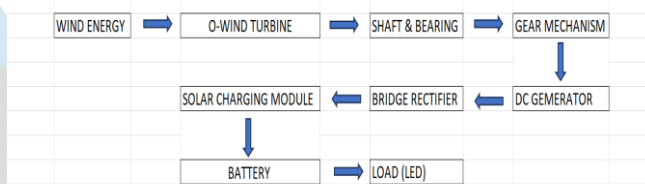


FIG: 3 - Block diagram for wind turbine

## V. DISCUSSION

The research focused on the design, development, and testing of a 3D-printed multidirectional urban wind turbine prototype to evaluate its suitability for urban energy applications. The discussion of the results highlights both the strengths and limitations observed during the study.

The experimental results demonstrate that the proposed spherical turbine design is capable of operating under multidirectional wind conditions, which is a key requirement for urban environments. Unlike conventional turbines, the prototype does not require alignment with wind direction, making it more adaptable to turbulent airflow commonly found between buildings.

The use of a lightweight PLA material and compact structure contributed to a relatively low inertia, allowing the turbine to initiate rotation at moderate wind speeds (around 4–5 m/s). This confirms the feasibility of using 3D printing technology for rapid prototyping and development of customized turbine designs.

However, the power output of the prototype was limited, which is expected for small-scale models. The energy generated is sufficient for low-power applications such as LED lighting or sensor systems but not adequate for large-scale energy demands. This reinforces the idea that such turbines are best suited as supplementary energy sources rather than primary power generators in urban settings.

Another important observation is the impact of airflow conditions on performance. The turbine performed more efficiently under steady airflow compared to highly turbulent conditions. This indicates that proper placement, such as on rooftops or elevated structures, is crucial for maximizing energy output.

The integration of measurement devices in the setup enabled accurate monitoring of voltage and current, providing valuable data for performance evaluation. The results also showed that the internal vent design plays a significant role in generating torque, validating the concept of using pressure differentials for rotation.

Despite its advantages, the prototype requires further optimization in terms of blade design, material strength, and aerodynamic efficiency. Future improvements could include the use of advanced materials, larger-scale models, and integration with hybrid renewable systems such as solar panels.

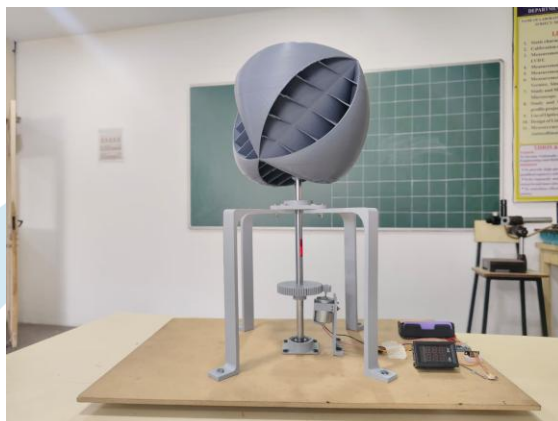


FIG: 4 - 3D Model of Wind Turbine

## VI. RESULT

The experimental data obtained from the testing of the 3D-printed urban wind turbine prototype provides a clear understanding of its performance characteristics under varying wind speeds.

The results show that as the wind speed increases from 5.0 m/s to 9.0 m/s, there is a consistent increase in turbine performance parameters such as rotational speed (RPM), voltage output, electrical power, and mechanical power.

The rotational speed (RPM) increased from 180 RPM at 5.0 m/s to 350 RPM at 9.0 m/s, indicating a strong positive correlation between wind speed and turbine rotation. This confirms that the turbine effectively converts wind energy into mechanical motion.

Similarly, the voltage output showed a gradual rise from 4.20 V to 6.00 V, demonstrating stable electrical generation. The electrical power output increased from approximately 1.76 W to 3.60 W, which reflects the capability of the turbine to generate usable electrical energy for low-power applications.

A significant observation is the increase in mechanical power, which rose from 24.04 W to 140.20 W across the tested wind speed range. This indicates that while mechanical energy capture is relatively high, there are conversion losses when transforming it into electrical energy, suggesting scope for improving generator efficiency.

Some minor fluctuations in intermediate readings (for example, around 6.4–6.5 m/s wind speed) were observed, likely due to turbulence and experimental variations, which are common in urban wind simulations.

Sr no	Wind speed	RPM	Voltage (V)	Electrical Power (W)	Mechanical power (W)	11	7.10	283	5.71	3.26	68.83
1	5.0	180	4.20	1.764	24.04	12	7.31	291	5.74	3.29	75.12
2	5.21	188	4.34	1.823	27.19	13	7.52	298	5.77	3.32	81.78
3	5.42	197	4.48	2.00	30.62	14	7.73	306	5.80	3.36	88.83
4	5.63	205	4.62	2.13	34.32	15	7.94	313	5.83	3.39	96.27
5	5.84	213	4.76	2.26	38.30	16	8.15	321	5.86	3.43	104.11
6	6.05	223	4.92	2.42	42.58	17	8.36	328	5.89	3.46	112.37
7	6.29	263	5.09	2.59	47.86	18	8.57	336	5.92	3.50	121.05
8	6.47	248	5.26	2.76	42.08	19	8.78	343	5.96	3.55	130.17
9	6.68	261	5.43	2.94	57.32	20	9.00	350	6.00	3.60	140.20
10	6.89	273	5.60	3.13	62.90						

FIG: 5- Characteristic of wind speed vs voltage

## VII. Conclusion

The present study successfully explored the design, development, and performance evaluation of a 3D-printed multidirectional urban wind turbine for sustainable energy generation. The research demonstrated that urban wind energy can be effectively harnessed using innovative turbine designs that are specifically adapted to low-speed and turbulent wind conditions.

The proposed spherical turbine design proved to be capable of capturing wind from multiple directions without requiring alignment, making it highly suitable for complex urban environments. Experimental results confirmed that the turbine operates efficiently within a wind speed range of 5–9 m/s, producing measurable electrical output sufficient for small-scale applications.

The use of 3D printing technology enabled cost-effective prototyping, lightweight construction, and design flexibility, which are essential for rapid development and testing. The data analysis revealed a direct relationship between wind speed and performance parameters such as RPM, voltage, and power output, validating the effectiveness of the design.

However, the study also identified certain limitations, including relatively low electrical output and energy conversion losses. These limitations indicate the need for further improvements in generator efficiency, aerodynamic optimization, and material selection to enhance overall performance.

Future work should focus on scaling the design, improving efficiency, and integrating smart monitoring systems to maximize performance and support the development of sustainable and energy-efficient urban infrastructures.

## VIII. REFERENCES

- [1] Micallef, D., & Van Bussel, G. J. W. (2018). *A review of urban wind energy research: Aerodynamics, technology and policy*. *Energies*, 11(9), 2204.
- [2] Toja-Silva, F., Colmenar-Santos, A., & Castro-Gil, M. (2013). *Urban wind energy exploitation systems: Behaviour under multidirectional flow conditions—Opportunities and challenges*. *Renewable and Sustainable Energy Reviews*, 24, 364–378.
- [3] Stathopoulos, T., Alrawashdeh, H., Al-Quraan, A., et al. (2018). *Urban wind energy: Some views on potential and challenges*. *Journal of Wind Engineering and Industrial Aerodynamics*, 179, 146–157.
- [4] Rezaeiha, A., Kalkman, I., & Blocken, B. (2017). *Effect of pitch angle on power performance and aerodynamics of a vertical axis wind turbine*. *Applied Energy*, 197, 132–150.
- [5] Balduzzi, F., Bianchini, A., Ferrari, L., & Magnani, S. (2012). *Microeolic turbines in the built environment: Influence of the installation site on performance*. *Renewable Energy*, 45, 163–174.
- [6] Howell, R., Qin, N., Edwards, J., & Durrani, N. (2010). *Wind tunnel and numerical study of a small vertical axis wind turbine*. *Renewable Energy*, 35(2), 412–422.
- [7] Islam, M. R., Mekhilef, S., & Saidur, R. (2013). *Progress and recent trends of wind energy technology*. *Renewable and Sustainable Energy Reviews*, 21, 456–468.
- [8] Paraschivoiu, I. (2002). *Wind Turbine Design: With Emphasis on Darrieus Concept*. Montreal: Polytechnic International Press.
- [9] Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). *Wind Energy Explained: Theory, Design and Application* (2nd ed.). Wiley.
- [10] Burton, T., Sharpe, D., Jenkins, N., & Bossanyi, E. (2011). *Wind Energy Handbook* (2nd ed.). Wiley.
- [11] Kumar, Y., Ringenberg, J., Depuru, S. S. S., et al. (2016). *Wind energy: Trends and enabling technologies*. *Renewable and Sustainable Energy Reviews*, 53, 209–224.
- [12] Gipe, P. (2004). *Wind Power: Renewable Energy for Home, Farm, and Business*. Chelsea Green Publishing.
- [13] Blocken, B. (2014). *50 years of computational wind engineering: Past, present and future*. *Journal of Wind Engineering and Industrial Aerodynamics*, 129, 69–102.
- [14] Pope, S. B. (2000). *Turbulent Flows*. Cambridge University Press.
- [15] Ashrafian, A., & Sedaghat, A. (2016). *A review on design and analysis of vertical axis wind turbines*. *Energy Equipment and Systems*, 4(2), 89–107.