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# RENEWABLE ENERGY SOURCES TECHNOLOGY TRANSFER CENTER'S CAPABILITY REGARDING WINDINESS MEASUREMENTS, STUDIES OF MICROTURBINS AND URBAN AREA AERATION

**Abstract**
The wind turbine lab of the Renewable Energy Sources Technology Transfer Center deals with a wide range of research issues. Some of them concern meteorology and climatology and include wind condition analysis in terms of the energy useful for the operation of wind turbines. Others are related to wind tunnel tests and involve wind engineering, including the design of wind turbines and the aeration of urbanized areas. Computational facilities will allow for the analysis of numerical distributions and simulations of the measured amounts.

**Key words**
wind forecast, useful wind energy, wind turbine, wind engineering, ventilation and aeration, wind tunnel

## Introduction

The laboratories of the Renewable Energy Sources Technology Transfer Center are the research and development base and technical facilities of the members of the *Bioenergy for the Region* cluster. Their primary role is to support the implementation of research and implementation of new solutions, and to enable the exchange of experience between enterprises, business environment institutions, and research units. The main axes of regional, national and international cooperation are the facilitation of knowledge transfer and the reduction of operating costs using a common research infrastructure.

The wind turbine lab of the Renewable Energy Sources Technology Transfer Center deals with a wide range of research issues. Some of them concern meteorology and climatology and include wind condition analysis in terms of the energy useful for the operation of wind turbines. Others are related to aerodynamic tunnel tests and pertain to wind engineering and, to some extent, the construction of flow machines, especially wind turbines. The laboratory offer is a response to the needs of the national economy, as well as individual and institutional clients. Research in terms of expertise and consultation, and compliance with the standards, is envisaged.

Existing European standards impose an obligation on aerodynamic testing in the field of approval and verification for accreditation in the field of aerodynamics of buildings and other departments of wind engineering [3]. Recommended actions in terms of the climate system presented in the Study of Conditions and Directions of Spatial Development in the City of Łódź [8] indicate the need to protect the existing air exchange corridors and areas of influx of oxygenated air masses from unfavorable changes, causing blocking or weakening of air exchange both near compact development in the center, as well as the newly built peripheral districts. It is important to enrich the existing system of natural and artificial winding corridors, especially on the east-west axis.

The Environmental Protection Law Act, in line with the Framework Directive 96/62/EC of the Council of the European Union, requires the use of air quality management systems (AQMS) to monitor the emissions, spread of particulate and gaseous pollutants and emissions. The tools and sources of information are field measurements and mathematical models of the spread of pollutants in the atmosphere. The assessment of the quality of the mathematical model is related to the concepts of validation and verification. Validation means a general comparison of modeling results with measurements, documentation of accuracy using statistics, and, in case of significant discrepancies, correction of mathematical formulas. Validation of the model is one of the basic conditions for its admissibility. Verification results may need to be corrected if the nature of the errors is systematic, such as overstating or understating the average values [10]. The measure of the mathematical model’s quality is the error statistics obtained from the comparison with the experimental data obtained from field measurements or in the aerodynamic tunnel.

## Measurements of windiness

In addition to the analysis of current anemometric measurements at the location of the planned turbine location, the multi-annual series of observations of the network of the Institute of Meteorology and Water Management are considered. Inclusion in the research model of measurement data series from a one-year and multi-annual perspective allows the prediction of windiness in a given location. The baseline data refer to the wind at a height of 10 m above the ground level, but after conversion it can also be applied to higher located turbine axes.

The smallest forecast error, less than 10%, occurs for open agricultural areas with small height differences. The uncertainty of the forecast is influenced by the proximity of forests or buildings causing turbulences resulting from the roughness of the base. Model data have the biggest errors in the case of urbanized, densely populated and high-altitude areas. Once the turbine's operating characteristics have been applied to the windfall forecast, the amount of electricity produced during the year can be estimated.

The TTC meteorological station records and collects meteorological data on insolation, thermal, humidity and wind conditions in a continuous system. Portable measuring equipment allows for recording the value of selected weather elements at the locations indicated by the investor - prosumer. Two weather hygrometers, one for indoor use for the purpose of assessing the climate of a passive building's rooms in terms of compliance with the norm, the other in a meteorological cage, two pyranometers for measuring the intensity of sun rays, two anemometers for measuring wind speed (the first is ultrasonic, the second is cranial), as well as a data collection module and software for recording, data visualization and device operation and alarm will be included in the meteorological station's equipment.

**Wind engineering**

Wind engineering is concerned with investigating the effects of wind on the environment, humans, and on buildings and engineering structures [1]. Research in the TTC wind laboratory will include the aerodynamic effects of building structures, such as resistance and aeroelastic vibrations. Wind climate simulations will also be carried out, laying in the field of interest of environmental engineering, architects and urban planners, including the ventilation and aeration of developed areas of varying architecture, and the spread of particulate and gaseous pollutants.

Modeling wind power plants is important because of the increasing number of structures and their power. One of the major uses of the aerodynamic tunnel is the study of wind turbine models. The efficiency and effectiveness of the operation of the wind turbine depends to a large extent on the type of turbine. There are many mathematical models of varying degrees of complexity that allow for simulating turbine operation. Models of turbines should be analyzed along with the wind model because wind drives the turbine rotor and the rotor operation causes disruptions to airflow. Jet theory is commonly used to determine the aerodynamic forces acting on turbine blades [9]. It is a combination of blade element theory with propeller jet theory. The starting speed of the wind turbine model in the tunnel is approximately 5 m/s, but under field conditions it is approximately 3 m/s, because the natural wind is gusty, with a greater proportion of turbulence than in the laminar tunnel jet. For each flow rate set in the tunnel, the magnetic brake load increases until the maximum power generated on the turbine is reached. The characteristics of the mechanical coupling, the elasticity of shafts, clutches and gearboxes can also impact the course of the generated power [12]. The result is recorded and measurements are conducted slowly enough to eliminate the inertia energy moment.

The moment of the wind turbine’s inertia depends on many parameters of the wind energy processing. The slowing down of the wind caused by passing the mast located behind the rotor by a turbine blade or the energy losses at the ends of the lobes has a significant effect on the course of the moment obtained [11]. Tip loss is caused by the flow of air at the end of the lobe from the overpressure side to the under pressure side. The effect is a decrease in the aerodynamic lift and the turbine's moment of inertia and power. It remains to be considered whether the turbine load caused by the generator will result in a decrease in moment fluctuations.

**The wind tunnel at RES TTC**

The aerodynamic tunnel is an integral part of the one-story TTC building in Konstantynów Łódzki at ul. Innowacyjna 11. Its construction is shown in Figure 1 and the building body is shown in Figure 2. It is a subsonic closed-loop tunnel with a closed measuring chamber that can be extended as an independent trolley with removable windows [2]. It is made of 4 mm thick sheet metal and is mounted on a foundation plate, which allows for stiffness of the structure during operation. The measuring chamber, (HxWxL) 800x600x2000 mm and cross section 0.48 $m^2$, was built in a laboratory room. The circular fan section has an internal diameter of 1050 mm. The velocity of the air stream is generated by a fan with an electric motor with a power of 22 kW and is fluently adjustable up to 40 m/s. To control the flow rate, it is necessary to adjust the speed of the fan motor using the frequency converter. Setting can be done manually via a potentiometer on the operator panel, or automatically via a programmable PID controller.

The fan diffuser changes the cross section from octagonal to square. Reducing the flow velocity at the outlet minimizes the loss and interference in the air flow to the funnel section. At the end of the diffuser is one of the inspection hatches. Two grids protect the steering wheel and the fan from the impact of the components lifted by the airflow.

The tunnel construction provides an even distribution of speed (with a tolerance of up to 1%) in an area that represents at least 80% of the cross-sectional area of the measurement space, in the vertical and horizontal planes, passing through its axis. The angle of deviation of the jet from the axis of the tunnel in both planes is less than 0.3. The construction of the measuring chamber is made of 10 mm thick clear plexiglass mounted in aluminum frames, which allows mounting of measuring objects. The chamber is connected to the tunnel structure via clamping grips.

Figure 1. Construction of the aerodynamic tunnel and measuring chamber (27.05.2014)

Figure 2. Headquarters of the Technology Transfer Center with the aerodynamic tunnel (29.07.2014)

Two reference pressure sensors, one barometric pressure sensor, and a temperature sensor are mounted in the tunnel. Ultimately, a modeling workshop equipped with cutting machines and a set of tools for model preparation will be established. Some of them will be created using a multicolor 3D printer.

**Aerodynamic tunnel measuring equipment**

The basic measurement tool in the aerodynamic tunnel is the aerodynamic scale, which is a measuring instrument that provides the ability to measure the forces and moments acting on a model via the flowing medium [3]. The target aerodynamic tunnel equipment includes three-component strain gauge scales and five-component scales. Computer analysis determines the locations of the maximum stress concentration of the tested structure. Thanks to this, strain gauges are applied in the places where the given force has the highest value [4]. The required weight amplification varies from 1000 to 3000. Due to two symmetrical force and moment converters, the amplifier circuit has two channels. The output signal is the sum of the signals of the two amplifiers recorded at a sampling rate of 100 kHz. The measurement equipment also includes a static pressure probe, a set of anemometers with probes, a sensor array for multi-point pressure measurement, inductive sensors, and devices recording, processing and amplifying signals from the sensors.

Measured quantities are flow and turbulence rate, wind pressure in the flow, pressure on model bodies, and forces and moments acting on the models or their fragments, such as roofs [5]. Dedicated software makes the collection, processing and graphic presentation of the collected measurement data possible. Most of the discussed equipment is not manufactured in Poland.

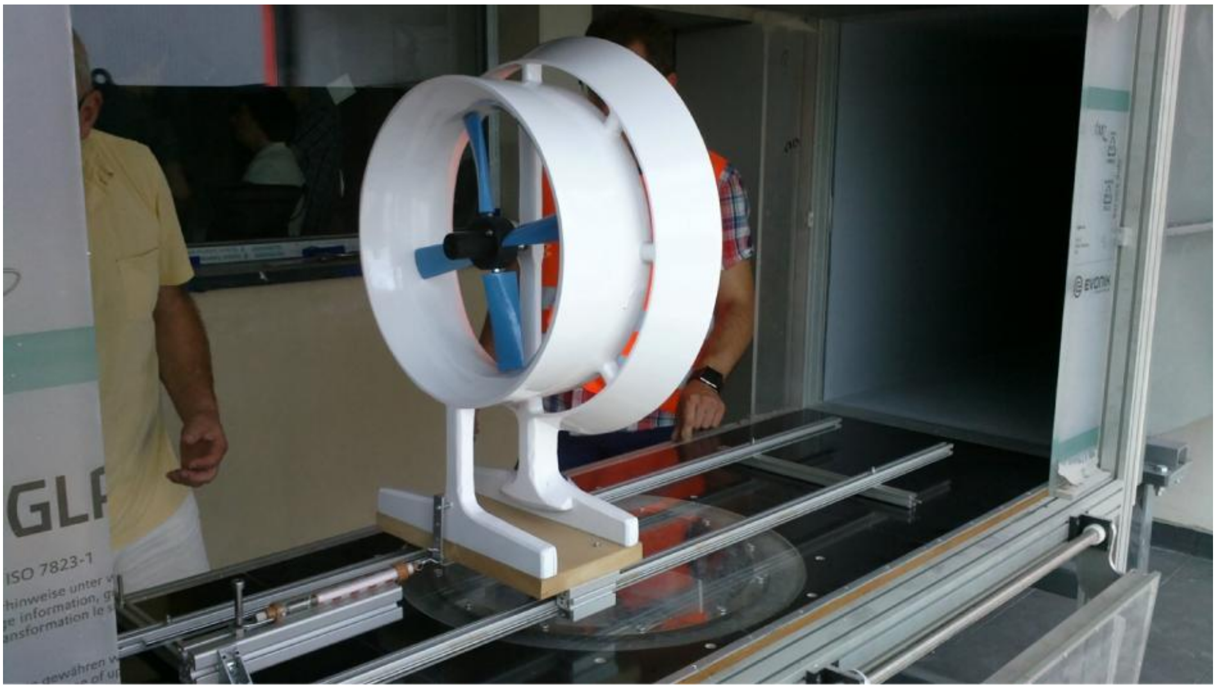


Figure 3. The aerodynamic tunnel measuring chamber with the tested wind turbine model

Different flow conditions in tunnels and field conditions, including turbulence and pressure changes, can be corrected using the appropriate corrections. Transfer of tunneling results to real objects is possible when the dynamic similarity requirements are met. The theories of similarity and dimensional analysis suggest that it is sufficient to know the dimensions of the body, the angles of the position of the body relative to the direction of the rate, the flow rate modulus, the temperature, the density and the viscosity of the medium, and the gas constant to determine the aerodynamic force acting on the body over which the thermodynamically perfect and nonconducting heat gas flows. The dimensionless quantities of similarity include the Reynolds number and Mach number. The description of the aerodynamic force vector is most conveniently prepared in a rectangular coordinate system oriented in a manner so that the x-axis coincides with the direction of the velocity. The aerodynamic center is the model point at which the aerodynamic moment is constant irrespective of the angle of attack of the air jet. The scale design allows the model frame to be freely rotated relative to each of the three axes. The angle of attack is changed manually. The measured aerodynamic forces are gross values and tare of the weight should be subtracted from them. Tare results from the fact that the weight axes do not coincide with the center of gravity of the scale and the model. The tare of the weight changes along with the angle of attack, its value is determined by measuring the forces and moments when the tunnel fan is off.

**Numerical analysis and simulations**

The rapid development of Computational Fluid Dynamics and computer-based wind turbine engineering enables many issues to be solved, but it is still necessary to conduct model experiments in aerodynamic tunnels to measure and explain the phenomena accompanying flow and flow around of viscous fluids [1]. For economic reasons, these studies are conducted on a reduced scale. Dimensional analysis and the theory of similarity allow, based on the results obtained in the tunnel, to formulate conclusions about the phenomena studied in their actual size.

Visualization of flow and turbulence is accomplished by applying a smoke contrast to the air stream and then recording it in the form of a series of high-speed images. The data obtained from the visualization in the tunnel after scaling can be compared with the simulation results. The CFD method makes it possible to simulate issues related to the transport of momentum, energy and mass in real systems [7]. This obtains information on the distribution of pressure and velocity field in the fluid flow and allows for analyzing the heat movement by simulating the temperature field and the mass movement when testing the spread of pollutants on the example of the concentration field. To do this, numerical equations describing the momentum exchange, energy balance and mass are solved using software. Accumulation, convection and diffusion are the three processes involved in transfer of momentum, heat and mass. The obtained equation solutions can be graphically presented, which facilitates the analysis of the system.

The computing facilities of the wind laboratory will allow for numerical simulation of the pressure distribution and wind speed field during flow over and flow around buildings and for typical types of terrain of different roughness. Simulations of static and dynamic wind impacts on buildings and constructions including vortex excitation and static and dynamic responses to sleek, suspended, and hanging bridges will also be conducted.

A numerical analysis of aeroelastic instability of the divergence type, aerodynamic trace galloping, torsion flutter and bending-torsion flutter, and vortex excitation under critical vortex separation conditions [5] is anticipated in a somewhat further perspective. During tests in the aerodynamic tunnel and numerical analysis, it is important to remember that the estimated results may differ from the actual ones, but are often overestimated due to high turbulence. Under actual conditions, turbulence reduces the impact of dangerous phenomena, such as whirlwind separation or galloping in the aerodynamic trace [6].

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