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The Effect of Von Karman Vortex Street on Building Ventilation

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***Abstract*— This paper deals with the utilisation of the von Karman vortex street principle to maximise air flow into buildings. Von Karman Vortex Street is a succession of eddies created close to the building that break away alternatively from both sides. A case study of 2 rectangular buildings placed at a certain distance from each other is presented and the effect on ventilation is determined. The stagnation region appears in the closest region downstream of the bluff body (building) and is a factor which considerably influences vortex shedding and subsequently ventilation. The stagnation region has to be minimized for maximizing the air flow. Vortex streets can result in natural ventilation which can save energy due to reduced running of electrical appliances. Thus, the green building concept can be satisfied. Based on this study, doors and windows can be placed at the wake regions, resulting in maximum ventilation.**

***Index Terms*—Green building, stagnation region, ventilation, Von Karman Vortex Street**

Abbreviations and Acronyms

h	Width of the building normal to which the wind flows
a	Distance between the 2 buildings
F	Vortex shedding frequency
U_e	Vortex propagation velocity
U_0	Actual wind velocity
r	Vortex life time
ε	Rate of viscous dissipation of vortex energy
ν	Kinematic Viscosity
R	Vortex radius
Re	Reynolds number

I. Introduction

A bluff body is defined as a body with a cross sectional shape that offers large resistance to the oncoming flow and retards it. The fluid stream fails to stick to the shape of the bluff body over which it flows, but breaks of behind it resulting in a wake region. This wake region results in the phenomenon of the Von Karman Vortex Street. This paper deals with asymmetrical vortices, as the only stable vortex system is a system of staggered asymmetrical vortices. The frequency of vortex generation is very essential for the extent of ventilation. It has been found out that the frequency is directly proportional to the velocity and inversely proportional to the diameter of the bluff body.

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II. Problem Statement

For this study the wind velocities and directions at different periods over the region of the buildings were obtained from the metrological department, Chennai (table 1) .Since we are considering rectangular buildings here, the diameter is taken to be the side facing the wind flow. The 2 buildings have dimensions 24 x 6 x 6 m and 15 x 6 x 6 m respectively and are situated at a distance of 15 m from each other (Fig.2 a). We are considering the ventilation of the 1st building. The diagram depicting building 1 with the positioning of doors and windows facing the wind is shown in Fig.2 b.

A. Assumptions

1. The effect of other buildings in the vicinity over the air flow is ignored.
2. Any cross flow of air is neglected.
3. The wind speed is constant for the specified height of the building.

B. Calculations

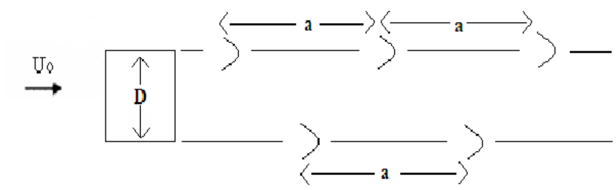

Fig 1 The layout of the building and vortex generation

$0.28<h/a<0.52$ (S.C Luo et al 2007) (1)
$F=U_e/a= (Uo/a)*(Ue/U_0)$
(Ue/U_0) can be related as
4π (h/a) (Ue/Uo) (l-Ue/Uo) = 1(S.C Luo et al 2007) (2)
For h/a=6 m/15 m =0.4 (here, h=D, the width of the building normal to which the wind flows)
We have Ue/U_0= 0.728 from equation (2),
Hence, Ue = 8.5 m/s
(Considering U_0 as 42 kmph which is equal to 11.67 m/s)
Vortex life time $r = a/U_e = 2.492 \times 10^{-4}$ hrs = 0.897 seconds
Therefore,
F= Ue/a = 1.1148 / second

V_0 is the velocity at the building

$= (k/2\pi r)\ [1\text{-exp}\ (-R^2/\ v^4 r)]$ where,

ε is the rate of viscous dissipation of vortex energy

ν is the kinematic viscosity

R is the vortex radius

Therefore,

V_0=27.2kmph (3)

A stable vortex on the lee side of an obstacle can occur when the Reynolds number is greater than a critical value and the Froude's number is less than 0.4.The vortex can exist when 60<Re<5000 where $Re= U_0D/v$

Hence, we find that the value of velocity at the building has increased considerably leading to an increase of air flow into the building.

Table 1.The maximum wind velocity and direction in Chennai, India

Date	Maximum wind velocity(kmph)	Direction of wind	Time of occurrence(IST)
16-12-2007	42	North North-east	10.48
17-12-2007	58	North North-east	18.02
18-12-2007	47	North North-east	14.57

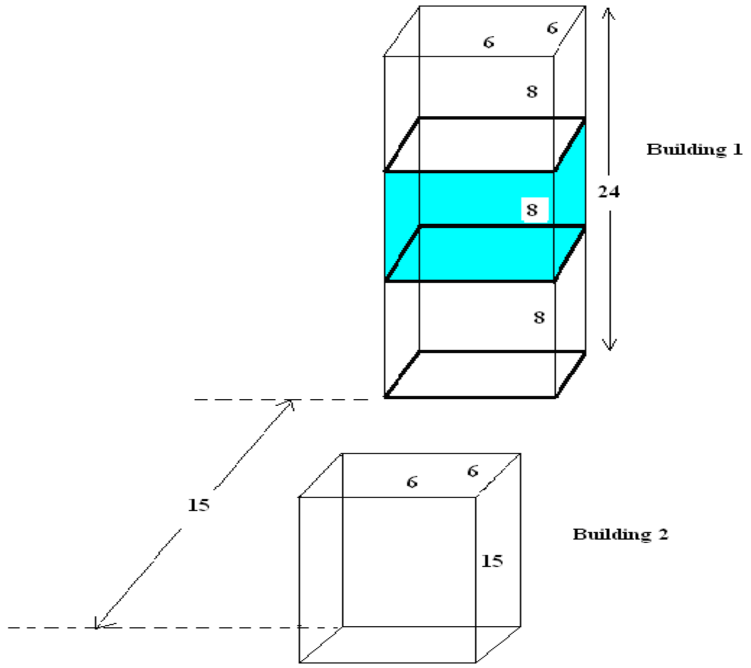

Fig2.a The dimensions of the building 1(6 x 6 x 24 m^3) and building 2 (6 x 6 x 15 m^3)

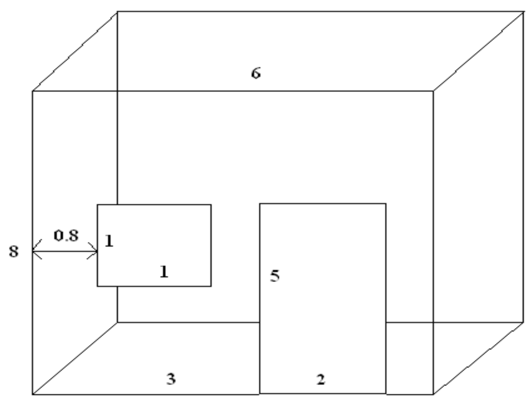

Fig 2 b. An expanded view of the 1st floor of building 1 with the position of door and window
(All dimensions in meters)

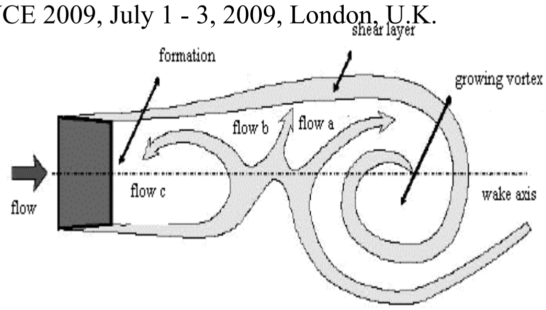

Fig 3. Forms of flow and the stages in vortex flow (Gregory L. Pankanin, 2007)

C. *Role of stagnation layer*

The stagnation region can be understood to be a certain volume of fluid clustered downstream of the bluff body. This volume performs the push-pull motion associated with vortex shedding. Understanding of its role is a key factor in the recognition of the Karman vortex street phenomenon. In the Birkhoff model, the stagnation region oscillates according to consecutive vortices, generated alternately on both sides of the bluff body. In the model, we distinguish between three streams:

- Stream “a”, entrained into the growing vortex
- Stream “b”, entrained by the turbulent layer,
- Stream “c”, directed back into the formation region, generating a new vortex.

From the point of view of the strength of the vortices, stream “c” should be maximized, stream “a” should be minimized and stream “b” should be sufficiently high for the detachment of the vortex. Stream "c" maximization is of the greatest importance and means an increase in the fluid movement just downstream of the bluff body and, hence, minimization of the stagnation region. (Gregory L. Pankanin 2007)

The two Objectives for establishing a stagnation region are:

1. It assists the vortex shedding process.
2. It relays the information that a vortex has been generated to the other side of the bluff body.

This means that the stagnation region plays a very important role as an information channel.

The flow region just behind the bluff body plays very important part in the determination of the frequency of the vortex shedding. Importance of this region relies on the fact that a close relationship exists between the stagnation region size, the strength of the vortices and the frequency of vortex shedding which in turn affects the ventilation.

A way to increase the quality and strength of the vortex generated has been proposed already(Pankanin 2007).Investigations were carried out with a rectangular bluff body with a splitter plate attached to the back side of the body. The length of the plate highly influenced the strength of generated vortices. A short splitter plate is added to the back side of the bluff body (the building 2) and this can increase the number and energy of generated vortices and results in high energy of the vortices. However, increases in length could result in vortex suppression. In our case, splitter plates would be provisions in windows and doors. If windows and doors are properly positioned so that they are in the vortex wakes, maximum ventilation can occur.

D. *Effect of Reynold’s number*

In recent years, considerable interest has been shown in studying the flow of Newtonian fluids past cylinders of circular and square cross-section oriented normal to the direction of flow. For a square cylinder, the separation points are fixed, in contrast to a circular cylinder. Based on a combination of numerical and experimental studies, different flow regimes for the square cylinder have been identified in the literature depending upon the value of the Reynolds number. (A.K Dhiman et al, 2007). The main flow regimes reported to date are: a creeping flow region in which no flow separation takes place at the surface of the cylinder ($Re \leqslant 1$). At low Reynolds numbers ($2 < Re < 60$), a closed steady recirculation region characterized by the formation of two symmetric vortices behind the bluff body is observed. A critical value of the Reynolds number seems to lie in the range 50–70, beyond which, a von Karman vortex street forms in the flow field. When the Reynolds number is further increased ($100 \leqslant Re \leqslant 200$), the flow separates at the leading edges of the cylinder also, and beyond around $Re = 160$, the flow becomes three-dimensional in an unbounded flow, the onset of which is not fully investigated yet in the literature.

III. RESULTS AND DISCUSSION

CFD analysis done in Fluent software on the air flow around the 2 buildings showed an area in the building which had possibility of maximum ventilation. This area was towards an extreme of the building. So, the window placement of building 1 at a distance of 0.8 m from the left wall is favorable for air flow.

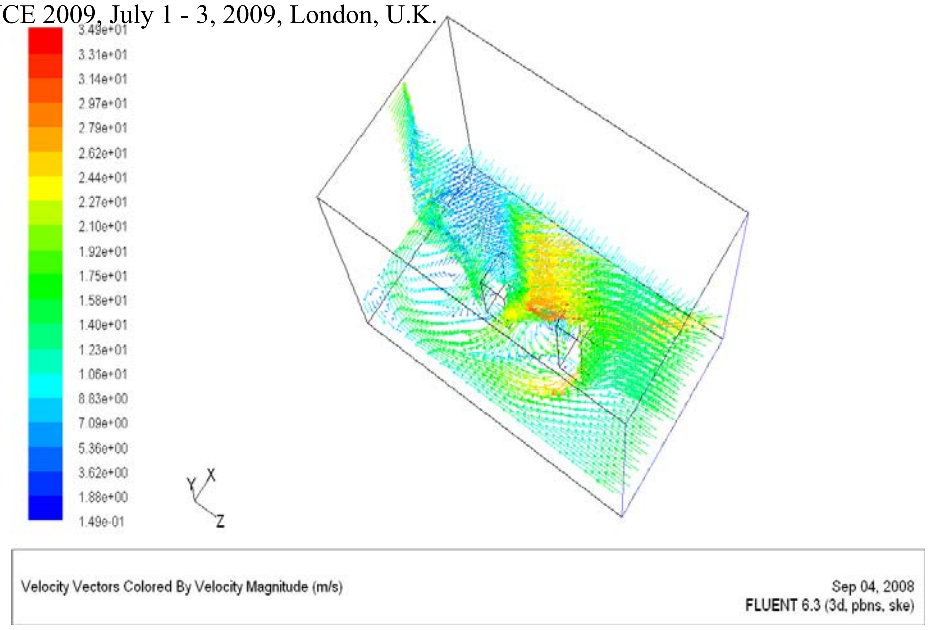

Fig 4 a. Fluent Vector model 1

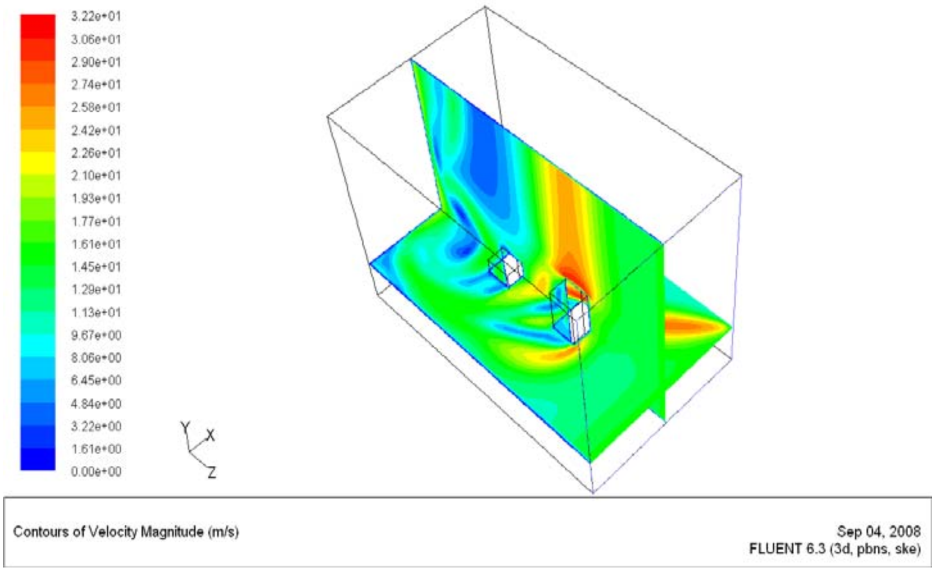

Fig 4 b.Fluent Contour model

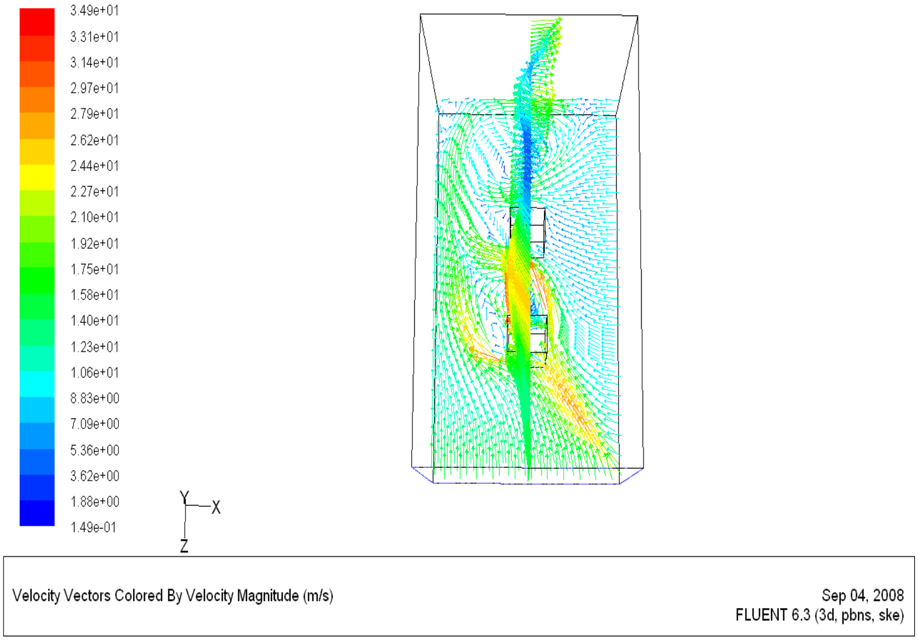

Fig 4 c. Fluent vector model 2

IV FUTURE SCOPE

Window and door placement done today is not based on calculations. The CFD analysis (Figure 4) shows the region where the air flow velocity is maximum in building 1.Windows and doors should be placed in this zone. Similar case studies are to be done for different pairs of buildings to arrive at a standard for window placement. If the positions of the windows and doors can be generalised for all buildings by taking into account the vortex street, it would lead to a standard which is not present in building construction today. Also the strength of the vortex can be increased by decreasing the stagnation region which in turn can be done by introducing splitter plates in the walls.

IV. CONCLUSIONS

Von Karman vortex Street is a common phenomenon which occurs between certain Reynolds numbers. Two rectangular buildings, 15 m apart were considered and the effect of the 1st building over the ventilation of the 2nd was determined. Also, the region where the wind impinges the 2nd building is determined using Fluent software. If a window or door is placed there, then the air flow inside the building could be maximized. For the present study, the wind velocity was taken to be 42 kmph flowing in a direction North-North east (on 16-12-2007 at 10.48 am). Similar trials for other sets of buildings could be done so as to generalize the window placement and set a standard for it.

The three phases of vortex development are: energy increase, the attainment of maximum energy and gradual energy decrease. Thus, the 1st building must be in the region of maximum energy. Splitter plate provisions in the doors and windows of buildings would lead to a considerable increase in air flow.

Increase in ventilation would mean a reduction in usage of fans thereby saving power. Hence, this will satisfy the green building concept if implemented.

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