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MEETING FUTURE ENERGY DEMANDS SUSTAINABLY: ASSESSING SMALL WIND TURBINE INSTALLATIONS IN URBAN BUILT ENVIRONMENTS

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ABSTRACT

To meet the world's future energy needs and address climate change, it is essential to investigate sustainable alternatives to conventional power sources, with wind power showing promise. Concerns over the negative climatic impacts of huge wind farms have sparked a growing focus on decentralized small- scale wind turbine setups. The study examines different types of tiny wind turbines, with a specific focus on horizontal and vertical axis designs. It discusses performance, blade design, control mechanisms, and manufacturing methods. It assesses the obstacles and prospects of incorporating wind turbines into urban landscapes, emphasizing urban areas' potential for sustainable electricity generation. This review emphasizes important variables for effective wind turbine deployment in urban areas, based on empirical facts and case studies. Policymakers, urban planners, and stakeholders in renewable energy initiatives can effectively harness wind energy in urban landscapes by addressing challenges and leveraging key insights. This will helpful guide for future green energy development in urban settings.

Keywords: Climate Crisis, Small Wind Turbine, Sustainable Energy, Urban Built Environment, Green Energy

1. INTRODUCTION

"As yet, the wind is an untamed, and unharnessed force; and quite possibly one of the greatest discoveries hereafter to be made, will be the taming, and harnessing of the wind." Lincoln 1860

The need to switch to sustainable energy sources has never been more urgent due to the world's rising energy demands and the threat of an impending climatic crisis. Conventional energy generation using fossil fuels not only worsens environmental degradation but also makes a substantial contribution to the increasing greenhouse gas emissions that cause climate change. Within this framework, the exploitation of Small wind turbines (SWTs) to harvest renewable energy from the air has great potential. Solar thermal systems offer a distributed energy generating option that has the capacity to help satisfy urban energy needs while reducing environmental harm. Nevertheless, the successful incorporation of wind turbines (SWTs) into urban built environments necessitates a comprehensive comprehension of several elements, including the accessibility of wind resources, improvements in technology, regulatory structures, and socio-economic variables. This study aims to explore the viability and consequences of implementing SWT systems in urban environments. It seeks to provide valuable perspectives on how sustainable energy solutions may effectively tackle the difficulties presented by increasing energy needs and climate crises. This article puts lights on the urban energy consumption load in India and globally. The researcher selects many existing models of small wind turbine systems as case studies and analyzes their functions and potential in terms of future recommendations for counties with high wind resource potential in India.

1.1. GLOBAL URBAN ENERGY DEMAND AND TRANSFORMATION OF GLOBAL DEMANDS ON RENEWABLE ENERGIES

It's time to stop burning our planet and start investing in the abundant renewable energy all around us."

The 21st century has seen a notable increase in the need for alternative energy sources because of continued industrial expansion, the depletion of fossil fuel supplies, and growing environmental consciousness. Modern civilization faces several challenges in its quest to eradicate poverty and move toward sustainable development as a result of rising environmental degradation, declining conventional energy sources, and an ever-increasing energy demand(Brundtland Report,September 2010). When it comes to the quest of sustainable development, energy stands out as a critical component that has to be properly handled .As explained in the Brundtland report (M.S. thesis, 2008), the idea of sustainable development is centered on meeting present demands without compromising the ability of future generations to meet their own requirements. Increase in urbanization and industrialization around the world in recent years has led to a consequent rise in energy demand(paul R et al.) .In order to meet the needs of the expanding population, there is a greater need for safe, secure, cost-effective, and environmentally friendly energy sources due to the anticipation that more people will live in metropolitan areas over the next several decades, particularly in developing nations(Jones DW et al).

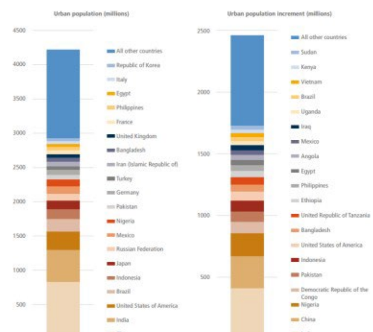

Figure 1: Urban population size in 2018 and increase in the projected urban population. In 2018, about half of the world's urban population lived in seven countries, and about half of the increase in urban population through 2050 is forecasted to concentrate in eight countries. Source: UN DESA 2019, p. 44.

The majority of future urban population increase will occur in developing and least- developed nations (LDCs), with emerging economies accounting for the majority of the world's existing urban population. In 2018, over half of the world's urban population resided in just seven countries, and projections indicate that eight nations would account for the majority of the growth in urban population until 2050 (UN DESA 2019). (Figure 1)Shuaib Lwasa (Uganda), Karen C. Seto (the United States of America) in their research talks about how Urban greenhouse gas (GHG) emissions are influenced by a number of intricate factors, such as the degree of urbanization, wealth, and population size.Dashwood J. puts a light on the fact that due to the massively increasing population the global energy consumption is estimated to increase by almost 30% between 2023 and 2050(3), posing new concerns about the increase in use of GHG emissions massively.(as seen in Fig 2)

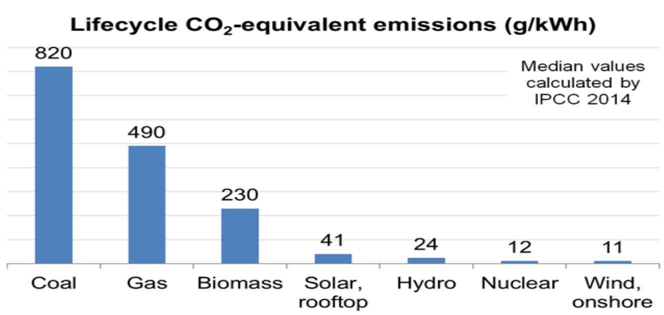

Figure 2: Global scenario of CO2 emissions maximum through fossil fuels which poses a concern in increase in GHG .(source UNECE 2020)

Making the switch to renewable/clean energy sources can decrease greenhouse gas emissions from the production of electricity, according to Tze-Zhang Ang et al. Hydro, solar, wind, biomass, geothermal, and hydrogen are important renewable energy sources that emit few or no air pollutants. Interest in renewable energy is fueled by public awareness of environmental protection. Fossil fuels include coal, petroleum, and natural gas. They are limited and bad for the environment. Although the use of renewable energy is increasing, fossil fuels still produce the majority of the world's electricity (29%), according to Figure 3. (Year]; Ang et al.

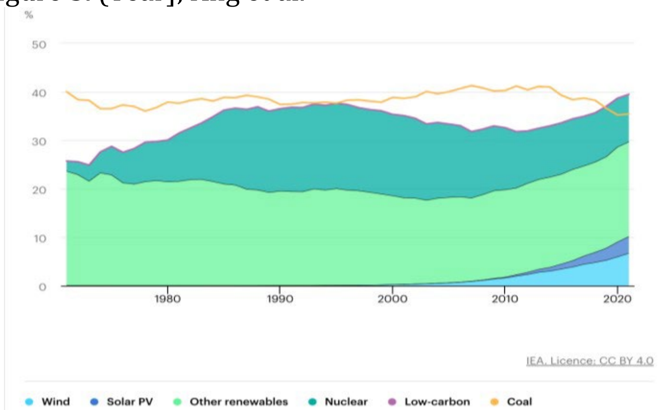

Figure 3 Shows the percentage of electricity generation composed by renewable energy sources, like wind, solar, and nuclear, as compared to coal, showing an increasing use of renewable energy from 1971 to today. (Image source: IEA)

According to the Natural Resource Defense Council, wind and solar energy have developed significantly and become more affordable, improving renewable energy's competitiveness against fossil fuels on a worldwide scale (NRDC, January 18, 2023). The World Health Organization (WHO) emphasizes the serious health dangers associated with air pollution and the pressing need to switch to renewable energy. By 2030, there might be a net gain of 9 million employment in the energy sector from investments in renewable energy compared to fossil fuels (UN). After hydropower, wind power has experienced substantial global expansion; in just ten years, installed capacity has grown ninefold (Breeze, 2014). Numerous countries give priority to wind energy in order to address environmental issues (Blaabjerg et al.).

1.2. ENERGY DEMAND AND WIND POTENTIAL IN INDIA

India started its wind energy adventure in the 1980s, albeit later than Denmark, and its expansion was fueled by government initiatives. India became Asia's leader in wind power despite obstacles, adding 875 MW in 2004 alone (GWEC, 2005). India's untapped wind energy potential is highlighted by Vishal Maurya et al. as being essential to ensuring economic growth and satisfying energy demands. India wants to become less dependent on foreign energy sources, especially nuclear power, by focusing on self-sufficiency. In order to meet its energy ambitions, India must continue on a fast growth trajectory (Maurya et al., [Year]).

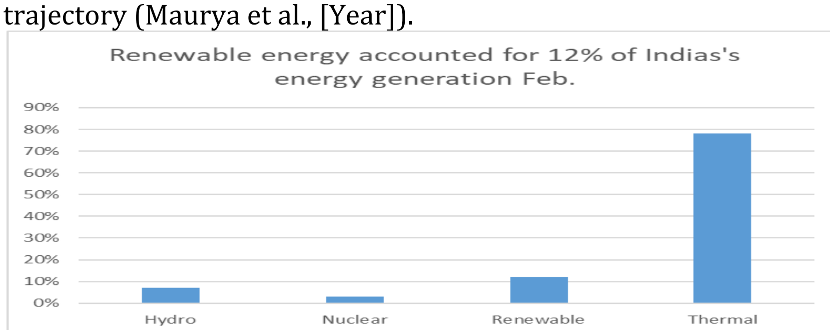

Figure 4 Share percentage of different energy sources in India

India is the world's third-largest energy user, accounting for around 7% of all human greenhouse gas emissions in 2018. The projected addition to India's urban population between 2018 and 2050 is expected to be around 416 million people, a 90% increase. Due to the rapid growth of almost all metropolitan areas and the conversion of towns into more urbanized settings, it is expected that India's energy consumption and greenhouse gas emissions would elevate as a result of this urbanization(Tong, K., Nagpure at el).

India's underutilization of its vast potential, particularly in coal-heavy industries, poses environmental risks (Fig 4). Figure 5 highlights significant coal dependence across sectors, unsuitable for long-term sustainability. Wind energy emerges as a promising solution to address energy needs, achieve self-sufficiency, and transition to a greener future despite challenges and government commitments.

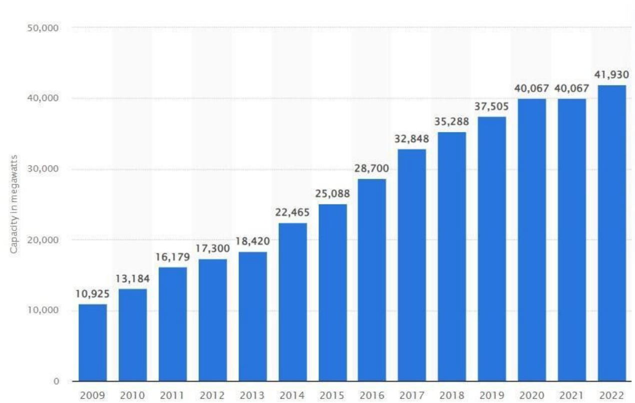

Fig 5 Wind energy capacity Installed in India from 2009 to2022 (in megawatts)

Wind power generation in India primarily focuses on seven states: Tamil Nadu, Gujarat, Maharashtra, Karnataka, Rajasthan, Andhra Pradesh, and Madhya Pradesh. Assessing wind resources across different regions in India relies on the ERA55 reanalysis dataset, freely accessible and provided by the European Center for Medium-Range Forecast (ECMWF), known as the most recent reanalysis dataset available (Hersbach et al., 2019). Fig6

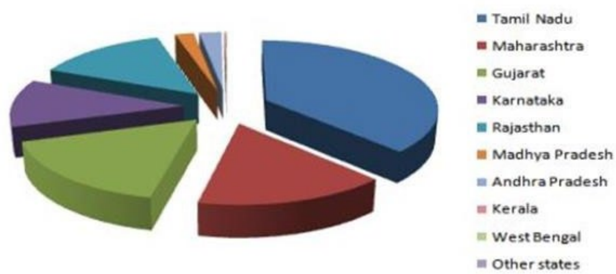

Fig 6 State wise wind energy production in India

The varied geography of India produces a variety of wind patterns, which are essential for the potential of wind energy(see table . The country's varied wind patterns are the cause of this abundance; powerful sea breezes help coastal locations, while channeling effects increase wind speeds in mountainous places. Urban regions may manage their growing energy demands in a sustainable way by incorporating wind power, particularly through tiny wind turbines. This would also promote India's aspirations for renewable energy and create better urban surroundings.

In order to evaluate the potential for wind energy, Table I gives a general summary of the wind directions and average speeds in the major Indian states. States like Kerala and Maharashtra have lower average speeds driven by southwest winds, but Gujarat and Rajasthan show greater average speeds, mostly from westerly directions. Planning for sustainable development is aided by this data for stakeholders in renewable energy.

Table I

State	Average Wind Speed (m/s)	Prevailing Wind Direction
Gujarat	6.5 - 7.5	Westerly
Rajasthan	5.5 - 6.5	Westerly
Maharashtra	4.5 - 5.5	South westerly
Tamil Nadu	5.5 - 6.5	South westerly
Karnataka	4.5 - 5.5	Westerly
Kerala	3.5 - 4.5	South westerly
Andhra Pradesh	5.5 - 6.5	South westerly
Madhya Pradesh	4.5 - 5.5	Westerly

Source: Global Wind Atlas. "India." Global Wind Atlas

This paper aims to investigate and assess sustainable alternatives to traditional power sources, with a particular emphasis on wind power, to fulfill the world's future energy demands and slow down global warming. With a focus on horizontal and vertical axis designs, the article specifically attempts to examine the feasibility of decentralized small-scale wind turbine configurations as an alternative to huge wind farms. The study also intends to evaluate the possibilities and challenges of incorporating wind turbines into urban environments, emphasizing their potential for producing sustainable power. The paper's goal is to offer insightful information on how to efficiently capture wind energy in urban environments to legislators, urban planners, and other stakeholders interested in renewable energy efforts.

2. OBJECTIVE OF THE STUDY

1. Examine the viability of small-scale wind turbine arrangements as environmentally friendly substitutes for traditional power sources, paying particular attention to designs with both horizontal and vertical axes.
2. Determine and evaluate the potential and difficulties involved in incorporating wind turbines into urban environments to provide sustainable power.

WIND AND ITS CHARACTERISTICS

Prior to moving on with our investigation, let us examine the complex qualities and possibilities of wind. Wind is a renewable energy source that originates from air mass movement. Because of its quantity and variety, it is a viable alternative for the creation of sustainable electricity and presents chances to harness clean energy and reduce environmental effects. Wind is the motion of the air with respect to the earth that is produced by variance in atmospheric pressure brought on by variations in temperature as a result of variations in solar radiation intensity arriving to the surface of the earth[Dashwood

J. et al].Wind often flows in three dimensions, from high atmospheric pressure regions to low pressure regions. The earth's rotation and the variations in atmospheric pressure cause currents to flow through the atmosphere, which act as a massive medium for energy transfer. Other elements, such as topographical features, modify the wind energy distribution in addition to these main forcing forces, particularly at the local level.

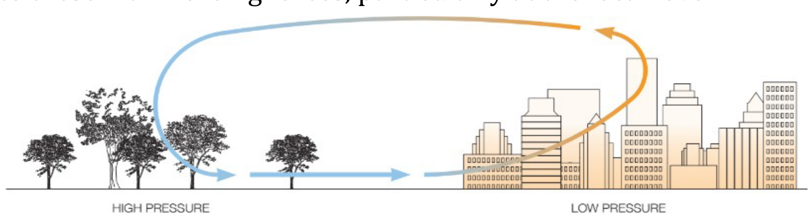

Fig 7 Wind Flow Pattern from high to low pressure zone.Specially depicting the scenarios around urban areas

In an urban setting, the resulting surface roughness of wind speed and direction, and therefore its extractable power, are significantly influenced by exposure to a high

turbulence zone, as seen in Fig. 8. Buildings are three-dimensional things, therefore, as the turbulence lessens, the wind speed around them rises.[Article January 18, 2023 Steps toward cleaner air].Wind flow is impacted by building height, spacing, and design, which has an impact on wind energy extraction. Wind direction and speed are greatly altered by urban surfaces and structures as well as by variations in daily pressure, providing a means of efficient renewable energy harvesting. To maximize the extraction of wind energy, it is essential to comprehend how urban features affect wind patterns.

CASE STUDIES

MICRO WIND TURBINES

Wind turbines capture the kinetic energy of the wind and use it to produce mechanical or electrical power [Song S.-H et al].As wind turbines have evolved, dependable devices that can communicate with the electrical grid have also been developed [Eliasson I et al]. This study emphasizes the effectiveness of small-scale wind turbines designed for urban environments in capturing wind energy, which is important in metropolitan locations with low wind speeds. Urban energy needs can be sustainably addressed by these turbines, which optimize energy output from finite wind resources. The aim of the study is to conduct a thorough analysis of these miniature wind turbines with the goal of implementing them in the future. The analysis will focus on emphasizing breakthroughs in cost reduction, efficiency enhancement, and sustainability for wider worldwide deployment. The development of micro turbines has been fueled by innovation over the decade, which has made it easier for them to be integrated with smart grid systems and urban applications. By the 2010s, the market for small turbines had grown significantly, particularly in distant and metropolitan areas. The table illustrates the evolution of micro wind turbine development from off-grid applications in the 1970s to broader deployment and innovation in the 2020s.

Year	Milestone
1970s	Introduction of early prototypes and experimental models of micro wind turbines for off-grid applications.
1980s	Commercialization of small-scale wind turbines for remote and rural areas, primarily in developed countries.
1990s	Technological advancements lead to improved efficiency and reliability of micro wind turbines, expanding their use.
2000s	Increased adoption of micro wind turbines in off-grid and on-grid applications, driven by renewable energy incentives.
2010s	Rapid growth in the micro wind turbine market, with a focus on urban applications and integration into smart grids.
2020s	Continued innovation in micro wind turbine technology, with a focus on cost reduction, efficiency, and sustainability.

Micro wind turbine development in India began in the early 2000s, primarily in response to increasing energy demands and a growing interest in renewable energy sources. Various types of micro wind turbines, including Vertical Axis Wind turbines (VAWTs), Horizontal Axis Wind Turbines (HAWTs), Savonius rotors, and H-rotors, have been developed and tested in different regions of the country.(see fig. 12)

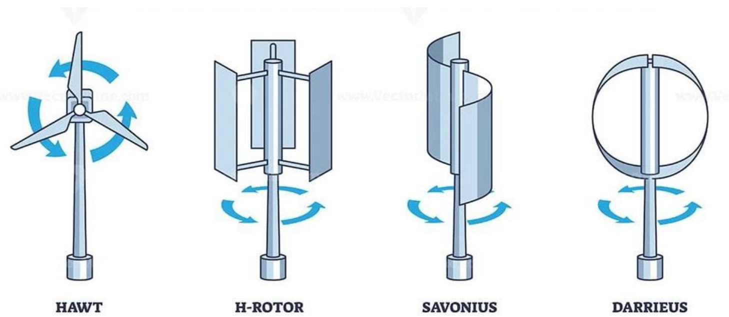

Fig 8 Various types of micro wind turbines have been developed to capture wind energy at macro- and microscales.

Micro turbines can be deployed in cities to take advantage of the different wind directions and speeds due to India's varied geography and different wind conditions in different states.The table II underscores the key features of micro wind turbines and their potential for alignment with the varying wind conditions across different states of India.

Table III

The table outlines key features of different wind turbine types and their suitability for wind generation in specific Indian states.

Micro wind turbine Type	Key Features	Suitable Wind Speed (m/s)	Cost of Installation & Maintenance	Suitable States in India
VAWT (Vertical Axis Wind Turbine)	Blades arranged vertically around a central axis, capturing wind from all directions; suitable for urban environments with turbulent wind.	3.0 - 7.0	Moderate	All states, particularly urban areas with varied wind conditions.
HAWT (Horizontal Axis Wind Turbine)	Blades arranged horizontally, perpendicular to the central axis; more efficient and commonly used in large-scale wind farms.	4.5 - 25.0	High	Wind-rich states like Gujarat, Tamil Nadu, Maharashtra, Rajasthan, Karnataka.
Savonius Rotor	Consists of curved blades in a drum-like configuration; simpler design with low efficiency but can operate in low wind speeds and has self-starting capabilities.	1.5 - 5.5	Low	Coastal states with lower wind speeds such as Kerala, Goa, parts of Maharashtra and Karnataka.
H-Rotor	Features two or more vertical blades perpendicular to the central axis, resembling the letter "H"; offers simplicity, stability, and suitability for harsh environments.	2.5 - 6.5	Moderate	All states, particularly those with diverse wind conditions and rugged terrains.

Built environment wind turbines, which provide flawless integration at the city level and have been a major focus of global research on micro wind turbine integration, have been thoroughly studied by the National Renewable Energy Laboratory(NREL).

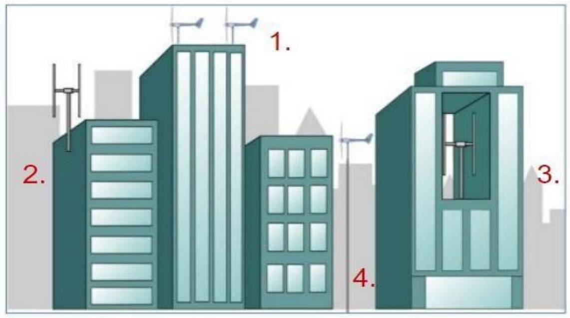

Fig 9 The National Renewable Energy Laboratory (NREL) has identified several types of built environment wind turbines that are suitable for integration at the city level.

As seen in Figure 12, built-environment wind turbines (BEWTs) are intended for installation on or between buildings in urban or suburban environments. Building constructions may also include these turbines, taking structural, architectural, and budgetary considerations into account.. Four types of BEWTS configurations exist: sidewall mounted, ground mounted, building integrated, and rooftop mounted.

Table IV Author's curation for analyzing different aspects of BEWTS.

Aspect	Roof-mounted BEWTs	Sidewall-mounted BEWTs	Building-integrated BEWTs	Ground-mounted BEWTs
Installation Location	Roof of buildings	Sides of buildings	Integrated into building design	Ground level
Wind Direction Sensitivity	Moderate sensitivity	Moderate sensitivity	Moderate sensitivity	Moderate sensitivity
Efficiency	Moderate efficiency	Moderate efficiency	Moderate efficiency	Moderate efficiency
Space Requirement	Utilizes existing roof space	Requires space on building exterior	Integrates into building design	Requires ground space
Maintenance	Accessible for maintenance	Accessible for maintenance	Accessible for maintenance	Requires ground access
Noise	Minimal noise	Minimal noise	Minimal noise	Minimal noise
Cost	Moderate initial investment	Moderate initial investment	Moderate initial investment	Moderate initial investment

POSSIBILITY OF BEWTS IN INDIAN DOMAIN

Several reasons are in favor of the potential installation of built environment wind turbines (BEWTs) in India. Opportunities for turbine integration may be found in India's varied urban environments, especially in public areas like parks and industrial zones. Turbines are now more aesthetically pleasing and efficient because of technological improvements, and investment may be encouraged by favorable legislation and incentives that can reduce installation costs. Campaigns for public knowledge can allay worries about wind energy's appearance and noise level. Overcoming technological and regulatory obstacles necessitates stakeholder collaboration, including government agencies and business partners. In addition, a number of case studies have been analyzed in this research to investigate the characteristics of BEWTS integration in India, offering insightful information about the performance, viability, and possible advantages for goals related to renewable energy and urban sustainability. The pressing need for clean energy and climate mitigation highlights the need of investigate BEWTs as a feasible renewable energy source in India's metropolitan regions, despite obstacles like space restrictions and early expenses. This study analyzes wind direction, efficiency, space requirement, maintenance, noise, and cost in existing Building-Integrated Wind Turbine Systems (BIWTS) projects globally. It aims to propose a system suitable for various cities in India, considering these parameters. Urban Wind Energy Harvesting System Fig. 13 Urban wind energy collection systems come in various forms: integrated within buildings (D), integrated between two buildings(b), free-standing (C), installed on building rooftops (A), placed alone near buildings (E) or as an installation near the streets. This categorization is based on data from sources[https://sdgs.un.org/es/goals/goal], supplemented by the authors' own elaboration.

A thorough investigation of many kinds of small-scale wind turbines is carried out in the case study analysis included in this research article, providing insight into their manufacturing processes, control systems, blade designs, and performance measures (see Fig. 13). The detailed analysis provides insightful information about the benefits and drawbacks of both horizontal and vertical axis designs. Additionally, the study explores the real-world effects of incorporating wind turbines into urban environments, emphasizing the benefits as well as the difficulties that come with such initiatives. The research highlights the viability of using metropolitan areas as centers for sustainable energy generation using wind power by utilizing empirical facts and real-world case studies.

This research offers policymakers, urban planners, and stakeholders engaged in renewable energy efforts practical advice by carefully assessing crucial factors for efficient wind turbine deployment in urban areas. The study promotes the integration of wind energy solutions into urban environments, therefore supporting sustainable development and minimizing the consequences of climate change, using a systematic strategy that resolves impediments and capitalizes on critical findings

CASE STUDY I
TWELVE WEST SKYSCRAPER

The Twelve West skyscraper in Portland has four Skystream 3.7 turbines that were installed in 2009. Situated atop 45-foot poles at a height of 82 meters on the 23-story structure, these roof-mounted turbines were anticipated to produce roughly 9,000 kWh annually, or 1% of the building's total electrical output. The actual annual production, however, was only about 5,500 kWh. Each turbine cost $20,000. The overall installation cost, including mounting pads and engineering, was $240,000. A 30% federal Investment Tax Credit was available for the project, which resulted in monetary rewards after it was finished. The project was considered successful in spite of obstacles including Turbine #3's maintenance problems, which occasionally required restarts. Its main goals were to raise awareness of renewable energy sources, increase the building's visibility, and emphasize its dedication to sustainability.

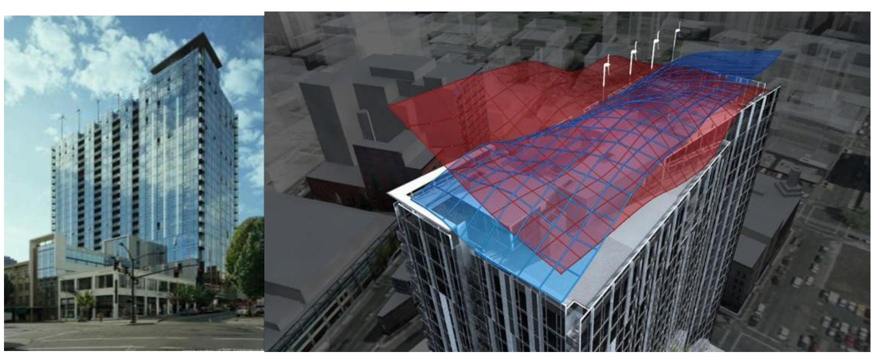

Fig 10 To determine the best location of the BEWTS on the building the architectural team took into account urban topography, weather data and seasonal variability of wind directions (pictured here) and then built a large-scale physical model of the building to test in a wind tunnel. - Photo Credit: ZGF Architects LLP

CASE STUDY 1 ANALYSIS: TWELVE WEST BUILDING WIND TURBINES

Parameter	**Description**
Wind Direction	Likely exposed to prevailing winds, enhancing efficiency. Detailed windstudies specific to the building's location would provide a clearer pictureof the wind direction's impact.
Efficiency	Estimated annual production of 9,000 kWh was optimistic; actual outputwas approximately 5,500 kWh per year. Lower efficiency could be attributed to factors such as wind speed, nearby structures, or suboptimalplacement of turbines.

Space Requirement	Roof-mounted turbines require minimal ground space, suitable for urbanenvironments. Mounting poles at 45 feet may add to visual impact but donot significantly increase footprint.
Maintenan ce	Issues with Turbine #3 requiring occasional restarts highlight theimportance of regular maintenance for optimal performance.

CASE STUDY II
WIND TURBINES AT DETROIT AIRPORT(BEWTS PLACED ALONE NEAR BUILDINGS)

The goal of the 2010 installation of six Windspire 1.2 turbines in Detroit, Michigan, was to test the feasibility of the technology at the airport. Nevertheless, the project encountered difficulties; as of July 2015, one turbine was non-operational due to a faulty inverter. Officials at the airport moved two turbines and tried to salvage enough parts from the remaining three to keep at least three running. The actual production was not tracked, but the estimated annual production was 2,000 kWh. Because of the manufacturer's insolvency, components were hard to come by, which made maintenance problems—such as inverter and bearing issues that have existed since the project's inception—even worse. Airport officials reported that despite the project's failure to meet energy production targets, interest in it has persisted due to its tourist appeal and potential as a model for other projects of a similar nature.

Fig 11 A vertical axis wind turbine installed at the Wind Turbines at Detroit Airport(Wind Turbines Powering Detroit Airport - green living, electric vehicle consultants, green guy, Companies, Car Expert, Electric Car News, New York, California, Florida, Missouri, Texas, Nevada (greenlivingguy.com)

These turbines, manufactured in Michigan, have vertical blades arranged in a cylindrical shape, in contrast to conventional turbines that have horizontal blades. Measuring only four feet in width and thirty feet in height, they have been positioned carefully to prevent any disruption to aviation traffic. This wind generator is built to capture wind energy at even slower rates, between 4.5 and 5 mph. The power it produces will help meet the airport's energy needs. In addition to being a sustainable project, this one also acts as a trial run for potentially larger turbine installations in the future.

CASE STUDY II ANALYSIS: WIND TURBINES AT DETROIT AIRPORT

Parameter	Description
Wind Direction	Not specified, suggesting potential suboptimal positioning for currentwind direction, which could impact efficiency.
Efficiency	Actual production was not tracked, but the estimated annual production was 2,000 kWh. However, one turbine was non-operational due to a faultyinverter, indicating potential efficiency issues.
Space Requirement	The installation of six turbines suggests a relatively small footprint,suitable for urban environments or constrained spaces.
Maintenance	The project encountered maintenance issues, including faulty inverters and bearing problems since its inception. The manufacturer's insolvencyfurther exacerbated these issues, highlighting the importance of reliable maintenance support.
Noise	No specific noise level provided, so the impact on noise levels in theairport environment is unclear.

Cost	Total installation cost not provided, but challenges due to the manufacturer's insolvency made sourcing components for maintenancedifficult, potentially increasing overall costs.

CASE STUDY III
STRATA TOWER (BEWTS INTEGRATED WITHIN THE BUILDINGS)

In London, UK, four Urban Green Energy (UGE) 4K turbines were installed in 2012, integrated into the structure of Strata Tower. The project aimed to assess the viability of integrating wind turbines into urban high-rise structures. Despite facing ongoing maintenance issues, including malfunctions with inverters and bearings, all turbines remain operational. Estimated production is approximately 8,000 kWh per year, and detailed tracking records indicate consistent performance meeting these levels. The project cost an estimated £100,000 and was eligible for government incentives and grants for renewable energy projects. Despite falling short of expected energy production, the project has garnered interest from visitors, suggesting potential for similar installations in urban settings.

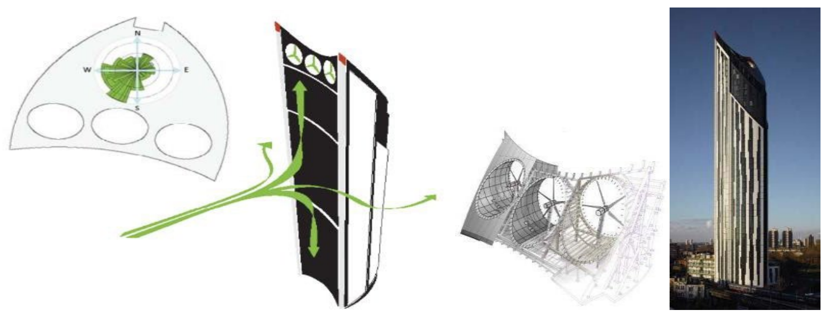

Fig 12 The wind rose for London has a predominantly south-westerly axis in summer-time and the curved elevation was suitably oriented to capture wind from this direction.(Integrating Wind Turbines in Tall Buildings (Author: Ian Bogle, Director, BFLS)

CASE STUDY III ANALYSIS: STRATA TOWER

Parameter	Description
Wind Direction	Not specified, but likely positioned to capture prevailing winds, enhancing efficiency due to their integration into Strata Tower, an urbanhigh-rise structure.
Efficiency	Estimated production is approximately 8,000 kWh per year, with detailed tracking records indicating consistent performance meeting these levels, suggesting reasonable efficiency despite ongoing maintenance issues.
Space Requirement	Integration into Strata Tower indicates a relatively small footprint, best solution for urban environments with limited space.
Maintenance	Ongoing maintenance issues, including malfunctions with inverters and bearings, have been encountered. Despite these challenges, all turbines remain operational, highlighting the importance of regular maintenance.
Noise	No specific noise level provided, so the impact on noise levels in the urban environment is unclear.
Cost	The project cost an estimated £100,000 and was eligible for government incentives and grants for renewable energy projects, despite facing maintenance issues and falling short of expected energy production.

CASE STUDY IV
BAHRAIN TOWER (BEWTS INTEGRATED BETWEEN TWO BUILT UP STRUCTURES)

Bahrain Tower, located in Manama, the capital of Bahrain, showcases the potential of urban wind energy by incorporating eight vertical axis wind turbines (VAWTs) into its architecture. These VAWTs were installed in 2023 and are already active, helping to power the building. Specifically crafted for city settings, they catch wind from all angles without requiring repositioning. With an anticipated 40,000 kWh of production per year, the turbines roughly match real production. The initiative is supported by government incentives even though the installation will cost $300,000. Low downtime and maximum performance are guaranteed by routine maintenance. The Bahrain Tower project exemplifies the viability of renewable energy in urban environments, lowering dependency on conventional power and supporting Bahrain's sustainability objectives.

Fig 13 The highly visible and dramatic wind turbines are seen as a strong iconic statement about the importance of alternative energy sources.(source: The Bahrain World Trade Center Has Built-In Wind Turbines | Amusing Planet)

CASE STUDY IV ANALYSIS: BAHRAIN TOWER

Paíameteí	Desciiption
Wind Direction	VAWTs at Bahrain Tower capture wind from all angles without repositioning,suitable for variable urban wind directions, enhancing efficiency.
Efficiency	Expected 40,000 kWh/year production; actual aligns, indicating efficientoperation meeting targets.
Space Requirement	Eight VAWTs demonstrate a small footprint, suitable for urban integrationwith limited space.
Maintenance	Emphasis on routine maintenance ensures maximum performance and minimaldowntime, crucial for sustained efficient operation.

CASE STUDY V
AEROLEAFS (BEWTS AS INSTALLATION ON STREETS))

The Aeroleaf turbine, available in France, Belgium, Spain, and Italy, has a distinctive vertical axis, double-blade design that resembles a leaf and a synchronous micro-generator that runs on permanent magnets. The purpose of installing these turbines—which were made to order for the client—was to advance sustainability and renewable energy. Maximizing energy production, the Aeroleaf operates for about 300 days a year, with a beginning threshold of 2.5 m/s wind speed. Designed for installations at the community or individual level, the Aeroleaf uses Watts to produce kiloWatts. The turbines' actual production is in line with predictions, despite the lack of maintenance records and predicted production data. With no gears or belts, the technology's quiet direct drive mechanism makes it perfect for harnessing erratic and weak winds, paving the way for greener energy in the future.

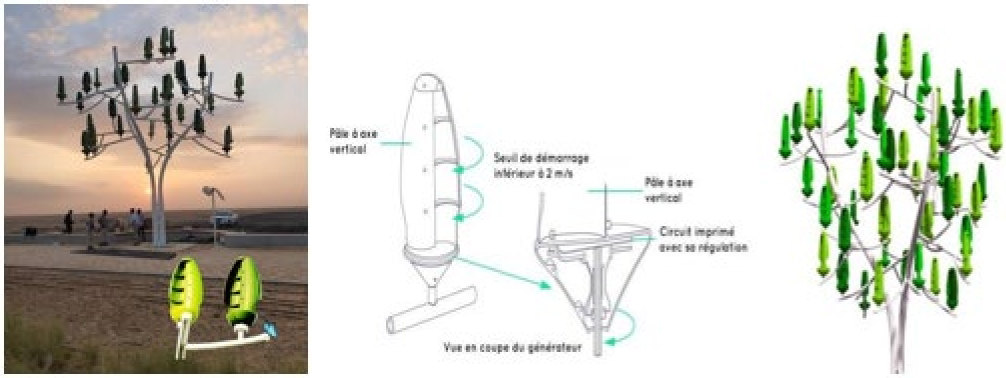

Fig 14 Ideal for individuals and small spaces, Windbush is suitable for use in small structures and buildings.

The average production of our solutions makes it possible to supply (on average per solution and per year)(as seen in Fig 15)

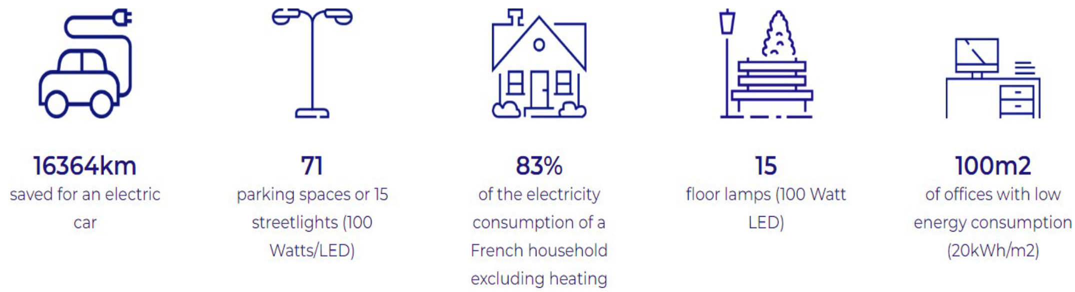

Fig15 The illustration talks about the energy conversion commitments from the Aeroleaf company(source: https://www.newworldwind.com/commitments.)

CASE STUDY V ANALYSIS: AEROLEAFS

Parameter	Description
Wind Direction	Not specified, but the Aeroleaf is designed to capture wind from all angles without needing repositioning, making it suitable for urban environments wherewind direction can be variable.
Efficiency	The Aeroleaf operates for about 300 days a year, with a beginning threshold of 2.5 m/s wind speed, maximizing energy production. Actual production is in linewith predictions, despite the lack of maintenance and production data.
Space Requirement	Designed for installations at the community or individual level, the Aeroleaf hasa small footprint, suitable for urban environments or constrained spaces.
Maintenance	No specific maintenance records are mentioned, but the technology's directdrive mechanism without gears or belts suggests it may require minimal maintenance for optimal performance.
Noise	The technology's quiet direct drive mechanism makes it suitable for urban environments, as it generates minimal noise, contributing to its suitability forcapturing erratic and weak winds.

3. DISCUSSION AND CONCLUSIONS

The case studies thoroughly examined a number of factors, such as installation site, efficiency, noise level, maintenance needs, space requirements, wind direction sensitivity (both speed and direction), and cost. It was possible to extract insights on how to successfully incorporate these systems into the Indian setting. In particular, factors such as wind direction sensitivity were examined closely to maximize performance under a variety of Indian climate scenarios. For successful integration and scalability within India's renewable energy framework, other factors such space requirement, maintenance efficiency, noise reduction, and cost-effectiveness were crucial.

Mumbai is a good location for projects like the turbines on the Twelve West Building and Strata Towers because of its powerful coastal winds, crowded metropolitan environment, and tall structures. To reduce noise and visual impact, however, thorough wind studies and cautious placement would be required. Bengaluru appears to be the best option for a wind turbine installation similar to the one at Detroit Airport. Given previous problems, its thriving tech sector makes effective maintenance possible. Although the direction of the wind was not stated, Bengaluru has several spots with good wind conditions. The city's urban setting is ideal for the little footprint needed, and its developing renewable energy sector provides affordable options. Industrial zones offer a way to reduce noise concerns. Thorough evaluations of the sites are required for the best possible location in Bengaluru. Chennai appears to be the perfect Indian metropolis for a project similar to Bahrain Tower's VAWTs. Because of its coastal position, efficiency is increased by strong and varied wind directions. The urban setting fits the little size needed for integration, and government subsidies help to defray the expensive initial outlay.

Chennai's strong infrastructure facilitates regular maintenance, which is essential for long-term functioning. The expenditure is further justified by the city's dedication to environmental sustainability and renewable energy. India's Chennai offers a lot of promise for urban wind energy projects. Because of its design, the Aeroleaf turbine can react to wind flowing from any direction without having to shift positions, which makes it appropriate for a range of Indian urban environments. The Aeroleaf's capacity to begin

producing electricity at a comparatively low wind speed threshold of 2.5 meters per second (m/s) is a crucial component of its adaptability. The Aeroleaf can capture energy from even the weak and unpredictable breezes that are frequently seen in urban areas because of its low beginning threshold. Because of this, the Aeroleaf's dynamic nature and low wind speed need make it a feasible alternative for urban wind energy generation across India, regardless of the particular wind conditions in different Indian cities.

It is clear from a deeper look at the aforementioned case studies that similar wind energy projects have a great deal of potential to be adopted by Indian urban contexts. To optimize wind energy consumption in India, I think architectural interventions at the inception level are essential, in addition to the elements included in these research. We can maximize the efficiency with which urban structures, such buildings and infrastructure, can harvest wind power by incorporating wind energy concerns into the earliest design process of these projects.Moreover, the integration of diverse wind energy system typologies in an urban context, as seen in the picture, may yield supplementary advantages. In close proximity to the grid system, a wide mix of wind energy technologies can assist reduce electric transmission losses. Because of this close proximity, energy needs to travel less distance from the source to the grid, improving total energy efficiency. In conclusion, while reducing transmission losses, implementing a range of wind energy technologies and integrating architectural interventions into Indian urban contexts can greatly advance the nation's renewable energy targets. India's sustainable development and energy security are greatly enhanced by this comprehensive strategy to urban wind energy integration.

Fig16 The possibility Of different BEWTS projects in Indian urban context where it is very close to the Grid System(the possible outcomes and suggestions for this study)

CONFLICT OF INTERESTS

None

ACKNOWLEDGMENTS
None

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