energies

MDPI

Review

A Review of Ducted Wind Turbines for Integration into Urban Building Environments, with a Focus on the Invelox System

Ahmad Dabche, Islam Abohela * and Hamidreza Gohari Darabkhani

School of Digital, Technology, Innovation and Business, University of Staffordshire, Stoke-on-Trent ST4 2DE, UK; ahmad.dabche@research.staffs.ac.uk (A.D.); h.g.darabkhani@staffs.ac.uk (H.G.D.)
* Correspondence: islam.abohela@staffs.ac.uk

Abstract

Ducted wind turbines (DWTs) have been proposed to improve wind energy capture and conversion where conventional open-rotor turbines are constrained by limited wind resources, turbulence, visual impact, or integration requirements. This review examines the engineering principles, major DWT types, and challenges associated with integrating DWTs into building environments. The review compares nozzle/lens, diffuser-augmented, and INVELOX-type systems with particular attention to aerodynamic augmentation, wind-direction sensitivity, geometric requirements, structural integration, noise and vibration, economic feasibility, environmental effects, and regulatory considerations. This paper synthesises findings reported in the literature and identifies areas where evidence remains insufficient for building-scale deployment. A literature-informed multi-criteria decision analysis MCDA is presented as an exploratory comparison tool; its scores are explicitly treated as literature-based judgements rather than measured performance data. The literature indicates that INVELOX-type systems are of particular research interest because of their omnidirectional intake and separation of the collection and generation functions, but published evidence for realistic urban building applications remains limited. Consequently, INVELOX should be regarded as a candidate technology requiring further experimental, numerical, structural, acoustic, economic, and field validation rather than as an established optimum. The review concludes by linking the identified evidence gaps to a staged research agenda involving urban flow CFD, wind-tunnel validation, structural and vibration assessment, aeroacoustics, lifecycle-economic analysis, and building-specific feasibility assessment.

Keywords: ducted wind turbine; urban wind energy; building integration; aerodynamic performance; energy sustainability; renewable energy systems; computational fluid dynamics CFD

Check for updates

Academic Editors: Mingwei Ge and Xintao Li

Received: 16 September 2026
Revised: 4 October 2026
Accepted: 8 October 2026
Published: 12 October 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

IPCC (The Intergovernmental Panel on Climate Change) asserted that total GHG (Greenhouse Gas) emissions from the building sector reached 12 $GtCO_2$-eq, accounting for 21% of global emissions. When considering only CO_2 emissions, buildings contributed to 31% of global CO_2 emissions [1], indicating that buildings possess significant potential for climate mitigation, contributing substantially to global climate goals when combined with sufficient measures, technological innovations, and the deployment of renewable energy. The state of atmospheric pollution in urban settings, along with rising energy demands, has made society more aware of the need for architectural decisions that reduce energy consumption and incorporate energy supply considerations into planning processes. Yet,

a significant percentage of the European population still lives in high population-density urban centres, where there is not enough space to provide the required energy supply with conventional roof-mounted photovoltaic or encompassing solar trumpet elements [2].

On the other hand, according to Abohela [3], the wind speed near urban structures can be considerably greater than the typical free-stream wind speed at that location under identical flow conditions when contrasted with an unoccupied area. A comparable phenomenon takes place when a concentrator is utilised to channel wind flow towards a wind turbine. Considering the accelerating effect of buildings, it is important to utilise buildings as concentrators.

In response to the demand for integrating renewable energy systems into building designs, architects and engineers are adopting new strategies to incorporate energy supply concepts earlier in the initial planning and design phases of construction.

Therefore, this article critically reviews the integration of DWTs into building environments, focusing on four objectives: (i) classifying principal DWT configurations; (ii) synthesising evidence on aerodynamic performance and building integration; (iii) identifying research gaps; and (iv) formulating a research agenda linking gaps to validation methods.

The contribution of this review is a structured synthesis that connects DWT configuration, building-flow interaction, engineering constraints, and evidence gaps. An exploratory multi-criteria framework based on the literature is used as a transparent synthesis tool, with its limitations clearly stated. Section 2 explains the fundamentals of Ducted Wind Turbines and compares major DWT types. Section 3 examines building integration. Section 4 critically maps the limitations of previous research to required methods and evidence. Section 5 discusses the principal findings and proposes a staged research agenda, while Section 6 provides the conclusions.

2. Fundamentals of Ducted Wind Turbines

2.1. Key Assumptions

DWT aerodynamic studies commonly idealise air as an incompressible Newtonian fluid for the low-speed conditions relevant to small wind turbines and solve the governing conservation equations using analytical, finite-volume, or Reynolds-averaged Navier–Stokes approaches. Simplified studies may assume steady flow, uniform inlet conditions, negligible heat transfer, and reduced-dimensional flow. These assumptions can be useful for parametric analysis, but they are not equivalent to the conditions around an urban building.

For urban applications, the incoming flow can contain atmospheric boundary layer shear, turbulence, directional variability, recirculation, and building-induced acceleration. Consequently, the validity of simplified assumptions depends on the research question. The distinction is important: assumptions reported by previous studies belong in the review, whereas any future validation plan for the present research should be presented separately as a proposed research methodology.

2.2. Working Principle

The working principles of how ducted wind turbines operate are introduced in this section. Their operability is based either on deflecting the flow to their rotor, by concentrating it in their annular rotor, or by both. Having different sizes and approaches, the different types of ducted wind turbines achieve distinct advantages and weaknesses.

In the case of an ideal duct, the wind flow through the duct becomes uniform and the velocity of the fluid in the space between the rotor and the duct increases. The wind turbine then captures a greater part of the kinetic energy of the wind.

The duct allows for a perfect streamline flow of the working fluid, as shown in Figure 1. The flow is symmetrical; there is no separation, and frictional losses are negligible. The

cross-section of the duct is an aerofoil. This generates lift, which in turn causes a ring vortex that generates a velocity to draw in more air mass flow across the rotor [4]. Circulation is also created due to the aerofoil lift action. Ducted wind turbines (DWTs) have proven to be highly efficient in increasing power output by an impressive magnitude of five to six times compared to the power generation capabilities of conventional wind turbines, based on [5].

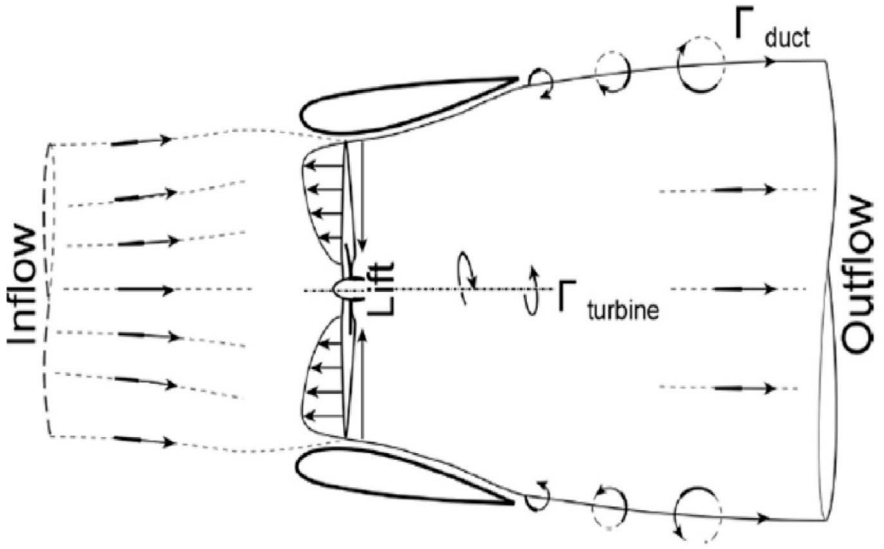


Figure 1. Schematic of stream-tube model for DWT [6].

The claim, however, was based on theoretical studies and lacked experimental or numerical data to substantiate it. Nonetheless, Figure 2 illustrates a full-scale 2.5 m ducted turbine designed and made by Clarkson University [7].



Figure 2. Ducted Clarkson rotor under test conditions [7].

The open rotor and ducted rotor were tested at the University of Waterloo's wind turbine test facility. The experimental results demonstrated a strong correlation between

the data and the numerical predictions, indicating a doubling of the power output at a given velocity. This suggests that the numerical strategy can serve as a viable approach for scalable design methodology.

Figure 3 is a plot of the wind tunnel results. It is noticed that the presence of the duct significantly increased the power output of the turbines. For example, at a wind speed of 9 m/s, the Bergey turbine (shown in Figure 4) generated approximately 700 watts, while the Clarkson open rotor configuration produced around 925 watts.

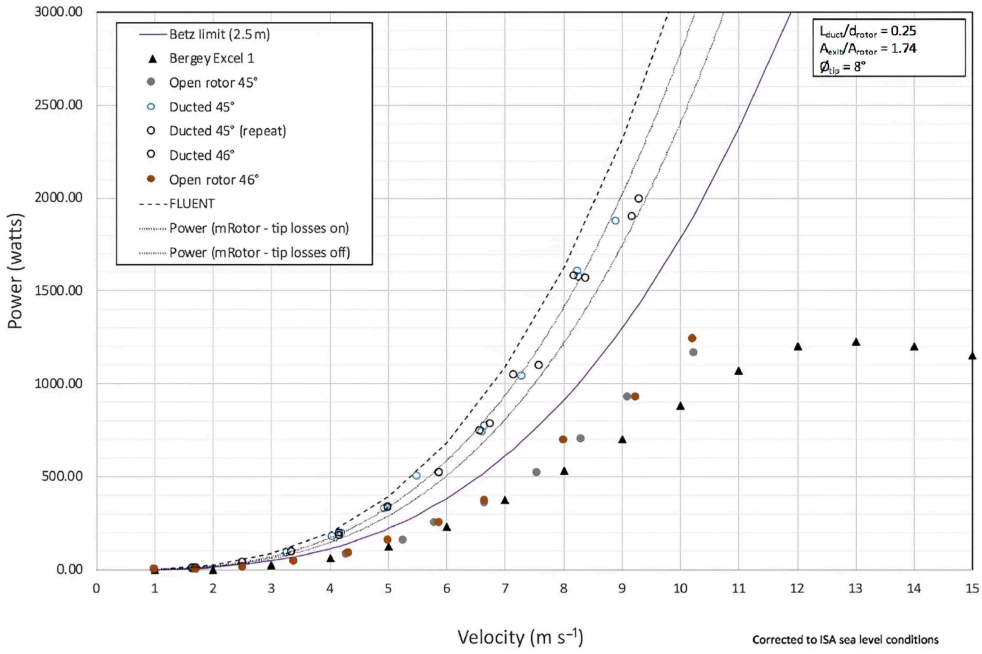


Figure 3. Wind tunnel power curve performance for Ducted and Unducted Bergey Excel WT [7].



Figure 4. Bergey Turbine Excel 1 [7].

When the duct was installed, the turbine's output rose to about 1880 watts. This indicates that the duct increased the power output to nearly double that of the unducted configuration. It is important to note that even though these values are above the Betz limit line, this does not mean that the theoretical Betz limit has been exceeded. The Betz limit

applies only to an open rotor. The Betz limit (The Betz limit is the theoretical maximum efficiency for a wind turbine, established by German physicist Albert Betz in 1919.) is the theoretical maximum efficiency for a wind turbine. Betz concluded that this value is 59.3%, meaning that at most only 59.3% of the kinetic energy from wind can be used to spin the turbine and generate electricity [8].

2.3. Types of Ducted Wind Turbines

A diverse and sophisticated array of ducted wind turbines is available, each meticulously classified according to its distinctive duct design and operational functionality. These designs enhance efficiency and performance, reflecting the advanced engineering principles that underpin modern renewable energy solutions.

2.3.1. Nozzle Lens

The blades of a nozzle-augmented wind turbine (NAWT), as illustrated in Figure 5, are enclosed within a bucket-shaped duct. This design allows the turbine to operate more efficiently than conventional open-blade systems by extracting more energy from the wind. In a nozzle system, the intake diameter is typically larger than the output diameter, which results in a slower airflow. As the air moves through the outlet, its velocity increases due to the reduced cross-sectional area, resulting in up to 83% higher energy capture than open-rotor designs. They are effective in low-to-moderate wind conditions and can reduce energy costs by 56% to 59% [9].



Figure 5. Nozzle Lens DWT [10].

Nozzle-type ducts play a crucial role in enhancing efficiency, particularly during periods of low wind speeds, making them especially beneficial in regions with variable wind conditions. In high wind areas, these ducts can also be advantageous as they enable more effective direction of mass airflow, thereby minimising energy loss. Moreover, nozzle-type ducts are well-suited for regions characterised by extremely dry air, as they assist in reducing air loss, further contributing to overall efficiency [11].

Nozzle-type ducts can be improved in efficiency and performance by optimising design, using advanced materials, and implementing efficient manufacturing techniques [12].

Nozzle-type ducts have several limitations due to their convergent design. One major issue is that a significant pressure drop can occur across the duct when there is rapid airflow, leading to increased resistance and potentially diminishing efficiency gains. Additionally, the complex shape and precise engineering required for nozzle-type ducts make them more challenging and expensive to manufacture. Maintaining structural integrity and aerodynamic efficiency during production can be difficult, necessitating the use of advanced manufacturing techniques and materials. Despite these challenges, nozzle-type ducts are crucial for enhancing wind turbine performance through increased airflow speed and improved energy capture [13].

One of the advantages of the Nozzle-lens turbine is its rim-based yaw control. This feature allows the wind-lens turbine to automatically adjust and face the wind due to the rim. However, designing a compact wind-lens structure as an upwind-type wind turbine proves to be challenging.

The results of the performance test conducted on a windy day are shown in Figure 6. The field data are represented as 1 min average readings. The results show a 2.5-fold increase in power output compared to traditional bare wind turbines, attributed to the concentration of wind energy [14]. Furthermore, in Figure 6, the cut-in speed is 3.5 m/s. Although the cut-out speed is not specified, it has been noted in [9] that the cut-out speed is 25 m/s.

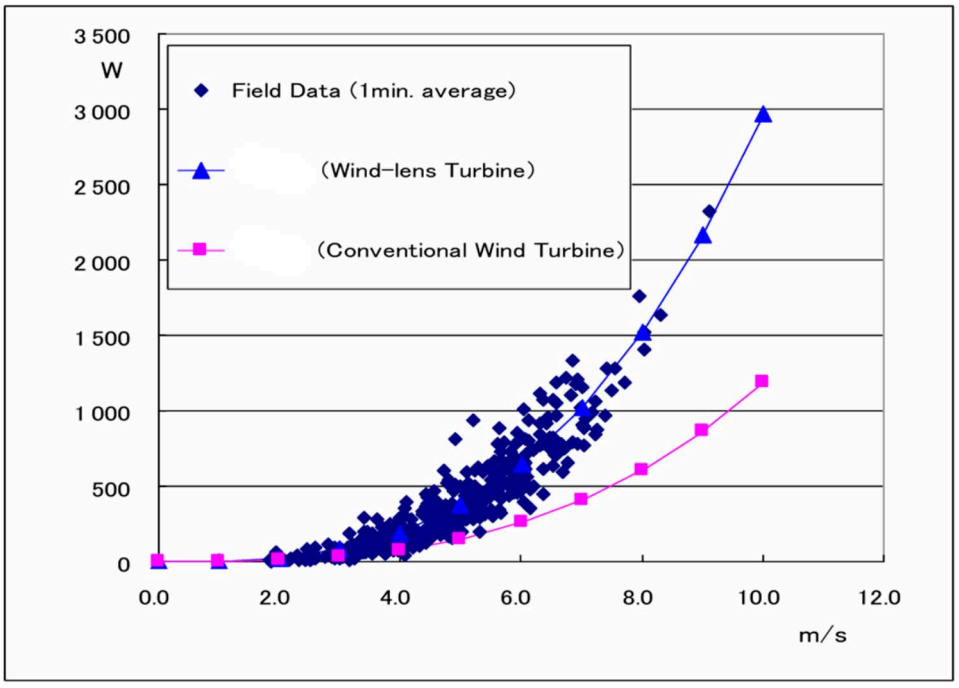


Figure 6. Field experiment power curve performance of 5 kW WT with and without a lens-nozzle [14].

2.3.2. Diffuser Wind Turbine

Diffuser wind turbines feature a cone-shaped wind diffuser that enhances the efficiency of wind energy conversion into electricity. The diffuser allows for higher wind velocities, improving overall efficiency [14], as shown in Figure 7.

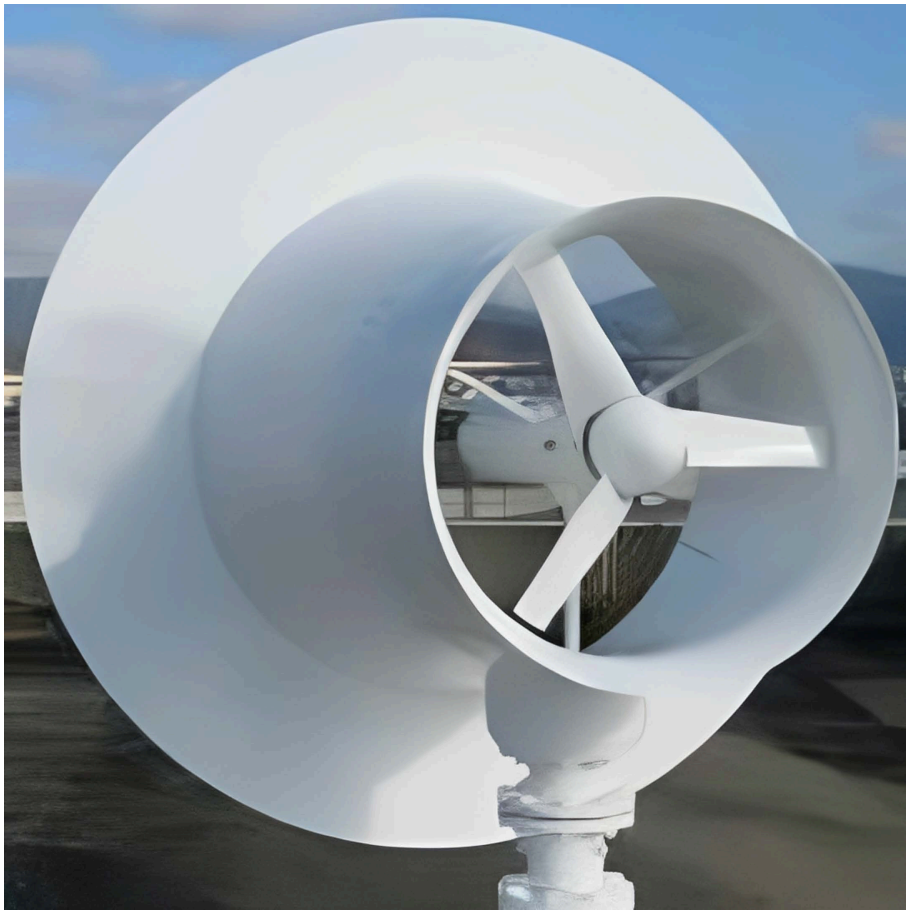


Figure 7. Diffuser WT [14].

Unlike conventional Bear turbines, which have vertically spinning blades mounted on a tower, DAWTs house their rotor blades within the diffuser attached to the tower. To maximise efficiency, the diffuser's exit hole must be larger than the entry hole, allowing for effective air diffusion. This design enables the wind to flow alongside the walls, creating specific points in the outgoing air [15]. Diffuser-type ducts have not shown significant or negative effects in areas with high wind speeds. It is recommended to incorporate diffuser-type ducts into wind turbines in urban settings or regions with low to moderate wind speeds [16]. However, it is crucial to recognise that the effectiveness of the duct design depends on how well it aligns with the turbine and the local wind conditions [17]. Diffuser-type ducts can generate an axial velocity that is equal to or greater than the free-stream velocity [18]. But there are also disadvantages, including increased costs due to the large duct structure; Also, it is less capable of increasing initial wind speed and less effective in low wind conditions [19].

Figure 8 decisively showcases the dramatic enhancement in output power when the wind turbine is fitted with a Nozzle Lens. This modification results in an extraordinary increase of 4 to 5 times in power output, underscoring the Nozzle Lens's effectiveness in maximising energy production.

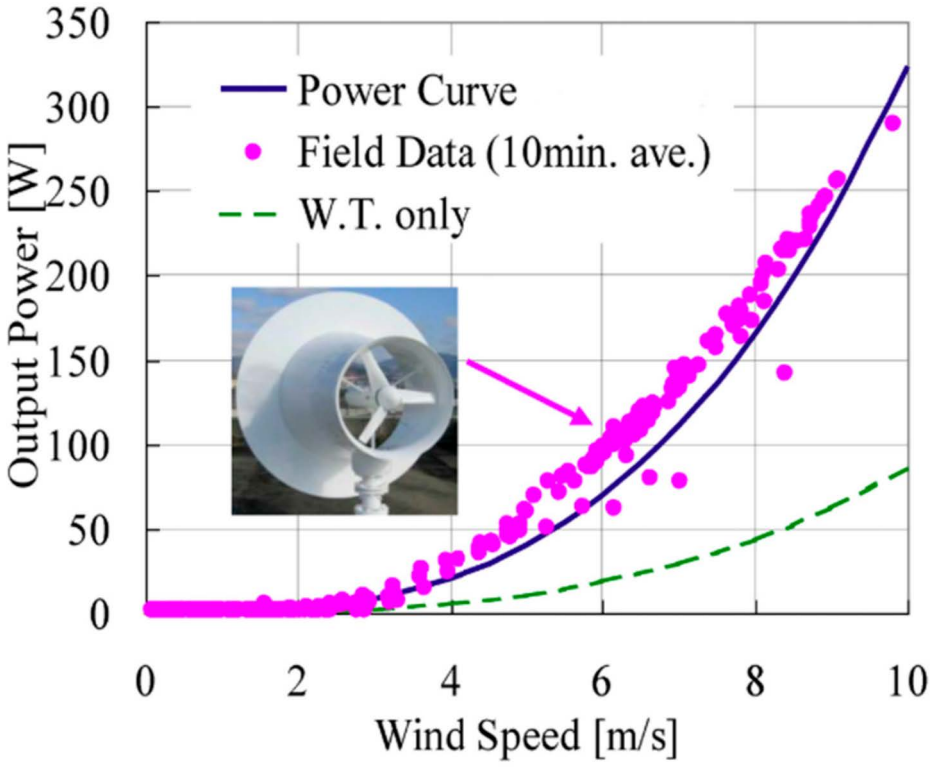


Figure 8. Field experiment power Curve performance of 500 Watts WT with and without Diffuser [14].

2.3.3. INVELOX Wind Turbines

INVELOX (increased speed) is an innovative wind capture system that offers engineers significant control over energy generation [20]. Unlike traditional wind turbines with large turbine systems, INVELOX, as shown in Figure 9, channels wind energy into a funnel, directing it into a narrower flow path that naturally increases speed. This method allows for the conversion of wind power into electricity, powering generators located underground or on the surface securely and cost-effectively [21].

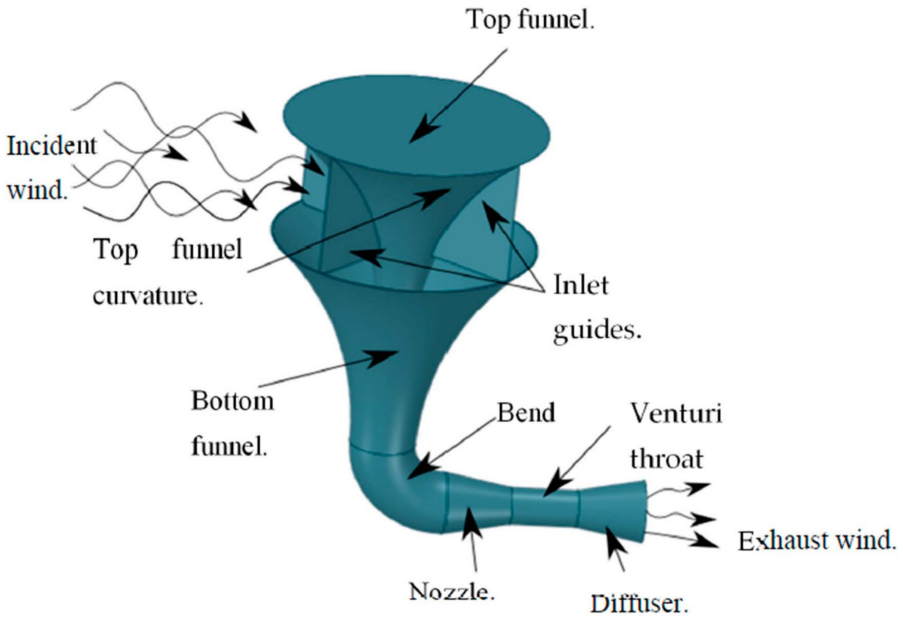


Figure 9. Invelox wind turbine [22].

The INVELOX system comprises five components. It uses a unidirectional intake to collect wind from any direction and channel it through a tunnel to the vent via an elbow. The wind drives a turbine to generate electricity and is then returned to nature.

The design of the INVELOX wind delivery system has significant potential for optimisation to enhance the conversion of wind energy into electrical energy. Research has shown that ducted wind turbine systems like INVELOX have superior performance compared to bare wind turbine setups in various scenarios. Their capability to gather air from a broad area, manage it effectively, and then direct it to a turbine leads to a substantial increase in turbine performance. Due to their ability to handle wind, they can be utilised in regions with low wind speeds (above 1 m/s) and varying turbulence levels. (less than 20%) [22]. This innovative turbine design generates greater energy at reduced expenses due to its effective wind capture and rising wind velocity. The system can enhance the power output by roughly 280% for each tower with blades that are 84% smaller than traditional wind turbines [22].

Figure 10 shows the INVELOX power curve where the 300 W generator was replaced with a 10 kW generator (without any changes to the blade) to get more power [23]. The data shows that placing the turbine inside the venturi duct roughly doubled the airspeed. The maximum power reached 3600 W, significantly higher than the blade's nominal power. Factors such as increased wind speed in the duct shifted performance from 300 W to 3600 W. The blade's cut-in speed of 3 m/s, cut-in speed of 20 m/s, and rated speed of 9 m/s limit power output, but optimising these speeds could potentially double energy output.

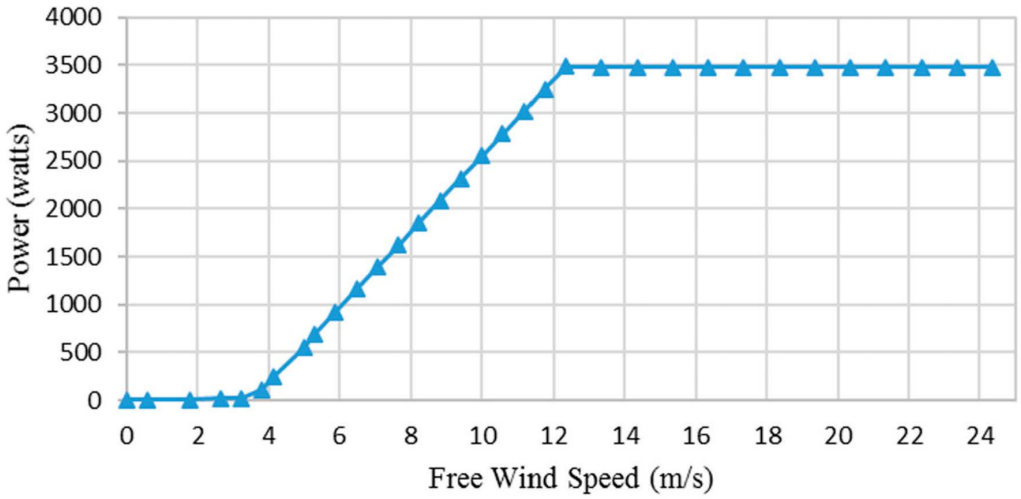


Figure 10. Invelox WT power curve [23].

The practical implementation of INVELOX systems has been primarily limited to numerical studies, with few empirical analyses conducted. This emphasises the need for more hands-on research, as the current lack of empirical data limits the ability to make quantitative assessments of manufacturing costs, complexity, and trade-offs associated with constructing INVELOX systems.

2.3.4. Multi-Criteria Decision Analysis (MCDA)

This study used Multi-Criteria Decision Analysis (MCDA) to evaluate three ducted wind turbine configurations based on criteria including power enhancement, low-wind performance, aerodynamic efficiency, manufacturing complexity, cost-effectiveness, urban suitability, and technology maturity [24]. This framework allows for systematic comparison of technologies by weighting each criterion and calculating overall performance scores.

The MCDA framework used in this study was adapted from standard multi-criteria decision-making methodologies proposed by [24,25].

A practical MCDA can compare the three turbine types:

1. Nozzle Lens DWT;
2. Diffuser Augmented Wind Turbine (DAWT);
3. INVELOX Wind Turbine.

To effectively conduct MCDA-based selection analysis, it is essential to clearly identify and accomplish the following steps:

Define the Evaluation Criteria

For ducted wind turbines, Table 1 shows the most relevant criteria:

Table 1. Evaluation Criteria.

Criteria	Description
Power Enhancement	Ability to increase power output
Low Wind Performance	Performance in low/moderate winds
Manufacturing Complexity	Ease of fabrication
Cost Effectiveness	Installation and operational cost
Structural Simplicity	Ease of integration and maintenance
Urban Suitability	Suitability for urban/turbulent environments
Technology Maturity	Availability of practical/experimental validation
Aerodynamic Efficiency	Ability to accelerate airflow

Assign Weights

Table 2 Shows that the weights reflect engineering importance (total = 100%).

Table 2. Weights assigned to evaluation criteria.

Criteria	Weight (%)
Power Enhancement	25
Low Wind Performance	20
Cost Effectiveness	15
Manufacturing Complexity	10
Aerodynamic Efficiency	10
Urban Suitability	10
Technology Maturity	5
Structural Simplicity	5

Score Each Turbine Type

A 1–5 score is used:

- 1 = Poor;
- 2 = Fair;
- 3 = Moderate;
- 4 = Good;
- 5 = Excellent.

The scores were derived qualitatively from the performance data reported in the literature review. In MCDA, when precise numerical datasets are unavailable for all alternatives, expert judgement and literature-based comparative scoring are commonly used [24,25].

The assigned scores were based on the advantages, disadvantages and experimental or numerical findings reported for each configuration in Sections 2.3.1–2.3.3, and are justified below with quantitative evidence when possible, from the literature where such evidence exists.

For Power Enhancement, the wind-lens (nozzle-type) configuration has been reported to achieve a power augmentation of 2–3 times that of a bare turbine for the practical compact-diffuser design, and 4–5 times for a longer, less practical diffuser geometry [14]. Diffuser-augmented configurations without a nozzle have achieved power-coefficient increases of up to 3.64 times through duct-angle optimisation [26]. For INVELOX, the reported throat-to-freestream velocity ratio increase of 50–110% [20] corresponds to a power increase of approximately 3.4 to 9.3 times when the cubic relationship between wind speed and power is applied, which is consistent with its score of 5. A closely related bio-inspired contraction-expansion duct has since reported a power coefficient 157% higher than a bare turbine and 30% higher than a conventional ducted turbine [27], reinforcing the venturi-type configuration's advantage on this criterion. Aerodynamic Efficiency scores for this criterion should be read alongside those for Power Enhancement rather than as fully independent evidence, since the two criteria draw partly on the same underlying studies. For Technology Maturity, the wind-lens configuration has the strongest evidence base, including a fielded 100 kW prototype at a rated wind speed of 12 m/s and an 18 m-diameter offshore floating unit off Fukuoka, Japan [9]; diffuser-augmented designs have numerous lab-scale experimental studies but limited full-scale deployment; and INVELOX evidence remains largely numerical, with field data limited to the single Manjil, Iran site [23], which supports its lower score of 2 on this criterion.

The Table 3 shows that the cost per kW produced for both Nozzle and Diffuser wind turbines is quite similar. However, the Invelox wind turbine is 50% cheaper than the Nozzle wind turbine. This may provide valuable insights into the scores associated with the Cost Effectiveness criteria for each type of ducted wind turbine (Table 4).

Table 3. The Cost per kW for different DWTs.

DWT	Cost per kW Produced ($/kW)
Nozzle	1500 [13]
Diffuser	1300 [13]
Invelox	750 [28]

Table 4. Scores for each Turbine type.

Criteria	Weight	Nozzle Lens	Diffuser WT	INVELOX
Power Enhancement	25	4 [14]	5 [26]	5 [20]
Low Wind Performance	20	5 [9,11]	3 [19]	5 [22]
Cost Effectiveness	15	3 [13]	3 [13]	4 [28]
Manufacturing Complexity	10	2 †	3 †	3 †
Aerodynamic Efficiency	10	4 [14]	4 [26]	5 [20]
Urban Suitability	10	3 †	5 †	4 †
Technology Maturity	5	4 [9]	4 †	2 [23]
Structural Simplicity	5	3 †	3 †	2 †

Note: Bracketed numbers cite the source supporting each score; † indicates a criterion for which no comparative quantitative data across all three configurations was identified, and the score remains an expert-judgement estimate.

Comparative quantitative data across all three configurations could not be found for Manufacturing Complexity and Structural Simplicity; the scores for these two criteria therefore remain expert-judgement estimates.

Figure 11 presents a radar chart in which each turbine's performance profile is outlined as a distinct area, allowing visual comparison of relative performance across all eight criteria.

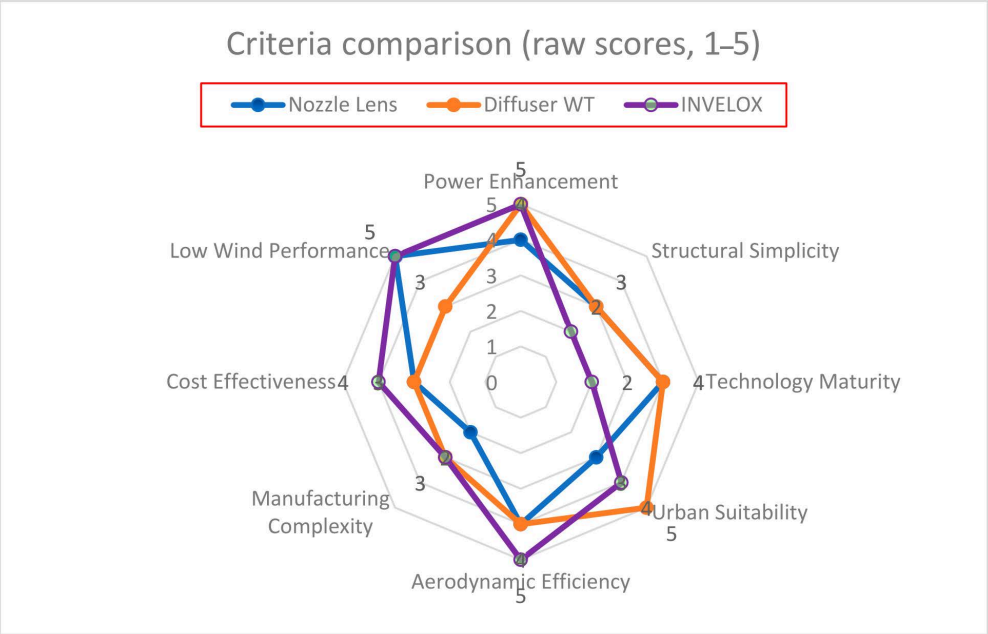


Figure 11. Radar Chart for Comparing Criteria for Each Turbine.

Calculate The Total Weighted Scores

To obtain the total weighted score, multiply each criterion score by its weight to find a weighted contribution. Sum these contributions across all criteria to determine the total weighted score for each option. Table 5 shows the total weighted score for each turbine type.

$$\text{Total Weighted Score} = \sum(\text{Weight} \times \text{Score}).$$

Table 5. The total Weighted Score for the three types of DWT.

Turbine Type	Total Weighted Score
Nozzle Lens	3.70
Diffuser WT	3.85
INVELOX	4.25

The stacked bar chart in Figure 12 provides a breakdown of each criterion's contribution to the total weighted score, clarifying the relative influence of individual criteria on the overall ranking.

MCDA Result and Interpretation

The MCDA identifies the INVELOX system as the most promising configuration, achieving the highest weighted score of 4.25 as shown in Figure 12.

The INVELOX model emerges as the top performer overall, with a score of 4.25 out of 5. It excels in the two most heavily weighted criteria—power enhancement and low wind performance—accounting for 45% of the total score. This strong performance in key areas boosts its overall rating, even though it scores the lowest in terms of technology maturity.

The Nozzle Lens and Diffuser WT models are nearly tied, scoring 3.70 and 3.85, respectively. They each have strengths and weaknesses across various criteria: the Diffuser excels in urban suitability and power enhancement, while the Nozzle performs better in low wind conditions and cost-effectiveness. As a result, the scores for these two models overlap significantly, rather than clearly separating them.

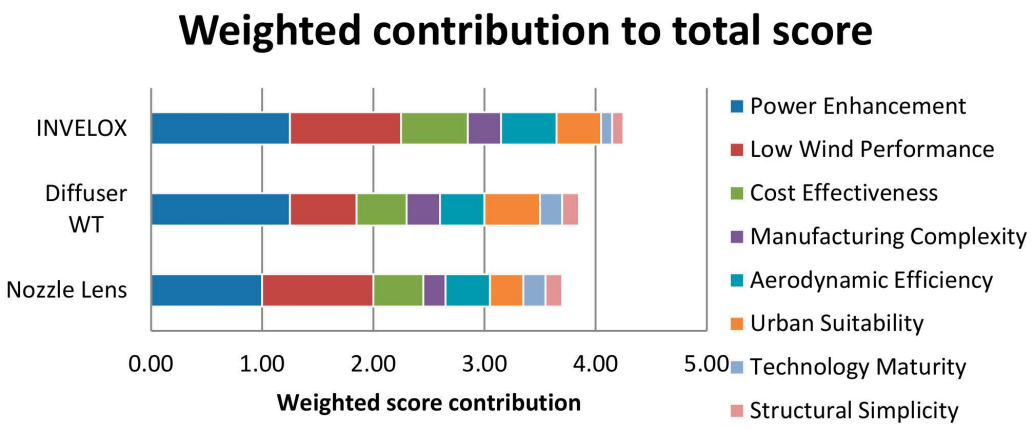


Figure 12. Weighted contribution to total score.

3. Integration of Ducted Wind Turbines in Buildings

In a typical urban setting, buildings are designed to provide controlled supporting environments for various interactive human activities. Clean energy derived from near-building sources has the potential to supply a significant portion of the total building energy needs. Urban buildings can either use stand-alone systems or integrated systems to take advantage of various natural power sources [29]. The most significant attributes of power-generation systems are their primary fuel, their conversion efficiency and, in the case of renewable energy systems, the predictability and reliability of the primary power source for a specific application.

For a stand-alone application for a typical building, the predictability and reliability of a power-generating system may be more critical than its energy-conversion efficiency. In this context, wind energy can play a significant role in the energy supply for typical urban activities [29]. More recently, ducted small wind turbines have been proposed in the building industry for distributed applications.

There are several reasons for this increasing interest, including:

(1) Increased urban wind velocity with acceleration of the flow between high-rise buildings due to building configuration: Reviews of CFD and wind-tunnel studies report that wind passing between adjacent high-rise buildings accelerates through a venturi-like channelling effect, producing pedestrian-level wind speeds markedly higher than the undisturbed approach flow [30].

(2) The development of stacked rotating mechanical components: An experimental field test conducted by Allaei et al. [31] in Chaska, Minnesota, demonstrated that installing two or three turbines inside INVELOX significantly increases power output, with increases of up to 72% and 90%, respectively.

(3) Noise-attenuation potential: Figure 13 presents the measured noise levels produced by a conventional wind turbine (100 kW) and a ducted wind turbine (100 kW) [32]. The results indicate that the duct or shroud effectively reduces aerodynamic noise by suppressing blade-tip vortices.

(4) Avian-friendliness: Ducts can affect local flow patterns, potentially altering bird flight behaviour around the turbine. Birds typically utilise wind corridors to conserve energy while soaring; a ducted design may disrupt or redirect these paths, increasing exposure probabilities [33].

(5) Potential visual aesthetics: Enclosing the rotor within a duct has been shown to provide full or partial visual shielding of the rotating blades, which reduces the perceived visual disturbance of the installation in urban or residential areas [34].

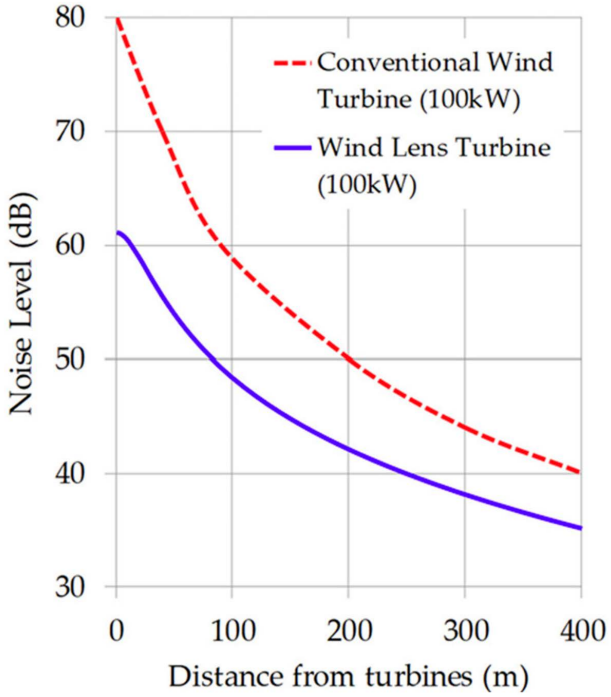


Figure 13. Measured Noise level of Ducted and Un-ducted (100 kW) wind turbine [32].

3.1. Architectural Considerations

The demand for renewable energies to achieve more sustainable and eco-efficient growth implies developing new enabling technologies, especially in urban and peri urban areas. The use of small wind turbines as distributed resources is one of the interesting alternatives to urban microgeneration. The concept of ducted wind turbines is enhanced by taking advantage of architectural morphology, both by using buildings as interactive infrastructure and by optimising their integration into them.

Interest is usually focused on technological systems and photovoltaic modules, which can be mounted on the roof or walls. These structural elements can be studied in a slightly associated way, satisfying pre-established geometrical or material restrictions, but without radically influencing the tectonics or the constructive structural system of the building. Therefore, an innovative design that integrates ducted wind turbines with PV panels in HRES systems presents a compelling solution for sustainable energy production [35].

Additionally, current research on roof-mounted and building-integrated turbines indicates that factors such as roof design, wind patterns, building elevation, and nearby urban layout influence energy production and optimal positioning [36]. In the case of DWTs, the issue is also related to duct obstruction and the pressure dynamics at both the intake and exhaust. Therefore, future research should provide details on the DWT's placement in relation to roof edges, corners, façades, adjacent structures, and pedestrian areas, along with information on the atmospheric boundary-layer profile and turbulence intensity.

3.2. Technological Challenges

Several difficulties were identified in the deployment of ducted wind turbines. Starting from the most significant possible challenge, the key factor remains the sizing and design optimisation of the duct. Hence, Small changes in the duct geometry can have a relatively large impact, as the larger momentum deficit increases the importance of near-wake velocity deficits and wake losses. Still, there is a limited understanding of the full ducted rotor performance and interaction mechanisms, based on which guidelines for even

simpler design codes could be developed [37]. The performance of ducted rotors depends strongly on the incoming wind velocity and direction. However, there remains insufficient knowledge of the effect of wind speed and turbulence intensity from solid obstacles on the uniformity of wind energy resource distribution on building roofs.

The environmental limitations imposed by buildings can have impacts on other important aspects of the ducted rotor. For example, in real situations, the use of the building's aerodynamic part to close the duct has two limitations: the maximum filling ratio of the given cylinder cannot always be mounted on the existing roof due to possible structural limitations; the overlapping of the wakes from the ducted rotors with the building's surface results in a significant interaction and may be the reason for partial or total separation of the respective flow [36]. Omnidirectional ducted wind turbines offer potential solutions to those technical challenges. Furthermore, traditional horizontal-axis ducted turbines typically need to face the wind, but omnidirectional variants, like those with guide vanes or vertical-axis designs, can capture wind from any direction without moving parts. This makes them ideal for turbulent urban winds, simplifying maintenance.

Also, Omnidirectional ducts offer better integration with building aerodynamics, it can be mounted on rooftops to exploit building-induced wind acceleration (e.g., Venturi effects at edges or corners) while minimising reliance on the building to fully "close" the duct. The shroud itself provides the enclosing geometry, potentially allowing smaller or more compact footprints that respect structural limits.

Ducted omnidirectional systems can direct exhaust vertically or manage wakes with diffuser shapes or guide vanes, reducing overlap with buildings and minimising separation risks. Research indicates that duct augmentation can accelerate flow, improve mixing, and enhance wake recovery, particularly in urban areas [16].

4. Limitations of Previous Research

4.1. Aerodynamic Performance in Urban Environments

A study carried out by Yueyang He [38] illustrates that wind patterns in urban environments are complex and erratic due to structures like tall buildings and trees, which create turbulence and variable wind speeds. However, current aerodynamic models often oversimplify these conditions, failing to accurately represent the dynamics in such diverse settings.

Previous research on urban small wind turbines has established that these conditions can produce both increased local wind speeds and highly turbulent inflow. However, the evidence also indicates that improved local velocity does not necessarily translate directly into proportional increases in electrical power. Urban turbulence and flow intermittency can increase dynamic loading, reduce aerodynamic efficiency and shorten component fatigue life [39].

The limitation of ducted wind turbines (DWTs) is crucial because the duct alters the flow before reaching the rotor, creating interactions among the urban atmospheric flow, building geometry, and the duct/turbine system. A DWT that works well in uniform free-stream conditions may behave differently in turbulent urban flow around buildings. Dannecker and Grant [40] highlighted the effectiveness of combining CFD and wind-tunnel testing for building-integrated ducts, finding generally good agreement but also challenges in accurately representing geometry and limited CFD cases. This is significant since simpler models may replicate mean velocity fields but miss key transient pressure fluctuations and asymmetric flow that affect DWT performance. Recent studies have used CFD to optimise ducted openings in high-rise buildings, with modifications to fillet radius and duct diameter increasing mean duct velocity and wind-power density [16]. However, these

studies often rely on steady RANS simulations and specific geometries, lacking a universal optimum for diverse urban designs.

Research on INVELOX systems is limited but promising; Samanta et al. [41] demonstrated the potential of funnel-based wind collection through experimental and CFD approaches. Still, these studies have not yet examined how INVELOX systems perform in the complex flow conditions of urban environments, influenced by neighbouring buildings and varying wind directions.

4.2. Optimisation of Duct Design

The literature shows that duct geometry significantly affects the velocity distribution, pressure recovery, and flow separation within a DWT. However, the optimisation problem is more complex than simply maximising the local velocity at the turbine plane.

Recent research has explored geometric factors like diffuser angle, duct diameter, inlet curvature, and fillet radius. For instance, simulations using computational fluid dynamics (CFD) on ducted openings in tall buildings showed that proper inlet filleting can reduce flow separation and significantly enhance the wind power density accessible to the turbine [16].

Current studies on ducted wind turbines (DWTs) reveal several limitations. First, many research efforts focus on optimising only a select few geometric parameters in isolation, resulting in local rather than system-wide optima. For instance, while increasing the inlet area can enhance mass flow, it may also lead to greater structural size, material usage, drag, and integration costs. Second, the aerodynamic optimum is influenced by incoming wind conditions; a design optimised for uniform flow may perform poorly in yawed or turbulent scenarios, which is particularly relevant for fixed DWTs situated in urban environments where wind direction frequently varies. Finally, simply housing an existing open-rotor turbine within a diffuser is not always the most effective solution. Bontempo et al. [18] emphasised the importance of considering the coupled aerodynamic behaviour of both the rotor and the duct, indicating that DWT design should prioritise the simultaneous optimisation of these two components.

The same issue applies to INVELOX-type systems. The nozzle configuration, turbine location, and inlet and outlet design work together as a coupled aerodynamic system. Changing any one component can affect the pressure distribution throughout the entire system. Therefore, optimising based solely on velocity amplification at the turbine plane may lead to an overestimation of practical performance if the related pressure losses, turbulence, and structural requirements are not taken into account.

4.3. Structural Integration with Buildings

Research on urban wind turbines has shown that turbulence and flow variations caused by buildings can lead to increased dynamic loading and fatigue issues for turbines installed in urban settings [39]. However, much of the existing literature focuses on the turbine's structural response, rather than examining interactions within the combined duct, support, and building system.

For Invelox WT, the projected area of the duct may be substantially greater than the rotor area. The duct can therefore experience significant aerodynamic forces even when the turbine itself is relatively small. In addition, pressure differences between the inlet and outlet can generate forces within the duct structure. These forces must ultimately be transferred through the support system into the building.

This issue is crucial for retrofit buildings, where existing roofs, façades, or structural frames must be assessed. Unlike new buildings designed with DWT loads in mind, there is limited guidance in the literature on when reinforcement is necessary and its impact on

the economic feasibility of DWT. The UK Building Regulations indicate that this issue is not just a generic turbine-design problem. Requirement A1 mandates that buildings must safely support combined dead, imposed, and wind loads without excessive deformation, while A3 focuses on preventing disproportionate collapse [42].

4.4. Noise and Vibration Mitigation

Noise and vibration are critical concerns for urban distributed wind turbines (DWTs) due to their proximity to occupied areas. The duct design can produce aerodynamic noise and induce structure-borne vibration. Research often separates aerodynamic from mechanical noise, but the acoustic behaviour of DWTs is complex because of rotor operation in confined spaces. The duct influences turbulence, pressure changes, and sound radiation. Future studies should explore noise-reduction methods, including blade design alterations, acoustic insulation, and active noise control.

In 2024, a study carried out by Mozafari et al. [43] found that the bio-inspired airfoils (Owl Wing) can achieve significant noise reduction and improved aerodynamic performance, with an 8 dB noise reduction and a 12% improvement in sound pressure level. An 8 dB reduction for a specific blade configuration does not guarantee the same reduction at an occupied building façade; acoustic propagation and interaction with the duct and building must also be considered.

Vibration poses a challenge in wind turbines, which are dynamic systems. Recent reviews highlight vibration and dynamic instability as key engineering issues [44]. For a building-integrated DWT, the relevant system includes rotating components, bearings, shaft, and support structure within the building. Effective damping systems can reduce vibration transmission to the building structure. Material science and engineering innovations are required to develop and test these systems.

4.5. Economic Feasibility and Lifecycle Analysis

Economic evaluation is one of the areas in which DWT-specific research exists but remains incomplete. Masukume et al. [45] specifically examined the techno-economic performance of ducted wind energy systems and noted that conventional economic approaches can inadequately represent the particular costs and benefits of ducted systems. Their analysis explicitly included the shroud as an additional capital-cost component and recognised operation and maintenance costs associated with the system.

Lifecycle Assessment: Environmental impacts from the production, operation, and disposal of DWTs should be assessed. This includes the carbon footprint, resource usage, and end-of-life recycling or disposal [46].

The gap is defined as the lack of a DWT-specific lifecycle economic model that integrates urban energy yield, duct manufacturing costs, installation, maintenance, and end-of-life treatment. INVELOX-type systems use a large wind-capture structure to enhance aerodynamic benefits. Economic evaluation involves not just power generation comparison with unducted turbines but also whether the increased energy production offsets the higher costs of their design, structure, and lifecycle.

4.6. Impact on Urban Microclimates

Inadequate understanding of the impact of DWTs on urban microclimates.

Wind Patterns: DWTs can alter local wind patterns around buildings. Studies should investigate these changes and their potential effects on ventilation, pedestrian comfort, and local weather conditions. DWTs actively extract energy from urban wind and create dynamic wakes, making their microclimatic effects distinct from passive elements like chimneys. This highlights a gap in current urban aerodynamics research.

Long-Term Environmental Impact: Longitudinal studies are needed to understand the long-term environmental impact of widespread DWT installation in urban areas [46].

4.7. Public Perception and Acceptance

Limited research on public perception and acceptance of DWTs in urban areas.

Public acceptance may be influenced by the visual impact of DWTs. Research should explore design options that are aesthetically pleasing and integrate well with urban architecture [47].

The existing literature offers limited evidence on public responses to specific DWT forms, primarily focusing on conventional wind turbines, making it inappropriate to assume similar public attitudes toward DWTs [47].

Future DWT research should focus on how specific design characteristics influence public perception, rather than viewing acceptance as a generic barrier. This could involve a comparative evaluation of exposed turbines, diffuser systems, façade-integrated ducts, and Invelox WT.

4.8. Policy and Regulatory Frameworks

The regulatory literature differs from the aerodynamic and economic literature in that there is no specific regulation that outright bans DWT installation. Instead, DWT deployment may be influenced by various regulatory and planning requirements not specifically designed for ducted wind-energy systems.

This distinction is important because describing "building codes" as a general barrier without identifying the relevant provisions does not constitute a critical review.

In England, the Building Regulations include structural requirements relevant to building-integrated DWTs. Requirement A1 mandates that buildings safely sustain and transmit various loads, while A3 addresses disproportionate collapse [42]. These provisions do not prohibit DWTs but require proof that additional loads from installation do not compromise structural safety. Planning requirements can be restrictive. Under English permitted-development rules, Class H applies to specific microgeneration wind turbines on detached homes or qualifying buildings. The permitted-development limitations include requirements concerning turbine height, projection above the roof, blade clearance, swept area, protected locations and visual/amenity considerations [48]. The research gap lies not in a universal prohibition of DWTs but in the lack of a defined regulatory pathway that addresses the aerodynamic, structural, acoustic, electrical, fire safety, planning, and maintenance aspects of building-integrated DWTs. Future regulations should align the physical characteristics of systems like INVELOX with relevant planning and building requirements, focusing on collector dimensions, attachment, duct loads, turbine enclosures, maintenance access, electrical equipment, and visual impact, rather than just the turbine-generator component.

5. Discussion and Research Agenda

The literature indicates three main conclusions: First, duct augmentation can substantially modify the aerodynamic environment of a rotor, although its effectiveness depends strongly on duct geometry, rotor loading, and inflow conditions; Second, building integration creates a coupled engineering problem in which aerodynamic benefits may be offset by structural, acoustic, installation, maintenance, and planning constraints; and Third, the available evidence varies considerably among DWT configurations, with INVELOX being particularly promising because its wind-collection and power-generation functions are spatially separated and its intake has been described as omnidirectional [20], although

insufficient evidence currently exists to establish a universal performance advantage in realistic urban building environments.

Consequently, future INVELOX research should adopt an evidence-led, staged methodology that first reproduces a published geometry and validates the CFD model against independent experimental or field data, drawing on the studies of Allaei and Andreopoulos [20], Sotoudeh et al. [49], Ayaz et al. [50], Samanta et al. [41], and Nardecchia et al. [51] as validation benchmarks; subsequently introduces realistic atmospheric boundary-layer and urban building inflow conditions; optimises the coupled duct–turbine configuration and turbine placement using the validated model; evaluates structural loads, vibration, and acoustic emissions; integrates annual wind-resource assessment with lifecycle economics and regulatory considerations; and, finally, validates the proposed system through prototype testing in a representative building environment. This sequence is important because numerical improvements in throat velocity should not be interpreted directly as increases in electrical energy yield unless rotor loading, generator characteristics, and system losses are also considered. Thus, future research should clearly distinguish between validated baseline physics, application-specific urban modelling, and design optimisation; establish model credibility before optimisation; and then evaluate the complete system from aerodynamic performance through structural, acoustic, economic, and regulatory feasibility.

6. Conclusions

This review examined the integration of ducted wind turbines into building environments, focusing on nozzle/lens, diffuser-augmented and INVELOX configurations. The literature shows that duct geometry can modify the flow available to a rotor and that experimental and numerical studies have demonstrated performance benefits under particular conditions. However, these benefits cannot be transferred directly between configurations or from controlled tests to urban buildings.

The review also shows that building integration is a coupled engineering problem involving atmospheric and building aerodynamics, duct geometry, rotor loading, structural response, vibration, noise, maintenance, lifecycle cost, microclimate, public acceptance and jurisdiction-specific regulation. For INVELOX in particular, the literature provides sufficient evidence to justify further investigation but not sufficient evidence to conclude that it is the most suitable DWT for urban environments. The appropriate conclusion is that INVELOX is a promising candidate whose urban applicability remains to be established through validated CFD, wind-tunnel testing and field-scale research.

Future research should therefore prioritise reproducible CFD validation against published INVELOX experiments, followed by realistic urban flow modelling and prototype testing. The proposed evidence chain—baseline validation, urban flow assessment, geometric and placement optimisation, structural and acoustic assessment, lifecycle-economic analysis, and field demonstration—provides a defensible pathway from literature review to future original research without presenting proposed research as an outcome of the present review.

Author Contributions: A.D. contributed towards the conceptualisation, writing—original draft preparation, and formal analysis of the manuscript. Writing—review, editing, validation, and supervision were performed by I.A. and H.G.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analysed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DWT	Ducted Wind Turbine
CFD	Computational Fluid Dynamics
HRES	Hybrid Renewable Energy Systems
GHG	Greenhouse Gas

References

1. Cabeza, L.F.; Bai, Q.; Bertoldi, P.; Kihila, J.M.; Lucena, A.F.P.; Mata, É.; Mirasgedis, S.; Novikova, A.; Saheb, Y.; Hu, S. Buildings. In *Climate Change 2022: Mitigation of Climate Change*; Shukla, P.R., Skea, J., Slade, R., Al Khourdajie, A., Van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., et al., Eds.; Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2022. Available online: https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter09.pdf (accessed on 7 October 2026).
2. Yang, Y.; Campana, P.E.; Stridh, B.; Yan, J. Potential analysis of roof-mounted solar photovoltaics in Sweden. *Appl. Energy* **2020**, *279*, 115786. [CrossRef]
3. Abohela, I.; Sundararajan, R. Analytical review of wind assessment tools for urban wind turbine applications. *Atmosphere* **2024**, *15*, 1049. [CrossRef]
4. Hansen, M.O.L. *Aerodynamics of Wind Turbines*; Earthscan: Assen, The Netherlands, 2007.
5. Aravindhan, N.; Bibin, C.; Ashok Kumar, R.; Sai Kalyan, K.; Sai Balaji, K.; Kugan, R.; Rajesh, K.; Arunkumar, S. Performance analysis of various types of ducted wind turbines—A review. *Mater. Today Proc.* **2022**, *80*, 188–194, Advance online publication. [CrossRef]
6. Dighe, V.; Suri, D.; Avallone, F.; van Bussel, G. Ducted wind turbines in yawed flow: A numerical study. *Wind Energy Sci.* **2021**, *6*, 1263–1275. [CrossRef]
7. Kanya, B.; Visser, K.D. Experimental validation of a ducted wind turbine design strategy. *Wind Energy Sci.* **2018**, *3*, 919–928. [CrossRef]
8. Betz Limit—Energy Education. Available online: https://energyeducation.ca/encyclopedia/Betz_limit (accessed on 7 October 2026).
9. Khojasteh, H.; Noorollahi, Y.; Tahani, M.; Masdari, M. Optimization of power and levelized cost for shrouded small wind turbine. *Inventions* **2020**, *5*, 59. [CrossRef]
10. Ohya, Y.; Karasudani, T.; Nagai, T.; Watanabe, K. Wind lens technology and its application to wind and water turbine and beyond. *Renew. Energy Environ. Sustain.* **2017**, *2*, 2. [CrossRef]
11. Sedaghat, A.; Waked, A.R.; Assad, H.E.M.; Khanafer, K.; Salim, B.N.M. Analysis of accelerating devices for enclosure wind turbines. *Int. J. Astronaut. Aeronaut. Eng.* **2017**, *2*, 9. [CrossRef] [PubMed]
12. Aldhufairi, M.; Muda, M.K.H.; Mustapha, F.; Ahmad, K.A.; Yidris, N. Design of wind nozzle for nozzle augmented wind turbine. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2022**, *95*, 36–43. [CrossRef]
13. Hosseini, S.E.; Saboohi, Z. Ducted wind turbines: A review and assessment of different design models. *Wind Eng.* **2024**, *49*, 833–854. [CrossRef]
14. Ohya, Y.; Karasudani, T. A shrouded wind turbine generating high output power with wind-lens technology. *Energies* **2010**, *3*, 634–649. [CrossRef]
15. Hosseini, S.R.; Ganji, D.D. A novel design of nozzle-diffuser to enhance performance of INVELOX wind turbine. *Energy* **2020**, *198*, 117082. [CrossRef]
16. Ruiz, C.A.; Kalkman, I.; Blocken, B. Aerodynamic design optimization of ducted openings through high-rise buildings for wind energy harvesting. *Build. Environ.* **2021**, *202*, 108028. [CrossRef]
17. Khojasteh, H.; Noorollahi, Y.; Tahani, M.; Masdary, M. Energy and economic analyses of a new ducted small wind turbine. *Environ. Energy Econ. Res.* **2022**, *6*, S047.
18. Bontempo, R.; Di Marzo, E.M.; Manna, M. Diffuser augmented wind turbines: A critical analysis of the design practice based on the ducting of an existing open rotor. *J. Wind Eng. Ind. Aerodyn.* **2023**, *238*, 105428. [CrossRef]
19. Ranjbar, M.H.; Mashouf, H.; Gharali, K.; Rafiei, B.; Al-Haq, A.; Nathwani, J. Power augmentation of ducted wind turbines for urban structures: Experimental, numerical, and economic approaches. *Energy Sci. Eng.* **2022**, *10*, 3893–3907. [CrossRef]
20. Allaei, D.; Andreopoulos, Y. INVELOX: Description of a new concept in wind power and its performance evaluation. *Energy* **2014**, *69*, 336–344. [CrossRef]

21. Anbarsooz, M.; Amiri, M.; Rashidi, I. A novel curtain design to enhance the aerodynamic performance of Invelox: A steady-RANS numerical simulation. *Energy* **2019**, *168*, 207–221. [CrossRef]
22. Chitura, A.G.; Mukumba, P.; Shambira, N. Increased velocity (INVELOX) wind delivery system: A review of performance enhancement advances. *Wind* **2025**, *5*, 19. [CrossRef]
23. FarahPour, H.; Saniei, P.; Khatibzadeh, A.; Radfar, P.; Raman TavanGostar Wind Power Plants (Wattwind) Ltd. INVELOX Wind Turbine Power Curve Modeling based on Field Data in Manjil, IRAN. In Proceedings of the Third International Energy Management and Technology Conference, Tehran, Iran, 27–28 February 2017.
24. Dodgson, J.; Spackman, M.; Pearman, A.; Phillips, L. *Multi-Criteria Analysis: A Manual*; Department for Communities and Local Government: London, UK, 2009.
25. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
26. Rahmatian, M.A.; Hashemi Tari, P.; Mojaddam, M.; Majidi, S. Numerical and experimental study of the ducted diffuser effect on improving the aerodynamic performance of a micro horizontal axis wind turbine. *Energy* **2022**, *245*, 123267. [CrossRef]
27. Liu, S.; Zhang, L.; Lu, J.; Liu, Z.; Jing, Z.; Zhang, X.; Cui, X.; Wang, H. A novel bio-inspired ducted wind turbine: From prairie dog burrow architecture to aerodynamic performance optimization. *Renew. Energy* **2025**, *256*, 123941. [CrossRef]
28. Sievert, T. Review of Editor's Choice—SheerWind Multiple Turbine INVELOX System—A BETTER WAY to Harvest Wind. 2024. Available online: https://w3.windfair.net/wind-energy/news/17733-editor-s-choice-sheerwind-multiple-turbine-invelox-system-a-better-way-to-harvest-wind (accessed on 8 July 2026).
29. Zhong, Y.; Li, Y. Statistical evaluation of sustainable urban planning: Integrating renewable energy sources, energy-efficient buildings, and climate resilience measures. *Sustain. Cities Soc.* **2023**, *101*, 105160. [CrossRef]
30. Zhong, J.; Liu, J.; Zhao, Y.; Niu, J.; Carmeliet, J. Recent advances in modeling turbulent wind flow at pedestrian-level in the built environment. *Archit. Struct. Constr.* **2022**, *2*, 283–305. [CrossRef] [PubMed]
31. Allaei, D.; Tarnowski, D.; Andreopoulos, Y. INVELOX with multiple wind turbine generator systems. *Energy* **2015**, *93*, 1030–1040. [CrossRef]
32. Watanabe, K.; Ohya, Y. A simple theory and performance prediction for a shrouded wind turbine with a brimmed diffuser. *Energies* **2021**, *14*, 3661. [CrossRef]
33. Brighton, C.H.; Portugal, S.J.; Taylor, G.K. Bio-informed blade patterns for mitigating bird collisions with wind turbines. *J. R. Soc. Interface* **2026**, *23*, 20250719. [CrossRef] [PubMed]
34. Hjort, S.; Larsen, H. A multi-element diffuser augmented wind turbine. *Energies* **2014**, *7*, 3256–3281. [CrossRef]
35. Gajewski, P.; Pieńkowski, K. Control of the hybrid renewable energy system with wind turbine, photovoltaic panels and battery energy storage. *Energies* **2021**, *14*, 1595. [CrossRef]
36. Abohela, I.; Hamza, N.; Dudek, S. Effect of roof shape, wind direction, building height and urban configuration on the energy yield and positioning of roof mounted wind turbines. *Renew. Energy* **2012**, *50*, 1106–1118. [CrossRef]
37. Rahmatian, M.A.; Nazarian Shahrbabaki, A.; Moeini, S.P. Single-objective optimization design of convergent-divergent ducts of ducted wind turbine using RSM and GA, to increase power coefficient of a small-scale horizontal axis wind turbine. *Energy* **2023**, *269*, 126822. [CrossRef]
38. He, Y.; Liu, Z.; Ng, E. Parametrization of irregularity of urban morphologies for designing better pedestrian wind environment in high-density cities—A wind tunnel study. *Build. Environ.* **2022**, *226*, 109692. [CrossRef]
39. Kc, A.; Whale, J.; Urmee, T. Urban wind conditions and small wind turbines in the built environment: A review. *Renew. Energy* **2019**, *131*, 268–283. [CrossRef]
40. Dannecker, R.K.W.; Grant, A.D. Investigations of a building-integrated ducted wind turbine module. *Wind Energy* **2002**, *5*, 53–71. [CrossRef]
41. Samanta, H.; Saha, D.; Golui, K.; Dey, R. *Experimental Investigation and the CFD Modeling of an Invelox-Type Wind Turbine*; Lecture Notes in Mechanical Engineering; Springer: Singapore, 2024; pp. 71–82. [CrossRef]
42. UK Building Regulations 2010, Schedule 1, Part A—Structure, Requirement A1/A3. Available online: https://www.legislation.gov.uk/uksi/2010/2214/schedule/1 (accessed on 7 October 2026).
43. Mozafari, M.; Sadeghimalekabadi, M.; Fardi, A.; Bruecker, C.; Masdari, M. Aeroacoustic investigation of a ducted wind turbine employing bio-inspired airfoil profiles. *Phys. Fluids* **2024**, *36*, 041918. [CrossRef]
44. Machado, M.R.; Dutkiewicz, M. Wind turbine vibration management: An integrated analysis of existing solutions, products, and Open-source developments. *Energy Rep.* **2024**, *11*, 3756–3791. [CrossRef]
45. Masukume, P.; Makaka, G.; Tinarwo, D. Technoeconomic analysis of ducted wind turbines and their slow acceptance on the market. *J. Renew. Energy* **2014**, *2014*, 951379. [CrossRef]
46. Chaudhry, H.N.; Calautit, J.K.; Hughes, B.R. Numerical analysis of the integration of wind turbines into the design of the built environment. *Am. J. Eng. Appl. Sci.* **2014**, *7*, 363–373. [CrossRef]
47. Dilimulati, A.; Stathopoulos, T.; Paraschivoiu, M. Wind turbine designs for urban applications: A case study of shrouded diffuser casing for turbines. *J. Wind Eng. Ind. Aerodyn.* **2018**, *175*, 179–192. [CrossRef]

48. The Town and Country Planning (General Permitted Development) (England) Order 2015, Part 14, Class H—Building-Mounted Wind Turbines on Domestic Premises. Available online: https://www.legislation.gov.uk/uksi/2015/596/schedule/2/part/14/crossheading/class-h-installation-or-alteration-etc-of-wind-turbine-on-domestic-premises (accessed on 7 October 2026).
49. Sotoudeh, F.; Kamali, R.; Mousavi, S.M. Field tests and numerical modeling of INVELOX wind turbine application in low wind speed region. *Energy* **2019**, *181*, 745–759. [CrossRef]
50. Ayaz, A.; Israr, A.; Khan, M.Z. Numerical and experimental investigation of geometric parameters influence on power generation of INVELOX wind turbine. *Energy Sustain. Dev.* **2023**, *77*, 101329. [CrossRef]
51. Nardecchia, F.; Groppi, D.; Garcia, D.A.; Bisegna, F.; De Santoli, L. A new concept for a mini ducted wind turbine system. *Renew. Energy* **2021**, *175*, 610–624. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.