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Study of Cornered Flow past a Building

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ABSTRACT

The main objective of the current proposed work is to emphasizes on the fact that there is a dire need to discover novel bionic shapes for the urban wind turbine rotors which would dovetail with the cornered flow patterns and thereby enable the capture of the high kinetic energy existing in the vicinity of the cornered flow past a building in an urban terrain. And this clearly affirms the effectiveness of the urban wind turbines and its utility as a renewable source rendering us with an alternative and superior way of electricity generation.

Introduction

Wind energy is one of the most potent renewable sources for the built environment. And thus, urban wind energy is incredibly diverse ranging in scale from small individual building-mounted wind turbines to large stand alone wind turbines. Two things which in particular characterize the urban wind regime: lower annual mean wind speed (AMWS) compared to rural areas and more turbulent flow. The decrease in the energy output (owing to the decrease in the wind speed and power output being directly proportional to cube of wind speed) from having local obstacles is actually inevitable. However, this decrease in the wind speed can be effectively recouped by the low transmission losses of urban turbines.

It is prominently observed that there exist high velocity zones in the vicinity of the cornered flow past the building and the terrace. In urban areas, main air flows from prevailing winds are strongly modified, depending on construction's morphology and urban microclimate's effects. The meteorological data on the wind speed are often available from outside city centres whereas this wind speed is tough to assess in the urban canopy layer.

Urban wind turbines

The urban environment poses numerous challenges in the extraction of wind energy. As the wind velocity profiles in the urban areas tend to be more turbulent and not along a single axis. The presence of the building increases the turbulence which results in the formation of large wake region in the downstream characterized by the recirculated flow. The building also changes the direction of wind from horizontal to incline. Thus, to be effective the wind turbine must not only be able to integrate with the architecture of urban environment but must also be able to tap the localized accelerating winds caused by the obstacles.

Three main categories of urban wind turbines are-

Small wind energy: Retrofitting and building-mounted wind turbines

Large scale stand alone wind turbines

Building-integrated wind turbines

Retrofitting and building-mounted wind turbines

Some of the key issues that are to be addressed before venturing into these systems are

a. Predicting the available wind resources and prevailing wind direction

b. Understanding the flow pattern over a building to know the boundary layer thickness enabling to estimate the extent of recirculated flow region

c. Selection of turbine design

d. Mitigating environmental impacts

e. Preventing structural damage

Flow characterization over buildings

And because of high density of the obstructions in urban areas, the wind behaviour observed here is not uniform leading to recirculation flows and regions of wake at the downstream of any building.

Below is the figure shown, indicating the wind velocity profile comparison and the roughness of both the rural and urban regions -

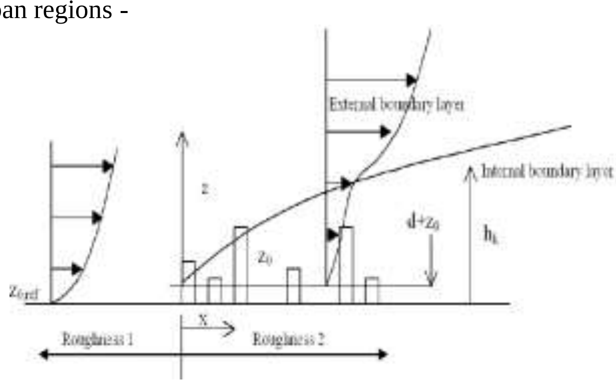

Fig 2.1: variation in Wind shear in Rural & Urban environment

Understandably, at the ground level the wind speed is practically zero owing to the no-slip condition. Now considering rural region the ground level acts as the reference level for the wind velocity. On the other hand, because of wind being severely obstructed by the buildings only above the average building height does the air movement becomes wind.

Thus, the reference level in urban region is found to be at a higher altitude compared to that of a rural region. In fact, for a given height if wind velocity of both rural and urban region is compared then wind velocity of rural region is observed to be higher.

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Building characterization

A first characterization of building shapes distinguishes aerodynamic building from bluff buildings. Aerodynamic buildings have a thin boundary layer attached to the surface of building. They are characterized by a small wake region. Whereas, the bluff buildings (most of the buildings are bluff) are characterized by early separation of the boundary layer from their surface and a large wake region.

At a building with sharp upwind edges, the boundary layer separates at the upwind edges and separation bubbles are formed on the sides and on top of the building. The main stream is deflected around the building and large wake at the downstream of the building is formed. Such a building is thus called bluff building.

Fig 2.2 A typical bluff building

Reattachment of streamlines

For a building having a small length (depth) in the wind direction, the entire side wall and the roof of the building are engulfed in separation zones. In this case, low pressure (high suction) exists throughout the roof and the side walls. On the other hand, for an elongated building the streamlines that separate from the windward edges reattach to the building walls and the roof in a manner as shown in the fig 2.3. The phenomenon is known as reattachment. Upon reattachment the external pressure recovers from its low values in the separation zones. Much less suction is encountered in the reattachment zone than in the separation zone.

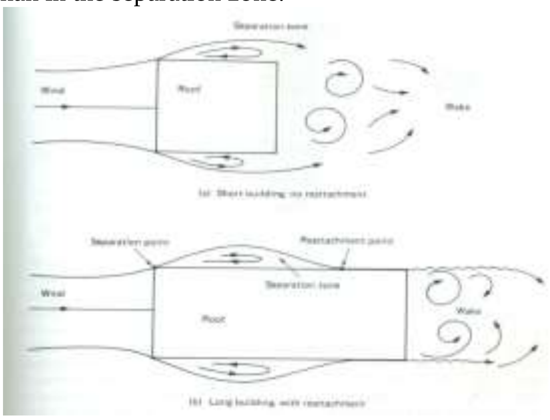

Fig 2.3 Separation and reattachment of flow along buildings of different lengths

Boundary layer region analysis over a building

As the wind strikes a building a parabolic shaped boundary layer region is formed at the top of the building owing to the viscous effects. Understandably, the region is composed of wind recirculation flows and eddies leading to higher drag force in the boundary layer region.

This drag force is actually made up of two contributions. The difference in local velocity around a building results in pressure differences at the surface of the building. This gives rise to the increase in the total drag called “Pressure Drag”. While, the “no-slip condition” at the surface of the building gives rise to the surface shear stress causing a contribution in total drag as “Skin Friction Drag” or “Viscous drag”.

In case of aerodynamic buildings, the Viscous Drag dominates the Pressure Drag. As the flow separation is delayed efficiently using the streamlined shape & the exposed surface area of the building results in shearing action towards the wind. However, at a bluff building the Viscous Drag is of the same order as that of aerodynamic building but the Pressure Drag is high as a result of flow separation taking place at the upstream itself. Consequently, at a bluff building the pressure drag dominates the viscous drag.

Flow separation

At a sharp upwind edge of the roof, the boundary layer separates from the building. The separation results in a region with low velocities, high turbulence level and recirculation of the flow at the roof and sides of a building. This recirculation region should be avoided for locating of a wind turbine. It is thus important to know the size of the recirculation region.

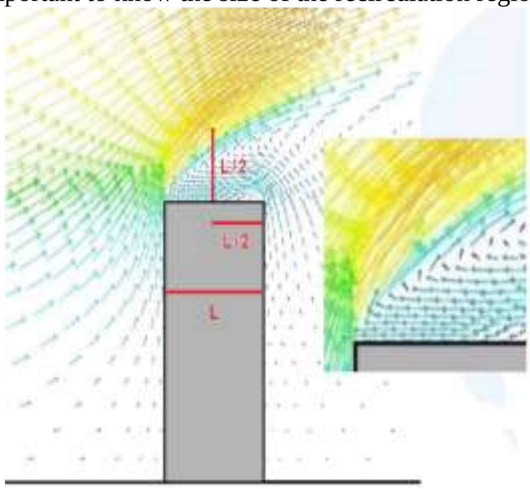

Fig2.4 positioning of a wind turbine in a Skewed flow

Because of the separation at the upwind roof edge, the velocity vector outside the recirculation region is not parallel to the roof. The angle between the roof and velocity vector outside the recirculation region (In viscid region) is called the “Skew Angle”.

The skew angle varies with-

- the position on the roof,
- roughness of the upwind area,
- sizes of the building,
- upwind edge rounding

The dependence on the position on the roof is to understand the velocities close to the building are high and decrease with increasing distance to the building. The pressure close to the building is consequently low and increase with increasing distance to the building. This pressure gradient forces the flow in a curved path.

Result and Discussion

The enormous amount of energy remains untapped in the cornered flow region, near to the terrace, instigating us the need to look for unconventional wind turbine shapes which can possibly dovetail with the cornered flow patterns. This can be undertaken to quantify the actual extent of the wind shear existing over the terrace of the building. This would ensure better placement of the conventional horizontal axis wind turbine/s over the terrace of the building and their optimal performance.

The velocity gradient above the terrace of the building shows that there exists a prominent wind shear region up to certain height. Thus placing a conventional horizontal axis wind turbine in this particular region of high wind shear may result in under-utilization of the wind turbines capability in extracting the kinetic energy from the wind. The most important observation was that there existed certain zones near the corner of the building, above the roof wherein the local velocities were greater than the free-stream velocity of the wind. This clearly suggests that, owing to the Corner effect, there exists a high localised acceleration zone of velocity in the vicinity of the corners of the building.

This observation unravels a key point i.e., enormous amount of energy remains untapped in the cornered flow region, near to the terrace, instigating us the need to look for unconventional wind turbine shapes which can possibly dovetail with the cornered flow patterns and tap the kinetic energy in the localized high velocity zones region near the corner of the building, above the terrace.

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