Impact Factor 5.8701 (ICI)

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
ISSN: 2321-7758 http://www.ijoer.in editorijoer@gmail.com

Vol.14., Issue.2, 2026
April-June

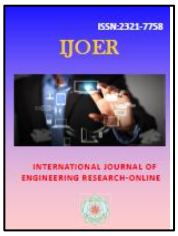
RESEARCH ARTICLE

ISSN: 2321-7758

Renewable Energy-Based Climate Control in Livestock Production Facilities: Wind Turbine Integration in Rural Iraq

Abbas Saykan Ali Jan
Assist. Lecturer, Al-Aqsa Evening High School, General Directorate of Education–Al-Rusafa Third, Ministry of Education, Baghdad, Iraq.
Corresponding author: AbbasSaykan85@gmail.com

DOI: 10.33329/ijoer.14.2.1



Article info
Article Received: 18/05/2026
Article Accepted: 16/06/2026
Published online: 23/06/2026

Abstract

This study aims to evaluate the wind energy potential and climatic suitability for small- and medium-scale applications in Erbil Province, Iraq. Long-term meteorological data (1940–2024) and detailed daily wind records for 2023 were analysed to determine prevailing wind directions, wind speed distributions, and power density at turbine hub height. Wind speeds measured at 10 m were extrapolated to 50 m using the power law ($\alpha = 1/7$). The annual mean wind speed was 4.3 m s^{-1} at 10 m and 5.41 m s^{-1} at 50 m, with 58% of occurrences between 2.0–4.0 m s^{-1}. The calculated average wind power density reached 63.89 W m^{-2}. A 60-head free-stall barn (9.4 × 39.6 m) required six ventilation fans and a fan-pad cooling system with a total energy demand of 4.7 kWh day^{-1}; thus, a 6-kWh wind turbine system was proposed. Results indicate that Erbil possesses moderate wind potential suitable for decentralized agricultural applications. Wind-powered ventilation significantly enhances thermal comfort and livestock productivity while reducing dependence on grid electricity.

Keywords: Wind energy potential; Erbil Province; Wind power density; Hub height extrapolation; Renewable energy assessment.

1. Introduction

Iraq has a large territorial area characterized by low population density in rural Central Districts, especially in parts of the Kurdistan Region and western provinces. In many of these areas, electricity supply is either unreliable or dependent on diesel-based generation, and access to continuous electrical energy remains limited [1]. As a result, decentralized renewable energy systems, such as wind-energy-based solutions, represent a technically viable alternative for meeting the energy needs of agricultural and livestock production systems. There is limited access to energy for end use in isolated and rural consumers in Iraq, including agricultural production farms, pastoral communities, villages, and small-scale livestock holders. This situation is mostly due to low individual electricity demand, scattered settlements, and long distances from transmission and distribution networks, which require high infrastructure investment and offer limited financial return for electric utility providers.

The increasing energy demand due to constantly changing and developing technology is one of humanity's greatest dilemmas. One of the factors determining the development levels of countries is the amount of energy they use. [2] Although the use of renewable energy sources is increasing rapidly today, fossil energy sources continue to be the primary global energy source. However, these energy sources have disadvantages such as being exhaustible, price volatility, and transportation from specific locations to other regions or countries. In addition to these disadvantages, due to the damage caused by greenhouse gases to the world's nature and atmosphere, countries are turning to renewable energy sources as healthy, clean, and sustainable energy sources. Renewable energy sources can reduce the negative pressure on the environment as well as diversifying the country's energy resources [3].

Iraq's geographical location renders it is advantageous than several countries about wind and solar energy. Despite the substantial initial investment required for these systems, the lack of raw material costs diminishes energy production expenses. Research demonstrates that renewable energy sources can be utilized cheaply in agricultural operations. Wind turbine systems and photovoltaic panel systems from renewable energy sources can complement each other rather than being alternatives to each other. Both systems have advantages and disadvantages [4]. The fact that wind does not blow continuously and that solar energy is only available during certain time periods provides an advantage in terms of energy supply security when these energy systems are used as a hybrid system rather than independently of each other. Additionally, having higher wind energy potential in winter months and higher solar energy potential in summer months makes it more appropriate to use these systems together for sustainable energy supply [5].

Livestock farming, a significant sector of agricultural output, is a crucial area of study concerning economics, social implications, and nutrition both globally and nationally. For optimal nutrition, the body's need for calories, proteins, fats, and carbs must be fulfilled in a balanced manner. Meat production, a significant source of animal protein in nutrition, is inadequate. Despite our nation's per capita meat consumption being lower than that of industrialized countries, data from 2025 indicates an average of 31.2 kilograms (comprising 13.4 kg of red meat and 17.8 kg of poultry) [6].

Iraq has a fairly good potential in terms of animal production and animal numbers. However, animal productivity is below the desired level. Among the main reasons for this are that the majority of the animal population is low-yielding, and due to poor planning of animal barns, adverse environmental conditions, and inadequate care and feeding [7-8].

The study of these energy potentials in the northern and western regions of Iraq points to possible locations where it is feasible to convert renewable energy sources, such as wind, in a regular and reliable manner, although not at high values (i.e., large scale) as observed in regions with very strong wind regimes, but still technically feasible due to regional characteristics. Iraq presents significant potential for the exploitation of renewable energy resources, particularly wind and solar energy, given its vast territory and varied climatic conditions. Therefore, appropriate conditions must be established for wind resource assessment and feasibility studies that, in the long term, can lead to the development of innovative equipment and processes. This objective aligns with research and development activities supported by governmental institutions and, in some cases, private initiatives. Similar renewable energy technologies have been implemented on a large scale in other countries through governmentsupported projects, including the United States, Germany, and Denmark. However, in Iraq, regions with consistently high wind speeds suitable for large-scale commercial wind energy installations are limited, while moderate wind regimes are more common in inland areas.

Wind resource assessments conducted in Iraq indicate that average wind speeds in many inland regions are lower than those required for large-scale commercial wind turbine applications. Under these conditions, the present study aims to initiate an investigation into the utilization of wind energy in regions characterized by low to medium wind speed regimes, differing from high-wind coastal or mountainous areas. In particular, wind speed ranges between approximately 1–3 m/s and 3–5 m/s are observed in parts of northern and western Iraq [5], which can be exploited for mechanical energy applications, such as driving ventilation systems, water pumping, and other agricultural operations, as well as for small-scale electrical energy generation.

In regions near Erbil and surrounding areas of the Kurdistan Region, prevailing winds are generally from the northwest and west, with annual average wind speeds reported in the range of approximately 3.5–5.0 m/s at 10 m above ground level, based on available meteorological station data [9]. Similar methodologies for wind regime analysis, involving the use of data from Erbil International Airport Meteorological Station meteorological stations combined with local observation stations, have been widely applied in previous wind energy studies conducted in different geographical contexts. The wind potential (W/m², per area of wind turbine blades) of a given region is typically determined through the analysis of hourly average wind speed data over extended periods, usually one year or more [10]. These data are obtained from meteorological stations installed near ground level (generally ≤10 m) and subsequently extrapolated to the intended wind turbine hub heights. This approach has been adopted in several wind energy studies and is applied in the present work to estimate the local wind energy potential under Iraqi climatic conditions.

1.1 Environmental Conditions in Animal Barns

The productivity obtained from animals is related to the environmental conditions of the barn where they are raised as well as their genetic structure and breed characteristics. In animal barns, many factors such as air temperature, relative humidity, air flow rate, harmful gas concentrations (CO_2, NH_3, H_2S, etc.), dust amount, lighting, number of animals per unit area, and sound can affect animal health and productivity. To ensure the comfort and welfare of animals in the barn, these environmental factors must be kept at appropriate levels and values [11].

The most important of these environmental factors is the air temperature inside the barn. The animal's body works like a machine; it takes the energy it needs from the feed it consumes. Animals use some of the energy from the feed they consume for maintenance and some for yield [12]. If the environmental conditions of the barn are not suitable, the animal tries to maintain its body temperature balance. To maintain body temperature balance, the animal uses the energy it obtains from feed, which negatively affects its yield. The animal tries to adapt to the environmental temperature with various physiological and behavioral changes.

In mechanical ventilation, the capacity of the fans to be used is determined according to the air change rate required for animal health and welfare. The amount of air change varies depending on the season, the animal species and breed in the barn, animal weight, and numbers. The ventilation amount varies between 1-6 minutes for poultry houses and 5-15 minutes for cattle barns, renewing the barn air. For fan selection, after determining the required air change amount per hour, the number of fans is determined by dividing by the air change capacity of a fan. The fans' air flow rates can be adjusted as desired with a control mechanism [13]. The electrical energy mandatory for automatic ventilation in animal barns can be obtained from renewable energy sources. For this, systems with solar panels (photovoltaics), wind turbines, or hybrid structures can be used.

1.2 Wind Energy Potential

Wind energy originates from the sun. While the sun heats the atmosphere, land, and seas at different rates, some parts of the atmosphere warm up while others cool down. In warm weather, air rises, and cool air fills the void. This creates air circulation and wind. As a renewable energy source, wind is clean and environmentally friendly, a domestic energy source, has no fuel costs, does not produce waste, and has a short construction period. However, its investment cost is high, and it is dependent on variable weather conditions [14].

Wind characteristics fluctuate based on temporal and regional factors, influenced by local geographical variations and the uneven heating of the Earth's surface. Wind is characterized by two distinct parameters: direction and velocity. Wind velocity escalates with altitude, and its theoretical power varies in accordance with the cube of its velocity [15].

1.3 Erbil Province Wind Energy Potential

Table 1 presents the wind energy potential statistics for Erbil, situated in the Kurdistan Region of Northern Iraq, characterized by elevated wind speeds. Wind speeds are recorded at a height of 2 meters above the ground.

Table 1: Long-term average monthly prevailing wind direction and wind speed data for Erbil Central District (1940-2024) [16]

Month	Mean Wind Speed (m s^{-1})	Prevailing Wind Direction
January	3.9	NW
February	4.1	NW
March	4.3	W–NW
April	4.6	W
May	4.8	W
June	4.5	NW
July	4.2	NW
August	4.4	NW
September	4.1	W–NW
October	4.3	NW
November	4.0	NW
December	3.8	NW
Annual Average	4.25 ≈ 4.3	
Dominant Wind Direction	Northwest (NW)	

Wind velocity grows with altitude. The rationale for using wind speed at a height of 50 meters in the computation is that the hub height of small and medium-sized wind turbines often corresponds to this elevation. The figures for Erbil presented in Table 1 will likewise markedly increase with elevation. Data on wind power plant potential indicates that Erbil province ranks fourth in Iraq for wind power plant installations. Erbil possesses a theoretical wind energy capacity of 3,850 MWe, with 124 wind turbine systems now operational and 58 under construction [17].

However, in this work, which aims at a preliminary assessment of wind potential, the discrete distribution (histogram) will be used as a basis for estimating the average speed in each interval, and the sum of the wind power portions from the average speeds resulting in the total power.

This research endeavors to guarantee that the electrical energy required for forced ventilation in animal barns is provided by wind turbine energy systems. Rural areas that contain cattle barns generally lack access to an electrical grid. The electrical energy produced by the wind turbine system for animal barns will enable ventilation and cooling via fans and a wet pad system. Data from a surface meteorological station at Erbil International Airport were employed to evaluate the dominant wind direction and mean wind speed intensity in Erbil Province. The average hourly wind speeds (m/s) and the frequency distribution (wind histogram) were evaluated using this data. Thereafter, the local wind energy potential was evaluated for a standard installation height of small- and medium-sized wind turbines.

2. Material and Method

Erbil province, which is the research area, is located in the northern part of Iraq within the Kurdistan region. The study is located between 43°–45° east longitudes and 35°–37° north latitudes of Iraq. Erbil is located northern part of Iraq and has a surface area of 15,074 km² Generally, there are no high mountains, steep slopes, or valleys within the province. According to general humidity indices, Erbil has wind in both the summer and winter, and its climate is classified as semi-arid to semi-humid according to the hydrographic region [18].

According to the national wind energy potential atlas of Iraq, Erbil and the northern part of the Arabian Gulf along Iraq's coastal zone near Basra exhibit comparatively high wind speeds under Iraq's semi-arid climatic conditions. Seasonal wind patterns, particularly during the summer months, enhance the feasibility of wind-based energy generation in these regions. Therefore, Erbil has a significant advantage in terms of producing electrical energy from wind [19].

A project has been designed to utilize wind energy, one of the key renewable energy sources suitable for Iraq's hot and dry atmosphere, to support ventilation and cooling systems in beef cattle barns in Erbil. The dimensions of the 60-head free-stall beef cattle barn, where mechanical ventilation and cooling systems will be implemented, are 9.4 × 39.6 m. For this barn housing 60 animals, ventilation fans, evaporative cooling pads (wet pads), and a wind turbine system to generate the required electrical energy will be designed to ensure adequate thermal comfort and air quality, particularly during high-temperature periods.

2.1 Estimation of Local Wind Power

The wind energy stored in the atmosphere is obtained from the kinetic energy of wind movement (atmospheric circulation resulting from solar radiation reaching the planet with differentiated effects in different regions) [20]. Of this amount, only a small part can be recovered in practice, with the technology and equipment available today. However, this wind energy potential represents a significant portion when considered for specific regions and uses, and can be estimated by means of wind speed duration curves for a given geographical location and altitude above sea level (which alters the specific mass of air) [21].

Since the energy generated by a wind turbine is a function of the air speed that moves it, the average speed obtained by measuring instruments (anemometers) that are at a certain height (h) must be corrected to the height (H) corresponding to the wind turbine installation. The correction model to be considered is the logarithmic extrapolation method in which the study of the boundary layer results in an expression of the velocity profile that is a logarithmic function. This exponential law is given by Eq. (1), as used by some authors [22-23], and approximates experimental results with satisfactory precision, widely used for preliminary wind potential analyses.

$$v_H = v_h \cdot (H/h)^{\alpha} (1)$$

Where:

v_H = Estimated wind speed (m/s) at height H(m);
v_h = Wind speed (m/s) measured at height h(m);
H = Installation height (m) of the wind turbine, referenced to the rotor axis/hub line;
h = Installation height (m) of the instrument for speed measurement (anemometer);
α = Shape parameter of the velocity profile, function of terrain roughness;

The value of the parameter "α" is dimensionless, a function of the topography of the data collection site (surface and surroundings) and varies between 0.06 up to 0.6, respectively for smooth locations (e.g., sea surface) and locations with high roughness (e.g., cities). In the estimate for the present study, it is considered equal to 1/7, as presented by Burton (2011) [22].

The wind power available at a given data collection point at height h can be evaluated by Eq. (2).

$$P_{Wind} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \text{or} \frac{P_{Wind}}{A} = \frac{1}{2} \cdot \rho \cdot v^3 (2)$$

Where:

P_{Wind} = Theoretical wind power available in the kinetic energy of winds, W;
ρ = Specific mass of air, typically at NTP given by 1.125 (kg/m³);
A = Air passage area or cross-sectional area of wind turbine blades, m²;
v = Average air speed, m/s;

It is emphasized that P_{Wind} is the theoretical instantaneous power and, under real conditions, only a portion of this power quantity (W = J/s, energy/time) can be transformed and absorbed by the fluid machines that constitute the wind turbines for energy conversion. This happens because the mechanism used for transforming air energy into mechanical torque is a wind rotor and its blades, in which the air arrives at speed v (m/s) and leaves with a lower speed, v_e (m/s) downstream of the rotor.

The physical limit for this transformation was established the maximum power to be extracted from the wind by a converter (wind turbine rotor) would be 59.3% of the theoretical power available in the wind, known as the Betz Limit [24]. In practice, modern commercial wind turbines reach up to 50% efficiency due to losses in the rotor blades, speed multipliers, and electric generators.

Thus, to achieve the values obtained with Eq. (2), one must consider the actual efficiencies of the equipment to be installed. In the present work, only the available wind power (theoretical) is considered for the preliminary assessment.

2.2 Modeling and Statistical Analysis

Based on the calculations performed, as well as the hourly anemometer records, these values were tabulated to determine absolute frequency (total number of events in a given interval) and relative frequency (%, ratio between the number of occurrences in the interval and the total number in all intervals). That is, Hourly and Daily Relative Frequencies

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
ISSN: 2321-7758 http://www.ijoer.in editorijoer@gmail.com
Vol.14., Issue.2, 2026
April-June

(HRF and DRF) were determined from Hourly and Daily Absolute Frequencies (HAF and DAF) [25].

For wind direction, the criterion established was the division of 360° into 12 intervals (or classes) of 30° each, with 0° as reference for geographic North. The highest relative frequencies among all intervals will indicate the prevailing wind direction. For wind speed, the total range between 0 and 10 m/s was used, although with few values recorded above 7 m/s with the anemometer at 10m height. Thus, it was divided into 10 intervals (or classes) of 1.0 m/s each: 0.0-1.0 m/s; 1.0-2.0 m/s; ... up to 9.0-10.0 m/s [26].

The speed distribution obtained results in a histogram of speeds over time. This is a discrete distribution that can be adjusted by statistical models resulting in a continuous mathematical function, called probability density function, which facilitates numerical manipulation of data for integration purposes and obtaining an average speed as a function of time, v = f(t).

Among the various statistical distribution options, the Weibull probability density function is the most common in several works in the literature on the subject. The Weibull function normally presents itself as the best option to estimate the amount of energy generated in wind systems from the average wind speed distribution and the amount of time (hours per month) [26-27].

2.3 Design of Wind Turbine System in Animal Barns

Table 2 summarizes the operational parameters and essential components of small-scale wind energy systems designed for agricultural applications in Erbil. It highlights wind speed characteristics, rated capacities, and supporting equipment required to ensure reliable electricity generation for barn ventilation, water pumping, and other rural energy demands under regional wind conditions.

Table 2: Operational Characteristics and Components of Small-Scale Wind Systems for Agricultural Applications in Erbil Province

Category	Parameter / Component	Typical Range / Specification	Relevance for Erbil Agricultural Use
Operational Parameter	Cut-in Speed	2.0 – 3.0 m s⁻¹	Suitable for moderate wind regimes observed in Erbil
Operational Parameter	Rated (Nominal) Speed	8 – 12 m s⁻¹	Appropriate for small turbines under regional wind conditions
Operational Parameter	Cut-out Speed	20 – 25 m s⁻¹	Protection during occasional strong winds
Operational Parameter	Rated Power	1 – 20 kW	Adequate for barns, water pumping, grain drying, and rural loads
System Component	Small Wind Turbine	Horizontal-axis, 50 m hub height	Optimized for NW prevailing winds
System Component	Battery Bank	24–48 V DC system	Ensures supply during low-wind periods

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
ISSN: 2321-7758 http://www.ijoer.in editorijoer@gmail.com
Vol.14., Issue.2, 2026
April-June

System Component	Charge Controller	MPPT type recommended	Maximizes efficiency under variable wind speeds
System Component	Inverter	220 V, 50 Hz AC output	Compatible with local agricultural equipment
System Component	Mechanical Ventilation Load	0.5 – 3 kW typical	Supports fan-pad cooling systems in barns
System Component	Control & Monitoring Unit	Digital controller	Enables system protection and performance tracking

Figure 1 illustrates the fan-wet pad system designed to deliver ventilation and cooling in animal barns, integrated with the wind turbine system. The inverter, charge regulator, and batteries depicted in Figure 1 were acquired as part of a project.

Ventilation and cooling can be achieved in animal barns by using water in different ways. Cooling systems in animal barns consist of fans, wet pads, a circulation pump, water transmission pipes, and a water tank. In using water for cooling in animal barns, evaporation of water is generally utilized. Evaporation of water occurs through the use of pads that have a wet and porous structure. Evaporation of just one gram of water removes 598 calories (2500 joules) of sensible heat from the air, which is why water has a cooling ability. The sensible heat of the air provides nearly all of the latent heat of evaporation needed for water to evaporate. Because the barn uses its heat to evaporate water, the air that enters the building is cooler [28]. The application of wet pads lowers the barn's interior temperature by 6 to 16 °C, depending on the local weather and seasonal changes. When it comes to animal barns, moist pads can't be used without mechanical ventilation. The wet pads are located on the barn wall, and the aspirators are on the wall across from it. The result is that the barn is filled with damp and cold air from the pads, which replaces the hot air that the aspirators expel outside.

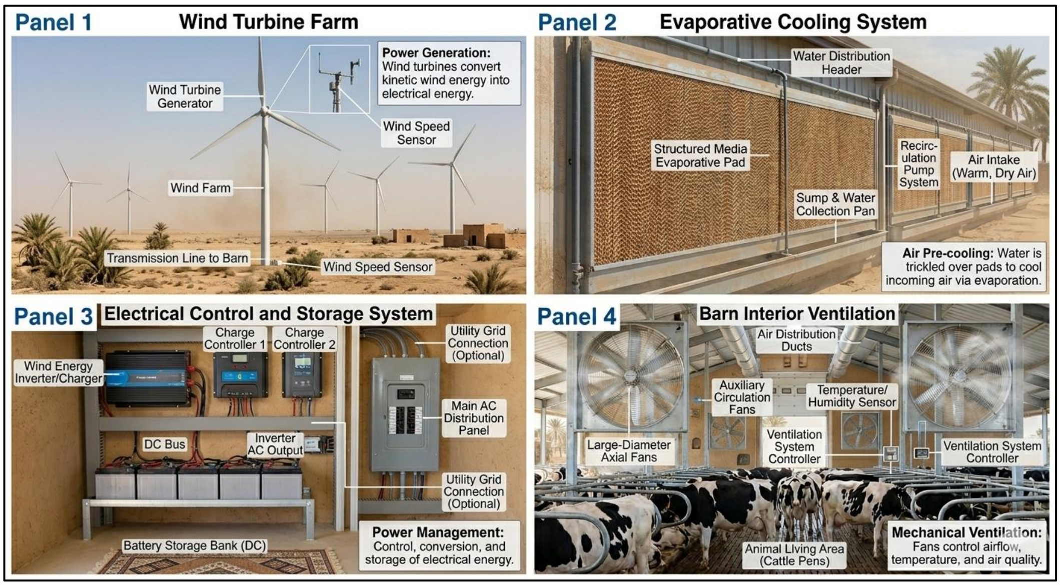


Figure 1. Parts of the wind turbine system that cool and ventilate animal barns

The ventilation amount in the animal barn can be calculated based on the barn's internal volume or the number of animals in the barn. The ventilation amount for one animal in summer months varies greatly depending on the geographical location of the experiment site and the seasons in which it is conducted. If the experiment was conducted in mild and cool places, the ventilation amount for 500 kg live animal weight is between 170 $m^3 h^{-1}$ and 250 $m^3 h^{-1}$ [29]. If conducted in hot regions, the ventilation amount varies between 500 $m^3 h^{-1}$ and 800 $m^3 h^{-1}$.

2.4 Cooling Systems in Animal Barns

Providing cooling to a certain extent in barns during hot seasons helps minimize heat stress in animals. This allows for maintaining healthy, quality, and efficient production. Although optimum temperature limits in beef cattle barns vary between 10 and 16 °C, in cold seasons, the lower limit can be as low as 5-6 °C due to the high heat generated by the animals. In these seasons, sufficient ventilation should be provided to remove moisture, harmful gases, and dust from the barn.

According to outdoor temperature in Erbil conditions, there are months when heating, ventilation, and cooling need to be done in the barn to ensure the living comfort of the animals. The months when outdoor temperature falls below 5 °Care December, January, and February. At low temperatures, increased moisture density inside the barn disturbs barn workers and animals. Therefore, heating may be required in the barn. In March, April, May, October, and November, when outdoor temperature is between 5 and 20 °C, ventilation is needed. In June, July, August, and September, when outdoor temperature is high and exceeds 30–40 °C, cooling should be done together with ventilation [30]. On days when air temperature is high, forced ventilation should be supported with wet pads.

3. Results and Discussion

3.1 Designing Fan-Pad Systems to be Used in Animal Barns

The dimensions of the 60-head beef cattle barn for which the wet pad will be designed need to be known. The width of the free-stall beef cattle barn is 9.4 m, length 39.6 m, and height 3.0 m. Sources from the literature [31] were used in designing the wet pads.

For every 25 m^2 of barn floor area, 1 m^2 of wet pad area is required. The required pad area for the barn with a floor area of 372.2 m^2 (9.4x39.6) can be found as follows (Equation 3).

$$A_p = A_b/A_1$$

$$A_p = \frac{372.2}{25} = 14.9\ \mathrm{m}^2 \quad (3)$$

The daily water requirement of this wet pad is about 30-40 L per 1 m^2 of pad area on hot days. A small circulation pump of 0.2 kWh is sufficient to transfer water from the water tank to the pad for wetting the pad.

The ventilation amount in animal barns is determined according to the geographical location of the barn, the season, and the number of animals. For the northern regions of Iraq, this value can be taken as 400 $m^3 h^{-1}$ for 500 kg live weight. Since the average weight of beef cattle in our country is 700-750 kg, the previously mentioned figures need to be increased by 50%. In this case, the ventilation amount per animal reaches 600 $m^3 h^{-1}$. The ventilation amount in the barn according to the number of animals (Equation 4):

$$Q_t = Q_1 \times n \quad (4)$$

$$Q_t = 600 \times 60 = 36000\ \mathrm{m^3h^{-1}}$$

can be calculated as follows.

Number of aspirators for ventilation (Equation 5):

$$n_a = \frac{Q_t}{Q_a} \quad (5)$$

$$n_a = \frac{36000}{9500} = 3.8 \sim 4\ \text{units}$$

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
ISSN: 2321-7758 http://www.ijoer.in editorijoer@gmail.com
Vol.14., Issue.2, 2026
April-June

is found. Since 2 aspirators will also be placed in the middle of the long barn, the number of aspirators in the system becomes 6.

The total energy requirement of the system (Equation 6):

$0.75\ \text{kWh} \times 6 + 0.2\ \text{kWh} = 4.7\ \text{kWh}$ is found.

To ensure the efficient operation of this ventilation system, a wind turbine system beyond the computed 4.7 kWh, specifically 6.0 kWh, is required. This is due to a temporal discrepancy in wind turbine energy generation. The issue of being unable to generate energy when required. The variable nature of wind, or its complete absence, hinders the generation of the desired energy. Consequently, a system exceeding the necessary specifications should be favored. The system functions efficiently, allowing surplus energy to be stored in batteries for subsequent utilization in the barn. Simultaneously, surplus energy may be utilized in the hydrophone employed in animal enclosures, the manure scraper, or for interior illumination.

By ensuring environmental conditions in animal barns, the growth, development, living comfort, and productivity of animals are increased depending on their genetic structure and breed characteristics. Barn ventilation plays an important role in providing barn environmental conditions. Ventilation is the introduction of clean air into the barn to replace the dirty, humid, and hot air resulting from animals' respiration and other vital activities. Air exchange in barns is best achieved independently of outdoor conditions through forced ventilation and fan-pad systems. In this context, appropriate relative humidity, air movement, radiation, lighting, air quality, ventilation and insulation properties of the barn, feeding system, water supply, sound, and odor conditions are well organized in an animal barn, increasing animal welfare and productivity.

One of the important elements for the healthy living and increase in economic and social standards of Iraq people is adequate and balanced nutrition (Karacan, 2017). Increasing yield per animal plays an important role in meeting the meat and milk needs of the country's people who cannot get enough protein. Thus, the protein deficit of the country's people is also met.

3.2 Preliminary assessment of wind energy utilization

Based on the historical series for the period from January 2023 to January 2024 (13 months), consisting of 8,760 hourly records of direction and speed, the following was obtained regarding the prevailing directions of surface winds at the Erbil International Airport Meteorological Station site (10m height).

Figure 2 shows the Prevailing Wind Direction in Erbil Province for the region under study. As can be seen, the prevailing wind directions are between 300° (WNW) and 360° (North), with a predominance for the ranges 300°-330° (West–Northwest, W–NW) and 330°-360° (Northwest, NW). The highest relative frequencies of wind direction occurrence, in descending order, are: NW (330°-360°), W–NW (300°-330°), W (270°-300°) and N (0°-30°). There is a very low occurrence of winds in the range of 120°-210° (South, S; Southwest, SW). These direction indices are important for the installation of small and medium-sized wind turbines, allowing them to be positioned more appropriately regarding the predominant flows.

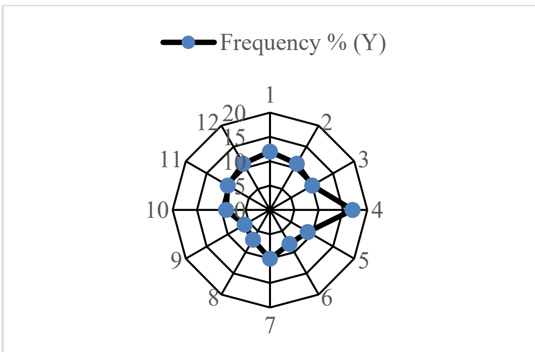


Figure 2: Preferential wind directions in Erbil Province.

Figure 3, presented below, shows the daily distribution (01/01/2023 to 01/01/2024) for the average surface wind speeds at Erbil Province airport. The results demonstrate that this phenomenon, local wind speeds, besides being variable throughout the 24 hours of the day, is also variable throughout the months, i.e., seasonal according to climatic seasons. Furthermore, after 1 year there are some changes in characteristics indicating differences in distinct years, i.e., periodic variation of wind speed (quantitative and qualitative), although still close enough to remain within the statistical distribution profile. This is evident in the data referring to 01/01/2024 in the 2.1–3.0 m/s range and referring to 01/01/2023 in the **1.1–2.0 m/s** and **4.1–5.0 m/s** ranges, as well as in the proportionality observed in the **3.1–4.0 m/s** and **4.1–5.0 m/s** ranges.

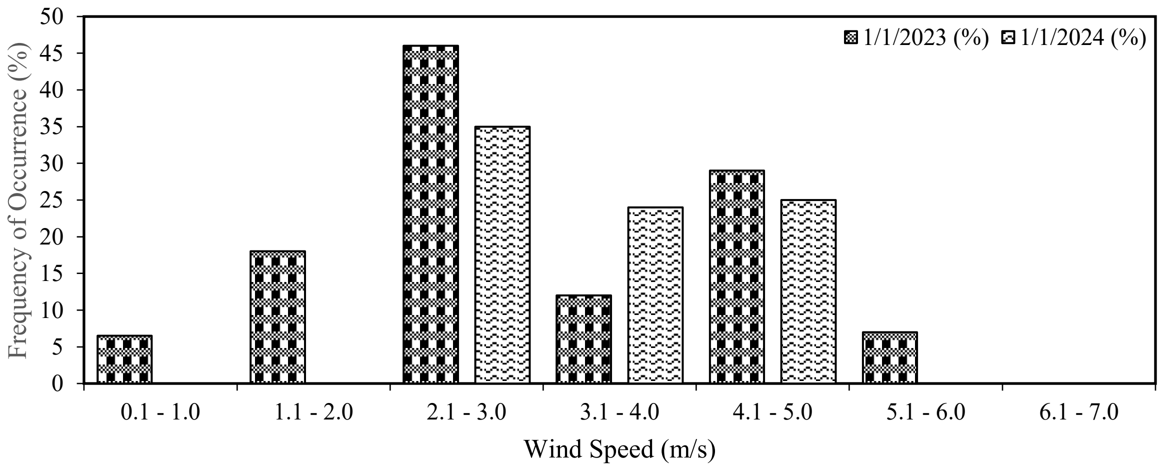


Figure 3: Histogram for wind speed (daily average) in Erbil Province – Typical day

Figure 4 shows the histogram corresponding to the 12-month period, referring to the year 2023. This was obtained from the monthly average wind speed, obtained from daily averages with 24 values each. The highest speeds, above 6.0 m/s, occur with frequencies totaling together about 3% of the total. It is noteworthy that about 58% of the time, speeds are between 2.0–4.0 m/s and 22% of the time between 4.0–5.5 m/s. These values are significant considering they refer to the height of the anemometer positioned 10m above ground, and higher than that in wind turbine installations. The maximum observed speed was 8.3 m/s (or 30 km/h) on July 18, 2023.

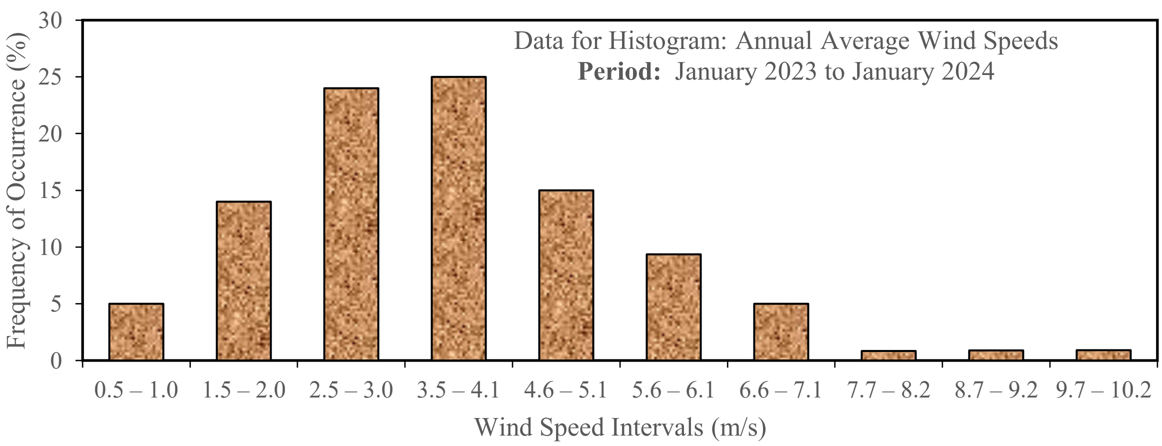


Figure 4: Histogram for wind speed (annual average) in Erbil Province – Year 2023-2024.

The distribution in Figure 4 can be modeled by a Weibull probability distribution function, which can be used to estimate the wind energy potential available at the site, as exemplified by Aljeddani and Mohammed (2023). However, as highlighted in the methodology, the preliminary results obtained here are based on the discrete distribution provided by the histogram.

Table 3 presented below shows the result of the wind potential from the discrete distributions (histograms). Although the Weibull distribution is more common in the literature, a preliminary result intended here is obtained with approximations from Figure 4. Considering the average speed in each range should be multiplied by a factor equal to $[(50/10)^{1/7}]$, i.e., 1.2589. Then, the wind power per unit area, P_{Wind} / A (W/m²), is obtained, which multiplied by the various occurrence frequencies results in partial power. The sum of the power portions for each occurrence frequency results in the total power per unit area (W/m²). Thus, the local wind power at 50m height is 63.89 (W/m²), which is an order of magnitude lower than the reference wind power in large-scale wind turbines. That is, the results are indicative for small to medium-scale utilization.

Table 3: Wind Power Potential at 50 m Hub Height during the Study Period

Wind Speed Class (m s^{-1})	2.5	3.5	4.5	5.5	6.5
Wind speed at hub height, v_H at 50m height	3.15	4.41	5.66	6.92	8.18
Cubic wind speed, v_H^3 (m^3 s^{-3})	31.25	85.75	181.24	331.38	547.45
Wind power density, P_{Wind} / A (W m^{-2})	19.7	54.1	114.3	209.0	345.2
Relative frequency, f (%)	28	30	15	7	3
Partial power contribution, Pp (W m^{-2})	5.52	16.23	17.15	14.63	10.36
Total average wind power density (W m^{-2})	63.89				

Using wind energy, one of the renewable energy sources, in agriculture will help solve the electrical energy problem. The main purpose in animal production is to ensure living comfort in barn environmental conditions for quality and high yield. However, in our country, natural ventilation systems are widely applied in animal barns. Natural ventilation fails to achieve the requisite environmental conditions in barns during warm seasons. Mechanical ventilation will enhance living conditions in animal stables. Mechanical ventilation regulates air temperature, humidity, and the concentrations of dust, dangerous bacteria, and gases in the barn atmosphere to optimal levels [33]. To attain efficient ventilation and cooling in animal barns, a fan-pad system must be employed. The fan-pad mechanism necessitates electrical energy for operation. The requirement for animal barns to be situated away from urban areas and in rural locations restricts the utilization of electrical energy. This issue can be resolved by deploying wind turbines along the coastlines of the Marmara Sea, which possess significant wind potential, to harness electrical energy. In areas of Iraq conducive to wind energy, wind energy systems can be utilized for agricultural applications.

4. Conclusions

This study evaluated the wind characteristics of the municipality of Erbil Province and estimated the local wind potential for small- and medium-scale applications using

13 months (2023–2024) of data from the Erbil International Airport Meteorological Station. The prevailing wind directions are between 300°–330° (W–NW) and 330°–360° (NW), indicating that turbine installation should consider these dominant flows and local topography to optimize energy extraction. The average annual wind speed is 4.3 m s^{-1}, with 58% of occurrences between 2.0–4.0 m s^{-1} and 22% between 4.0–5.5 m s^{-1}, demonstrating moderate regularity. At 50 m hub height, the estimated wind power density is 63.89 W m^{-2}, suitable for small-scale uses such as water pumping, grain drying, ventilation, and decentralized electricity generation. Although lower than coastal large-scale potentials, the resource is adequate for rural and agricultural needs. Continued long-term measurements at greater heights are recommended to improve feasibility assessments. Wind-powered mechanical ventilation systems can effectively enhance barn environmental control where grid electricity access is limited.

References

[1]. Hassan, M. K. R. (2023). Factors affecting urbanisation in Iraq: A historical analysis from 1921 to the present. *Urbanisation, 8*(1), 61–78.

[2]. Ali, R. (2021). The relationship between human resources development and sustainable development strategy: A case of Iraq. *Akkad Journal of Contemporary Economic Studies, 1*(1), 29–44.

[3]. Abass, K., & Al-Asad, K. (2018). Energy audit and energy conservation in Iraq: A case study. *International Journal of Trend in Research and Development, 5*, 6–10.

[4]. Hassan, Q., Algburi, S., Al-Musawi, T., Viktor, P., Jaszczur, M., Barakat, M., Zuhair, A., & Habeeb, A. (2024). GIS-based multi-criteria analysis for solar, wind, and biomass energy potential: A case study of Iraq with implications for climate goals. *Results in Engineering, 22*, 102212. https://doi.org/10.1016/j.rineng.2024.102212

[5]. Al-Assadi, Z. (2024). Harnessing renewable energy in Basra, Iraq: Study the wind energy. *Technium: Romanian Journal of Applied Sciences and Technology, 23*, 54–62. https://doi.org/10.47577/technium.v23i.11633

[6]. Al-Rubaye, S., & Price, E. (2023). The economic impacts of using renewable energy technologies for irrigation water pumping and nanoparticle fertilizers on agri-food production in Iraq. *Sustainability, 15*, 5478. https://doi.org/10.3390/su15065478

[7]. Abdulkareem, T., Eidan, S., Ibrahim, F., Al-Salihi, K., Al-Abbadi, O., Abdulkareem, M., & Abdul-Rahman, Q. (2020). *Analytical study of the reality of camel breeding in Iraq*. Center for the University of Baghdad.

[8]. Neima, H. M., & Hassan, K. M. (2020). Trends in livestock production and red meat industry in Sulaymaniyah Governorate, Kurdistan Region of Iraq: A review. *Journal of Animal and Poultry Production, 11*(5), 189–192. https://doi.org/10.21608/jappmu.2020.102723

[9]. Salih, A. M. (2021). *The impact of urban form and shading on microclimate and indoor air temperatures of dwellings: A case study of Erbil, Kurdistan, Iraq* (Doctoral dissertation, Newcastle University, UK).

[10]. Jabbar, B. J. (2024). Charting the course: Geopolitical dynamics and market realities in the Iraqi Kurdistan energy sector. In G. M. Muhamad & N. T. Khayyat (Eds.), *Resource management performance: A sectoral analysis in the post-conflict Kurdistan Region of Iraq* (pp. 39–62). Springer.

[11]. Demirel, B. (2024). Utilization opportunities of agricultural biomass in Iraq. *Journal of Erciyes Agriculture and Animal Science, 8*(1), 108–113.

[12]. Gaillard, C., Durand, M., Largouët, C., Dourmad, J.-Y., & Tallet, C. (2021). Effects of the environment and animal behavior on nutrient requirements for gestating sows: Future improvements in precision feeding. *Animal Feed Science and Technology, 279*, 115034. https://doi.org/10.1016/j.anifeedsci.2021.115034

[13]. Pishnamazi, A., Renema, R., Paul, D., Wenger, I., & Zuidhof, M. (2015). Effects of environmental temperature and dietary energy on energy partitioning coefficients of female broiler breeders. *Journal of Animal Science, 93*. https://doi.org/10.2527/jas.2015-9214

[14]. Zhang, J., Zhang, M., Li, Y., Qin, J., & Wei, K. (2020). Analysis of wind characteristics and wind energy potential in complex mountainous region in southwest China. *Journal of Cleaner Production, 274*, 123036. https://doi.org/10.1016/j.jclepro.2020.123036

[15]. Duhok Governorate. (2018). *Sustainable energy action plan (SEAP): Kurdistan Region of Iraq – Duhok Governorate*. Clima-Med / EU-UNDP Local Area Development Programme. https://www.climamed.eu/wp-content/uploads/files/Iraq_Duhok-Governorate_SEAP.pdf

[16]. International Renewable Energy Agency. (2025). *Energy transition assessment: Iraq*. IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_COU_Energy_transition_assessment_Iraq_2025.pdf

[17]. World Bank. (n.d.). *Iraq historical climate data*. https://climateknowledgeportal.worldbank.org/country/iraq/climate-data-historical

[18]. Mustafa, S. A., Aziz, N. A., & Alwan, I. A. (2025). Land suitability evaluation for wind power farms in Iraq using GIS-based multi-criteria evaluation. *International Journal of Energy Production and Management, 10*(3), 468–479. https://doi.org/10.56578/ijepm100309

[19]. Mahmood, F. H., Resen, A. K., & Khamees, A. B. (2020). Wind characteristic analysis based on Weibull distribution of Al-Salman site, Iraq. *Energy Reports, 6*, 79–87.

[20]. Esmael, R. S., Kareem, S. W., & Abdulrahman, I. K. (2013). Wind energy proposed in Kurdistan–Iraq. *International Journal of Engineering Research and Applications, 3*(6), 1531–1537.

[21]. McKenna, R., Lilliestam, J., Heinrichs, H. U., Weinand, J., Schmidt, J., Staffell, I., Hahmann, A. N., et al. (2025). System impacts of wind energy developments: Key research challenges and opportunities. *Joule, 9*(1), 101799. https://doi.org/10.1016/j.joule.2024.11.016

[22]. Burton, T., Jenkins, N., Sharpe, D., & Bossanyi, E. (2011). *Wind energy handbook* (2nd ed.). John Wiley & Sons.

[23]. Carvalho, D., Rocha, A., Gómez-Gesteira, M., & Santos, C. S. (2013). Wind resource modelling in complex terrain using different mesoscale-microscale coupling techniques. *Applied Energy, 108*, 493–504. https://doi.org/10.1016/j.apenergy.2013.03.074

[24]. Coelho, P. (2022). The Betz limit and the corresponding thermodynamic limit. *Wind Engineering, 47*.

https://doi.org/10.1177/0309524X221130109

[25]. Spiegel, M. R., Schiller, J., & Srinivasan, R. A. (2012). *Schaum's outline of probability and statistics* (4th ed.). McGraw-Hill Education.

[26]. Wilks, D. S. (2011). *Statistical methods in the atmospheric sciences* (3rd ed.). Academic Press.

[27]. Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). *Wind energy explained: Theory, design and application* (2nd ed.). John Wiley & Sons.

[28]. World Meteorological Organization. (2018). *Guide to meteorological instruments and methods of observation (WMO-No. 8).* WMO.

[29]. Yüksel, A. N., & Yüksel-Türkboyları, E. (2018). Using photovoltaic cells for ventilation and cooling of the animal barns. In *Proceedings of the 1st International and 14th National Congress on Agricultural Structures and Irrigation (ICASI-2018)* (pp. 49–55). Antalya, Turkey.

[30]. Kupi. (n.d.). *Erbil weather and climate*. https://www.kupi.com/en-ae/explore/iraq/erbil/weather

[31]. Wang, Q., Lyu, W., Li, W., et al. (2025). Design and validation of the multi-parameter control strategies for fan-pad cooling systems in rabbit housing during summer. *Transactions of the Chinese Society of Agricultural Engineering, 41*(5), 217–226. https://doi.org/10.11975/j.issn.1002-6819.202408085

[32]. Aljeddani, S. M. A., & Mohammed, M. A. (2023). A novel approach to Weibull distribution for the assessment of wind energy speed. *Alexandria Engineering Journal, 78*, 56–64. https://doi.org/10.1016/j.aej.2023.07.027

[33]. Gürdil, G., Kic, P., Demirel, B., & Yaylagül, E. (2020). Design construction farm scale evaporative cooling system. *AMA: Agricultural Mechanization in Asia, Africa & Latin America, 51*, 67–71.