

Numerical Calculations for Increasing the Velocity of Wind through a Duct and Contraction Nozzle from Incompressible Flows in the Windward Areas to Produce Electricity by Wind Turbine

Ali S. Bazgir¹, Mohammadreza Hashemi²

¹Moscow Institute of Physics and Technology

²Islamic Azad University

Ever since humanity discovered various energy resources available in nature, it has been inventing devices, known as machines, which make life more comfortable by using energy resources. We get electricity, which is a secondary energy source, from the conversion of other sources of energy, like coal, natural gas, oil, nuclear power and other natural sources, which are called primary sources. As we know, the flows, which without any limitation are produced in the nature and on the buildings (External Flows), blow abundantly especially in the windward areas. It is also common for homeowner to install Wind Turbine near their home to make use of wind energy. In this case, the velocity of wind is so important because every wind turbine needs an appropriate and specific amount of velocity to be turned by wind.

Electricity for powering our home is made in power stations. A power station contains large machines called turbines, which are turned very quickly. Power stations need large amount of energy to turn the turbines.

In other side, according to overt researches, nowadays the consumption of all sorts of energy has been increased. As a matter of fact, with daily development of science and technology and decreasing of natural and nonrenewable resources, the optimal use of all sorts of energy is so important to human. There is no doubt that Wind Energy, which is renewable energy, has obvious role in different energy supply such as Electrical power. Wind is one of the greenest forms of energy, as it uses no fossil fuel and does not emit greenhouse gases. Most homes that have residential wind installation are still tied into the power grid, both to use electricity when the wind is not blowing and to sell excess power to the grid when it is. A typical residential wind system can offset 1.2 tons of air pollutants and 200 tons of greenhouse gases. New home wind options make it easier to install a wind turbine in a residential footprint, on the roof or on the ground on the home's lot [1].

As we said, Wind Turbines are one of the most significant electrical energy resources. It may be practical each building or tower supply its electricity energy by installing turbines in the buildings.

It has been proposed to capture low-velocity wind in a duct and then increase its velocity to spin a wind turbine. It is the aim of this project to bring distributed wind energy to life by making it a natural part of the power infrastructure. In the windward areas by installing a cylinder duct in one side of the building, at high-altitude of the building, an incompressible flow can be artificially made. It can be also put a contraction nozzle in high section of the duct to increase the velocity of the flow, depending on difference between the nozzle diameters. In the end of the contraction nozzle, a wind turbine's axis is vertically installed to convert the wind energy to electrical power.

As we know the external flows, which without any limitation are produced in the nature and on the buildings, blow repeatedly in the windward areas. Low-velocity wind flow commonly blows in high-empty-spaces into the buildings. A wind turbine can be installed ahead of a high empty-space into the buildings and then electricity can be generated by capturing the wind energy that has been captured by wind turbine. However, the produced wind in the empty space of building is known to be exceedingly small, and it is not the most effective way to generate energy for our purposes so a contraction nozzle would help us to increase the flow velocity.

According to the following assumptions, we derive the inlet velocity for starting the wind turbine (in the real design, the numerical amounts would be easily changed):

1. Temperature is constant ($T = 25^{\circ}\text{C}$). Otherwise, we would add heat transfer equations in radial systems to obtain temperature in each section.
2. The material, which is used for creating of cylinder duct, is steel.
3. The wind flow throughout the cylinder duct and nozzle should be maintained as incompressible flow to be prevented from noises.
4. To prevent from any noise in the building, the work track would be completely isolated.
5. Regardless of the calculations of boundary layer in the closed-conduit flow, we have calculated the velocity of the air at the output of the nozzle.

These numerical amounts are changeable, thus, the size of this scheme would be changed in the real experimental design. According to Fig.1, we calculate the velocity of the wind spinning the wind turbine and then calculating the wind turbine's power.

Input Zero

It is assumed that the air velocity is about 1.7 m/s . In the zero part mesh connection, Figure 2, is used to prevent birds and the other things from entering to cylinder tunnel. There are net minor losses of this part, which is ignorable, but we would easily assume that with these losses the velocity of the input air in the part 1 reaches to $1.5 \text{ m/s} = 5.4 \text{ km/h}$.

Input One

We have the required parameters at normal pressure and temperature.

$$\text{Air at } 25^\circ\text{C, } 100\text{kpa} \rightarrow \begin{cases} P = 1.169 \text{ kg/m}^3 \\ \nu = 1.562 \times 10^{-5} \text{ m}^2/\text{s} \\ R = 0.287 \text{ kJ/kg.k} \end{cases}$$

Where P , ν and R are pressure, velocity and gas constant respectively.

Between Inlets One and Two

The amount of Reynolds Number shows that we have Laminar flow, $Re < Re_{critical} = 5 \times 10^5$, between inlets one and two so the major loss coefficient can be calculated by:

$$Re = \frac{VD}{\nu} = \frac{1.5 \times 2}{1.562 \times 10^{-5}} = 192061.45 \left. \begin{array}{l} \varepsilon/D = \frac{3}{2000} = 0.0015 \end{array} \right\} \rightarrow f \approx 0.0003, \quad \text{Major loss [2]} \quad f = \frac{64}{Re} \quad (1)$$

Where ε, D, V and ν are respectively relative roughness(roughness height), cylinder diameter, the velocity of the flow between inlets one and two and kinematic viscosity.

To calculate the velocity in inlet 2, we have Modified Bernoulli equation [2]:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_L$$

$$\rightarrow \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + f \frac{L}{D} \frac{V_1^2}{2g} \quad (2)$$

Where P, V, L, ρ, g, Z are respectively pressure, velocity of the flow, cylinder length, density of the fluid, acceleration of gravity and the height of inlets. By inserting the numerical amounts to equation (2), we have:

$$\rightarrow 0 + \frac{(1.5)^2}{2 \times 9.8} + 0 = 0 + \frac{V_2^2}{2 \times 9.8} + 0 + 0.0003 \frac{0.5 (1.5)^2}{2 \times 9.8}$$

$$\rightarrow 0.114 = \frac{V_2^2}{2 \times 9.8} + 0.000008 \rightarrow V_2 = 2.23 \text{ m/s}$$

Where P_1 and P_2 are the same atmosphere pressure.

Inlet Three

Pressure is dropped a little so we assume that the numerical amount of pressure is:

$$P_3 = 99900 \text{ pa}$$

Between Inlets Two and Three

To calculate the velocity of the flow in inlet3, V_3 . We should use Modified Bernoulli equation between inlets two and three, so we have:

$$\frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 = \frac{P_3}{\rho g} + \frac{V_3^2}{2g} + Z_3 + H_f$$

$$\rightarrow \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 = \frac{P_3}{\rho g} + \frac{V_3^2}{2g} + Z_3 + \sum K \frac{V_2^2}{2g} \quad (3)$$

Where $K \frac{V_2^2}{2g}$ is the amount of minor losses and K is Minor losses coefficient which is given as 0.9 for Knee joints in table of minor losses [3]. We insert the numerical amounts to equation (3), and then we have:

$$\rightarrow \frac{100 \times 10^3}{1.169 \times 9.8} + \frac{(2.23)^2}{2 \times 9.8} + 0 = \frac{99900}{1.169 \times 9.8} + \frac{V_3^2}{2 \times 9.8} + 1 + 0.9 \frac{(2.23)^2}{2 \times 9.8} \rightarrow V_3 = 13.09 \text{ m/s}$$

Inlet Four

Putting some roughness between inlets three and four leads the flow to turbulence and then the speed of the air will be increased. This could be calculated by applying the Modified Bernoulli equation with major losses but we assume that $V_4 = V_3$ so:

$$V_4 = 13.09 \text{ m/s}$$

Between Inlets Four and Five

A contraction nozzle, which converts compressive energy to kinetic energy, has been installed between inlets four and five with diameters respectively 2 meter and 0.75 meter.

According to velocity calculations for incompressible flows, the continuity equation (mass flow rate to be constant between two inlets) has been utilized [3] to obtain the velocity of the flow in the high diameter of the contraction nozzle, which is given by:

$$\dot{m}_4 = \dot{m}_5 \rightarrow \rho V_4 A_4 = \rho V_5 A_5 \rightarrow V_5 = \frac{\rho V_4 A_4}{\rho A_5} \quad (4)$$

Therefore, we insert the numerical amounts into the continuity equation (4):

$$\rightarrow V_5 = \frac{13.09 \times \pi r_4^2}{\pi r_5^2} = \frac{13.09 \times \pi (1)^2}{\pi (0.375)^2} = 93.08 \text{ m/s}$$

After that the Mach number is needed to determine the kind of flow in channel, therefore the Mach number would be given as:

$$M = \frac{V}{C} \quad (5)$$

Where C and V are respectively the velocity of sound and the velocity of incoming air [3]. The velocity of sound can be given by:

$$C = F(T) \rightarrow C = \sqrt{KRT} = \sqrt{1.4 \times 287 \times (273 + 25)} = 346.02$$

Where K, R, T are ratio of special heat, gas constant and temperature respectively [4].

Then, inserting the numerical amounts to equation (5) implies that:

$$M = \frac{V}{C} = \frac{93.08}{346.02} = 0.269 \text{ (low subsonic flow)}$$

$M < 0.3$ So our assumption concerning incompressible flow through the tunnel and nozzle remains valid.

Deviation Angle of the Nozzle

Now we need to determine Deviation Angle of the Nozzle. It must be remembered that the numerical amounts can be changed in the real design so that, depending on nozzle diameters and width of the Rotor Blades of the Wind Turbine, Deviation Angle of the Nozzle would be wider.

Where D, d, l and α are respectively large diameter, short diameter, the height of the nozzle and deviation angle. By inserting the numerical amounts in equation (7), we have:

$$\tan 2\alpha = \frac{2 - 0.75}{2 \times 1.5} = 0.416$$

Then $\alpha = 11.30^\circ$.

Wind power

So it is showed that the velocity of the incoming air of the wind turbine blades can be easily increased by utilizing a well-designed duct along with a contraction nozzle in the path of the wind, used in the roof of a building or through a duct into the building. Now it is of critical economic importance to know the power and therefore energy produced by different types of Wind Turbine in different conditions of wind velocity. Wind power depends on the amount, speed and mass of the air therefore we can calculate the power converted from the wind into rotational energy in the turbine using the following equation [5]:

$$P = \frac{1}{2} \rho A V^3 C_p \quad (6)$$

Where P, ρ, A, V and C_p are produced power, the air density, the swept area of the turbine that can be calculated by $A = \pi r^2$ (where r is the blade length of the wind turbine), wind speed and power coefficient. The power coefficient is the ratio of power extracted by the turbine to the total contained in the in the wind resource. Albert Betz calculated that no wind turbine could convert more than 59.3 % of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit [6], and is the theoretical maximum coefficient of power for any wind turbine.

In this example, we are given the following data:

$$\rho = 1.23 \text{ kg/m}^3$$

$$A = \pi(0.375)^2 = 0.44 \text{ m}^2$$

$$V = V_5 = 93.08 \text{ m/s}$$

$$C_p \approx 0.4$$

So we can calculate the electricity power of the wind turbine. Inserting the numerical value of the given data of the experiment into the equation (6) we have:

$$\begin{aligned} P &= \frac{1}{2} \rho A V^3 C_p \\ &= \frac{1}{2} \times 1.23 \times 0.44 \times 93.08^3 \times 0.4 \\ &= 87288.47 \text{ w} \end{aligned}$$

$$P = 87.3 \text{ kw} = 7542720 \text{ kwh}$$

Fluent simulation of velocity

There is minor loss of nozzle through the nozzle. To increase the velocity of the incoming air of wind turbine, some roughness is put between inlets 3 and 4 wall or before entering the flow to the contraction nozzle but it causes flow to be separated and in the designing of this duct, we can eliminate roughness. Moreover, Roughness should not be installed in the beginning of the cylinder duct because the flow will be damped in the beginning of the pattern. Installing the roughness in the middle of the pattern, only in one section, converts transitional motion to rotational-transitional motion that leads the flow to turbulence flow and a high-velocity air at the beginning of the wind turbine. It would be indicated that the velocity could be increased by such a method to spin a wind turbine and software simulation of this method is an evidence for indicating the increase of the velocity of wind and then initiating a wind turbine to producing the needed electricity of a building.

In this work, the cylindrical straight duct followed by a joint and nozzle has been designed by using GAMBIT software. The modeling section choosing for the project is a uniform duct of diameter 2 meters and length 0.5m followed by a joint of the same diameter, a cylinder duct with some roughness of length 0.5, and a contraction nozzle of 2m and 0.75m. The created model is meshed for further simulation which is shown in Fig.4, after meshing velocity vectors colored by velocity magnitude (m/s) are simulated by Fig.5 by using FLUENT software. Fig.6 shows windflow velocity and mass flow rate at different inlets of Fig.1. These analytical simulations are presented for the desired scheme scales based on the theoretical calculations of

the fluid dynamics. As shown in Fig.6, an optimum design of the duct can increase the velocity of the wind flow for spinning the wind turbine at the end part of the scheme so that the wind turbine will produce electrical power more efficiency.

The result of this study provides a basis for producing energy in the buildings from incompressible flows of the windward areas. It suggests that each building would be self-sufficient of electricity power plants. From the numerical analyses, it was found that by decreasing the segment area of the nozzle, the wind speed gets increase and it reaches peak at nozzle output or wind turbine inlet. So the electricity for powering our home would be practically made in the process of amplified-velocity wind in a duct and contraction nozzle to initiate a wind turbine. Although this study involves assumptions but the theoretical concepts and software simulations shows that wind velocity would be enough increased in an isolated pattern to spin a wind turbine and then the required electricity power can be produced by wind turbine in the buildings, which is economically of advantages for saving energy.

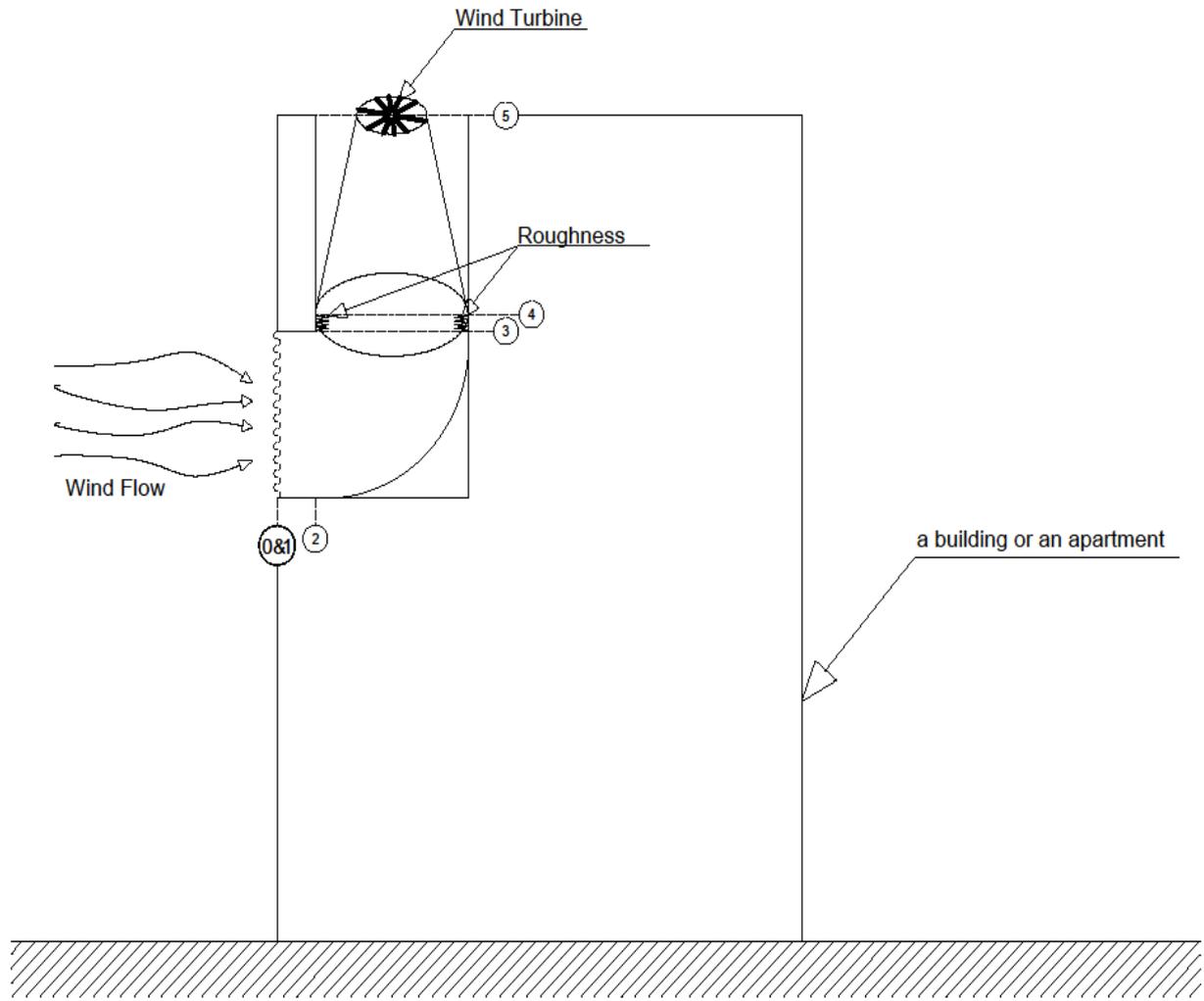


Figure 1. A schematic of wind flow through the intended pattern to spin a wind turbine in top of the building.

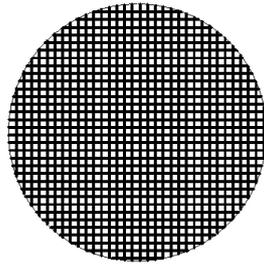


Figure2. A mesh connection.

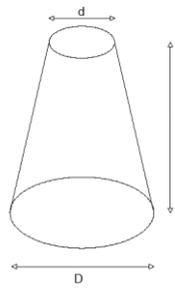


Figure 3. A Contraction Nozzle increases the velocity of the flow.

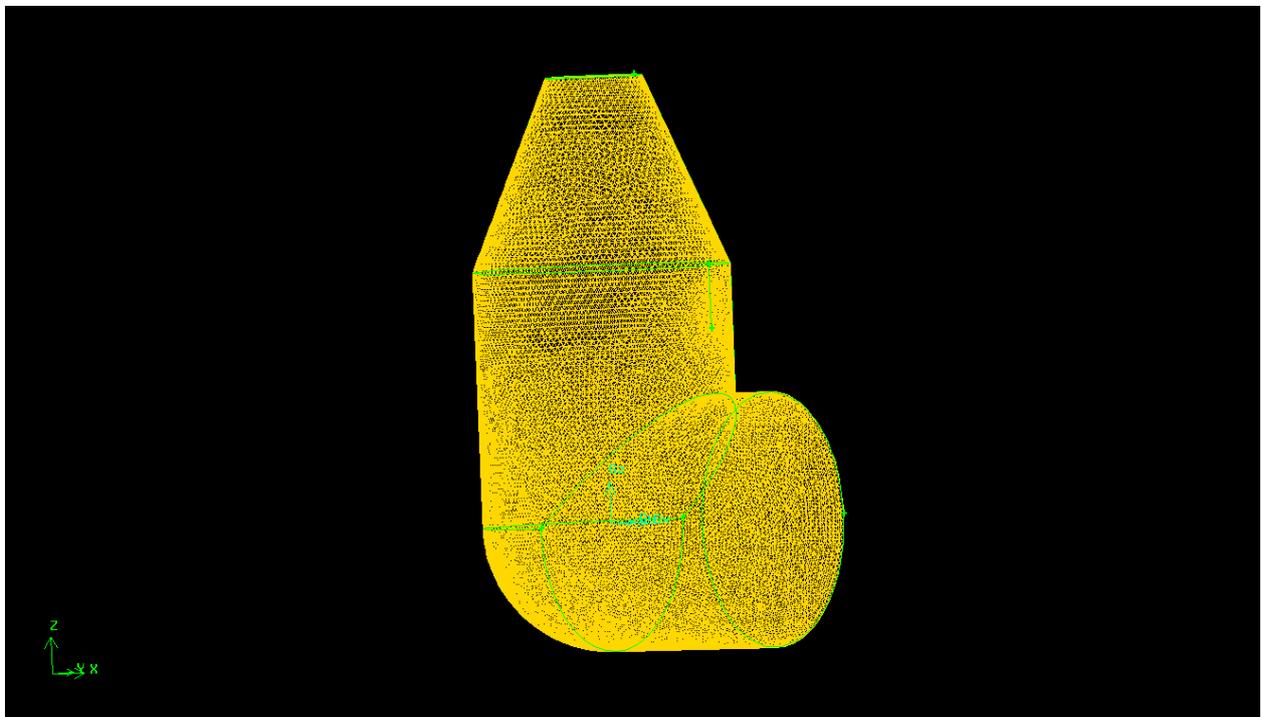
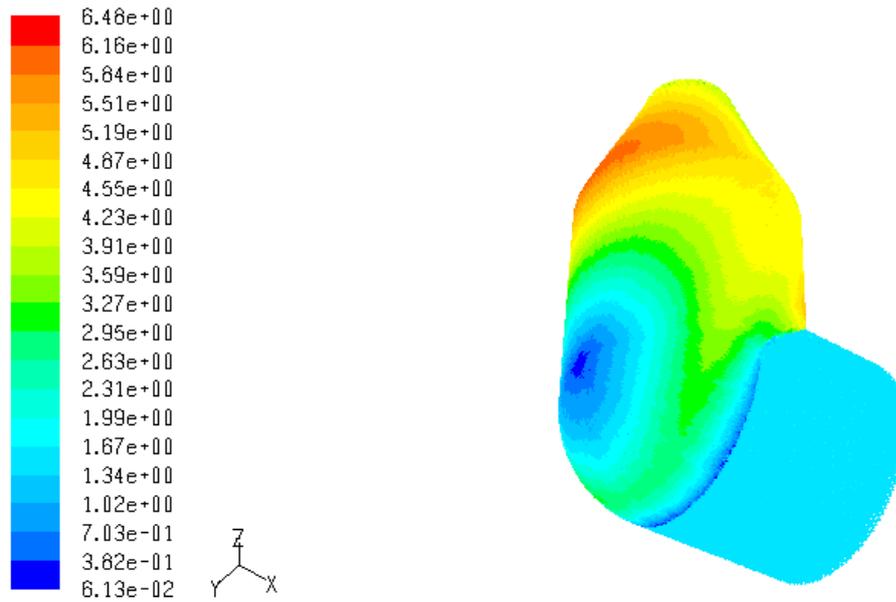


Figure 4. Computational scheme after meshing.



Velocity Vectors Colored By Velocity Magnitude (m/s)

FLUENT 6.3 (3d, dp, pbns, lam) Jun 24, 2016

Figure 5. Three dimensional velocity vectors colored by velocity magnitude.

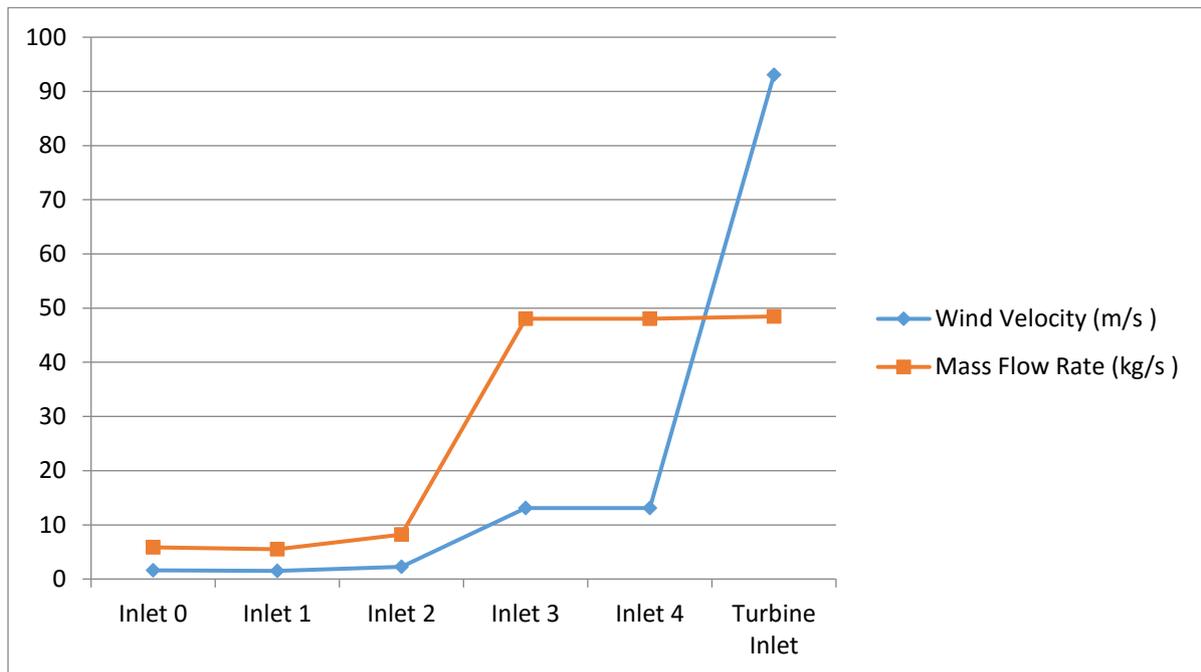


Figure 6. Numerical simulation of mass flow rate and wind velocity at different inlets for the given data of the numerical values.

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