EJPMR, 2025, 12(12), 348-353 **Review Article** **Impact Factor 7.065**

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

ISSN (O): 2394-3211
ISSN (P): 3051-2573
Coden USA: EJPMAG

WIND MILL AND WIND TURBINE: A CORRELATION APPROACH OF THE AERODYNAMIC PRINCIPLE OF WIND

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Shri Sarvajanik Pharmacy College, Gujarat Technological University, Arvind Baug, Mehsana-384001, Gujarat, India. **DOI:** https://doi.org/10.5281/zenodo.17786526

How to cite this Article: 1Dr. Dhrubo Jyoti Sen, 2*Dr. Pruthviraj K. Chaudhary, 2Shloka V. Chaudhari, 3Anandkumar M. Raval, 4Dr. Bharat G. Chaudhari. (2025). Wind Mill And Wind Turbine: A Correlation Approach of The Aerodynamic Principle of Wind. European Journal of Biomedical and Pharmaceutical Sciences, 12(12), 348–353.

Article Received on 04/11/2025 **Article Revised on 25/11/2025** **Article Published on 01/12/2025**

ABSTRACT

A windmill is a machine that converts wind's energy into rotational energy, typically using sails or blades. Historically, windmills were used for mechanical tasks like grinding grain or pumping water, while modern windmills, more accurately called wind turbines, generate electricity. The process works by wind pushing against the blades, causing a shaft to spin, which connects to a generator that produces electricity. A wind turbine is a device that converts wind's kinetic energy into electrical energy. It works by using large blades, which are designed like airplane wings, to capture the wind's force, causing them to spin. This rotation turns a shaft connected to a generator, which then produces electricity. **Wind mill:** Wind energy to mechanical energy: Wind flows across the angled blades, creating a difference in air pressure on each side. This difference generates lift, which is stronger than drag, causing the rotor to spin. **Wind turbine:** Mechanical energy to electrical energy: The spinning rotor connects to a generator, either directly or through a gearbox, which converts the rotational energy into electrical energy.

KEYWORDS: Air, wind, breeze, wind mill, wind turbine.

INTRODUCTION

Air is the mixture of gases that makes up the Earth's atmosphere, while wind is the horizontal movement of that air. Wind occurs because of differences in air pressure, flowing from high-pressure areas to low-pressure areas. Air is a static substance all around us, but wind is air in motion, with a specific speed and direction.

Air: What it is: The gaseous mixture that surrounds the Earth, composed mainly of nitrogen and oxygen, along with other gases like carbon dioxide and argon.

- **State:** It is the fundamental "medium," present everywhere and essential for life.
- **Visibility:** It is invisible.

Wind: What it is: Air that is moving.

- **Cause:** Differences in atmospheric pressure caused by temperature variations.
- **Movement:** It flows from high-pressure to low-pressure areas.
- **Characteristics:** It has speed and direction.
- **Visibility:** It is invisible, but its movement is made visible by its effect on objects like trees and leaves.

Air is the mixture of gases in the Earth's atmosphere, while wind is the movement of that air. Air is a static substance that makes up the atmosphere, while wind is the term for air in motion, which is caused by differences in air pressure. Wind can be defined as air that moves across the earth. Wind can be categorized as different types based on the speed at which it moves. One category of wind is a wind breeze. A breeze occurs when air moves from an area of high air pressure to an area of lower air pressure.

Figure 1: Wind turbine & Wind mill.

Wind is created when warm air rises and cooler air rushes in to replace it. Storms: This is an event when strong winds, heavy rain, and sometimes lightning combine! Such storms form when air masses of different temperatures collide. Moving air is called wind. This movement is caused by differences in air pressure, which result from uneven heating of the Earth's surface. When air is heated, it becomes lighter and rises, and cooler, denser air moves in to take its place, creating wind.

Table 1: Difference between air & wind.

Feature	Air	Wind
Definition	The mixture of gases that forms the Earth's atmosphere.	The horizontal movement of air.
Motion	Generally static or still.	Always in motion.
Cause	The atmosphere itself.	Differences in atmospheric pressure between different areas.
Characteristics	A mixture of gases like nitrogen, oxygen, and carbon dioxide.	Has a specific direction and speed.

Formation of wind: Uneven heating on Earth causes air in different areas to heat up or cool down at different rates. Warm air rises, creating a low-pressure area. Cooler, denser air sinks, creating a high-pressure area. Air naturally moves from a high-pressure area to a low-pressure area, and this movement is what we call wind.

Types of wind

- **Breeze:** A gentle, moving air.
- **Storm:** A strong, moving air current.

The four main types of winds are primary (planetary) winds, secondary (periodic) winds, local winds, and variable winds. Primary winds are global, like the trade winds and westerlies, while periodic winds change seasonally, such as monsoons. Local winds are shorter-term and influenced by local geography, like sea and mountain breezes, and variable winds are non-regular, influenced by changing atmospheric conditions.

Figure-2: Blades of wind turbine & wind mill.

1. Primary (Planetary) Winds: These winds blow continuously throughout the year over large areas of the Earth. They are driven by Earth's rotation and large-scale heating differences between the equator and the poles. Examples include the trade winds, westerlies, and polar easterlies.

2. Secondary (Periodic) Winds: These winds change direction or strength with the seasons or on a regular basis, but not continuously throughout the year. Examples include seasonal winds like the monsoon and regular daily winds like land and sea breezes and mountain and valley breezes.

3. Local Winds: These are winds that blow over a short distance and are influenced by local geographical features, such as landforms and bodies of water. They are typically influenced by daily heating and cooling patterns. Examples include sea breezes, land breezes, valley breezes, and mountain breezes.

4. Variable Winds: These winds are unpredictable and don't follow a consistent pattern. Their direction and speed are influenced by changing weather patterns and atmospheric pressure systems.
Air is constantly moving around the earth. This moving air is called wind. Winds are created when there are differences in air pressure from one area to another.[1]

Wind mill: The first windmills were developed in Persia between the 9th and 13th centuries for tasks like grinding grain and pumping water, using a vertical axis and rectangular sails. The first horizontal-axis windmills, more similar to modern designs, appeared in Western Europe around 1300. Inventors like **Daniel Halladay** [Daniel Halladay (November 24, 1826 in Marlboro, Vermont – March 1, 1916 in Santa Ana, California) was an American engineer, inventor and businessman, best known for his innovative 1854 self-regulating farm wind pump at Ellington, Connecticut] and **Charles Brush** [Charles Francis Brush (March 17, 1849 – June 15, 1929) was an American engineer, inventor, entrepreneur, and philanthropist.] later developed more advanced designs for commercial and electrical use in the 19th century.

Wind turbine: A wind turbine is a device that converts wind's kinetic energy into electrical energy. It works by using large blades, which are designed like airplane wings, to capture the wind's force, causing them to spin. This rotation turns a shaft connected to a generator, which then produces electricity.

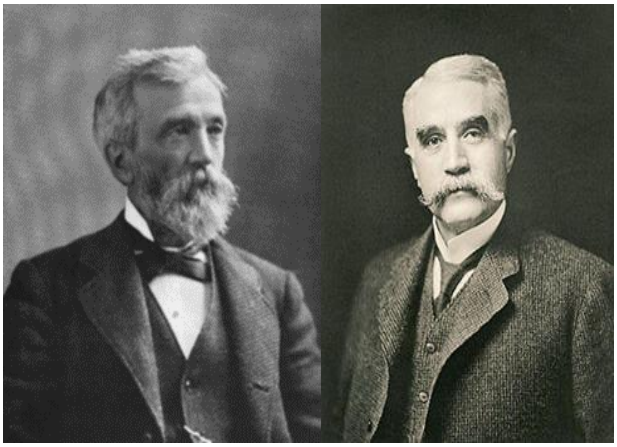

Figure 3: Wind mill inventors: Daniel Halladay & Charles Brush.

How it works
Capturing wind: As wind flows over the turbine's blades, it creates a pressure difference, which generates "lift" and causes the rotor to spin.
Generating rotation: The spinning blades turn a rotor connected to a drive shaft.

Producing electricity: The drive shaft is connected to a generator, which converts the mechanical motion into electrical energy.

Speed and power: The rotor's speed can be directly connected to the generator or, more commonly, sent through a gearbox to increase the rotational speed before it reaches the generator, allowing for a physically smaller generator.

Key parts
Blades: Capture the wind's kinetic energy.

Rotor: The assembly of blades and the hub they are mounted on.

Nacelle: The housing at the top of the tower that contains the generator, gearbox, and other mechanical components.

Generator: Converts the rotational energy into electricity.

Types of turbines
Horizontal-axis wind turbines: The most common type, with blades that rotate on a horizontal axis, similar to a propeller.

Vertical-axis wind turbines: Rotate on a vertical axis and come in a variety of shapes and designs.

Where they are used: Wind turbines are often grouped together in "wind farms" to generate electricity on a large scale. They are typically placed in areas with strong and consistent winds, such as open fields or offshore locations. Smaller turbines can also be used for individual homes and businesses.

James Blyth, [James Blyth (4 April 1839 – 15 May 1906)] a Scottish engineer, is credited with building the world's first electricity-generating wind turbine in 1887. Hot on his heels, **Charles Brush** [March 17, 1849 – June 15, 1929] built the first large-scale wind turbine in the United States in 1888. Later pioneers like **Poul la Cour** [13 April 1846 – 24 April 1908] made significant contributions to the efficiency and understanding of modern wind turbine design.

James Blyth: Built the first wind turbine to generate electricity in Scotland in 1887, using it to power his holiday home.

Charles Brush: Developed and installed the first large-scale electricity-generating wind turbine in Cleveland, Ohio, in 1888.

Poul la Cour: A Danish inventor and scientist who was instrumental in the development of modern wind turbines. He realized that fewer blades were more efficient and that regulators could provide a steady power supply.

Figure 4: Wind turbine inventors: James Blyth, Charles Brush & Poul la Cour.

Early windmills (Persia and China)

- Timeframe: 9th to 13th centuries.
- Design: Vertical axis windmills with long shafts and rectangular sails covered in cloth or reed matting.
- Uses: Pumping water and grinding grain.

European windmills

- Timeframe: Around 1300 AD.
- Design: The first horizontal-axis windmills appeared in Western Europe, evolving into the postmills and stone towermills used to drain land and for other purposes.
- Modern and electric windmills

1850s: Daniel Halladay and John Burnham created the Halladay Windmill, the first commercially viable windmill in the U.S. for pumping water.

1887: James Blyth built the first windmill for electricity in Scotland.

1888: Charles Brush built the first wind turbine for electricity generation in the U.S. to power his estate.

1941-1943: The Smith-Putnam wind turbine, a large-scale experimental wind turbine, supplied power in Vermont.

Late 20th century: A renewed interest in wind energy began, driven by oil crises and government incentives, leading to the development of modern large-scale wind turbines for electricity generation.

A windmill is a machine that converts the wind's kinetic energy into mechanical energy to perform work, such as grinding grain, pumping water, or generating electricity. Modern versions, called wind turbines, are primarily used to create electricity, while historical windmills were more commonly used for other tasks.

Figure 5: Blades of wind mill & wind turbine.

How a windmill works

- **Blades/Sails:** Wind blows against the angled blades, which are mounted on a rotor. Capture the wind's energy.
- **Rotation:** The force of the wind causes the blades and the attached shaft to spin. The assembly of blades.
- **Mechanical power:** This rotational energy can be used to power a device like a water pump or millstones for grinding grain.
- **Shaft:** Transmits rotational energy from the rotor to the machine.
- **Tower:** Provides a stable platform at a height where wind is stronger.
- **Electricity generation:** In modern wind turbines, the spinning shaft powers a generator to produce electricity. Converts mechanical energy into electrical energy in modern turbines.

A windmill is a machine that converts the kinetic energy of wind into rotational mechanical energy. This rotation has historically been used for tasks like grinding grain, pumping water, and sawing wood, but modern windmills, often called wind turbines, use the energy to spin blades connected to a generator to produce electricity.

- **How it works:** The wind turns the blades (or vanes/sails), which spins a shaft. This rotational energy is then used directly for mechanical work, or it is used to power a generator to create electricity.
- **Components:** Key components include the blades, a hub or rotor, and a tower. Modern electric-generating windmills also have a gearbox and a generator, often located in the "nacelle" at the top of the tower.
- **Types:** Windmills are broadly classified into two types based on the axis of their blades:
- **Horizontal axis windmills:** The most common type, with blades rotating on a horizontal shaft, similar to a propeller or turbine.
- **Vertical axis windmills:** The blades rotate on a vertical axis.

Applications

- **Historical:** Grinding grain, pumping water, and powering other machinery.
- **Modern:** Generating electricity, with modern wind turbines being a major source of renewable energy.

Types and uses

- **Historical:** Used for grinding grain into flour, pumping water, and sawing wood.
- **Modern:** Often called "wind turbines" and are used to generate electricity, with groups of them called "wind farms".
- **Other uses:** Can also be used for various other mechanical tasks.
- In modern wind turbines, the spinning shaft powers a generator to produce electricity.

The main difference is that a windmill converts wind into mechanical energy to perform physical tasks like grinding grain or pumping water, while a wind turbine converts wind energy into electrical energy for power generation. Windmills are older technology for direct mechanical work, while wind turbines are a modern development designed specifically to produce electricity through a generator.[2]

Table 2: Comparison between Windmill & Wind Turbine.

Feature	Windmill	Wind Turbine
Primary Function	To do mechanical work, such as grinding grain or pumping water.	To generate electricity.
Energy Output	Mechanical energy.	Electrical energy.
Key Components	Blades, rotor shaft, and the machine being powered (e.g., a mill or pump).	Blades, rotor, gearbox, and a generator.
Blade Design	Often have large, canvas-like blades that rely on wind pressure.	Typically have two or three blades designed to maximize lift and drag forces.
Technology	Older, traditional technology.	Modern, advanced technology.

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases.

The Muppandal Wind Farm, located in Muppandal, Kanyakumari district, Tamil Nadu, is India's largest operational onshore wind farm. The project was developed by Tamil Nadu Energy Development Agency. The Muppandal Wind Farm's installed capacity is 1,500 MW, which makes it the 4th-largest operational onshore wind farm in the world. The world's largest wind turbine is the 20-megawatt offshore turbine made by Mingyang Smart Energy and installed in China. It has a massive rotor diameter of up to 292 meters and a swept area of over 66,000 square meters, which is equivalent to more than 12 NFL football fields. It is designed to generate enough electricity to power about 96,000 homes annually and withstand extreme weather conditions, including level-17 typhoons. The world's largest wind farm is the Gansu Wind Farm in China, a 20GW facility with over 7,000 turbines. The largest single wind turbine in the world is the MySE 16.0-260, a 16-megawatt offshore turbine manufactured by Ming Yang Wind Power, with a 260-meter rotor diameter. China is also home to the largest offshore turbine, the 26-megawatt offshore wind turbine, which was completed in 2024.

A windmill's axis is the central shaft around which the blades rotate, and it is the defining feature for its two main types: horizontal axis (most common) and vertical axis. Horizontal axis windmills have blades that spin on an axis parallel to the ground, while vertical axis windmills have blades that spin on an axis perpendicular to the ground.

Horizontal-axis windmills (HAWTs)

Axis orientation: The rotor shaft is horizontal, parallel to the ground, and the blades are like a large propeller.

Direction: They must be pointed into the wind to be effective, which is why they have a "yaw system" to turn them.

Components: The generator and gearbox are typically housed in a nacelle at the top of the tower.

Efficiency: HAWTs are the most common type of wind turbine and are generally more efficient for large-scale power generation.

Vertical-axis windmills (VAWTs)
Axis orientation: The main rotor shaft is vertical, perpendicular to the ground.

Direction: They can accept wind from any direction, so they do not need a yaw system, making them useful in areas with variable wind direction.

Components: The generator can be located at the base of the tower, which simplifies maintenance.

Designs: There are several designs, including the drag-based Savonius type and the lift-based Darrieus and H-type.

Applications: VAWTs are often considered better for smaller-scale applications, such as residential use, or for use in turbulent urban environments.

A wind turbine's axis refers to the orientation of its rotor shaft, which defines it as either a horizontal axis wind turbine (HAWT) or a vertical axis wind turbine (VAWT). HAWTs have a vertical main shaft, like a traditional windmill, and are most common for large-scale electricity production. VAWTs rotate around a vertical shaft, have blades oriented vertically, and are often better for smaller, residential, or urban applications because they can handle wind from any direction.

Horizontal Axis Wind Turbine (HAWT)
Axis: The rotor shaft is horizontal and parallel to the ground.

Operation: Needs a yaw system to face the wind to work effectively.

Applications: Commonly used for large-scale energy production, often in windy, open areas or offshore.

Design: Blades are tapered and twisted to account for changing airflow speeds along their length, and the generator is typically at the top of the tower.

Vertical Axis Wind Turbine (VAWT)
Axis: The rotor shaft is vertical.
Operation: Can accept wind from any direction without needing to reorient itself.

Applications: Often used for small-scale, residential, or urban installations, and can handle turbulent or gusty conditions well.

Design: Blades can have a simpler aerodynamic design. Key components like the generator and gearbox can be placed at the base of the tower, which simplifies maintenance.

CONCLUSION

A windmill is a machine that converts wind's energy into rotational energy, typically using sails or blades. Historically, windmills were used for mechanical tasks like grinding grain or pumping water, while modern windmills, more accurately called wind turbines, generate electricity. The process works by wind pushing against the blades, causing a shaft to spin, which connects to a generator that produces electricity. A wind turbine works by converting the kinetic energy of wind into mechanical energy and then into electrical energy. When wind blows, it spins the turbine's blades, which in turn spin a shaft connected to a generator. The generator uses this rotational force to produce electricity.

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