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Study of Flow Structure in Street Canyon between Dome shaped buildings through CFD

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ABSTRACT: This article presents the findings of some tests run using Computational Fluid Dynamics. The software used was FLUENT. Simulation was carried out for study of air flow structure in street canyon formed between two dome shaped buildings. The main issue considered was the ability of the air in the street canyon to be enriched. For this the simulation was carried out for 2D model of street canyon using computational fluid dynamics. Reynold's Averaged Navier Stokes (RANS) equation is equipped using realizable K-ε model. Various results for different aspects ratios are measured for comparison. Aspect Ratios considered are 0.5, 1 and 2. Three basic entities were focused upon i.e. Wind Velocity, Static Pressure and Turbulent Kinetic Energy. This determines the effectiveness in enriching the street canyon.

Keyword- Street Canyon; K-ε Turbulence Model; Aspect Ratios; Realizable Sub-model

1. INTRODUCTION

As the time progressed, mankind progressed as well. We built settlements and developed new technology to ease the living. Though the technology assisted us in many ways, but they posed new threats as well. In today's world, pollution is one such major threat. The most common type of pollution that we all face is Air Pollution. With more and more automobiles running on the roads, it is very important to make sure of proper disposal of air pollutants from the lower surface to upper atmosphere. For such a motive, we need to understand the flow of air in various conditions. This article focusses on the flow of air through street canyons.

The multiple buildings form a canyon between them. This is termed as street canyons. With the road in between the two buildings, the flow of air is not as linear inside as it is outside or above the buildings. So, there occurs difference in replenishing or enriching of the air inside. In such cases, the pollutants present in the canyon is inhaled by the pedestrians resulting in diseases.

There have been many methods to solve such problems regarding the flow of air. Air Pollution Models include OSPM, PUFF-PLUME and SAFE AIR etc. Now, the shift has taken to more technical field using computers for calculations in Navier-Stokes equations. The models devised for such turbulent flows are used in the software FLUENT. Many researches have taken place using FLUENT software. (Gromke et. al.2008; Meroney et al., 2000; Chan et.al. 2003; Vardoulkis, S. et al. 2003)

Configurations of Street Canyons

Street Canyons are formed in the spaces between two buildings. Though commonly known as Urban Canyons, they are found in rural areas also. They are the spaces allowing the passage of people, vehicles and air through it. In this matter, the height of building (H), the width of the road (W) and length of the road comes in heavy consideration.

The ratio between heights in width (H/W) is known as *Aspect Ratio* (A.R). Oke classified the types of street canyons based on the aspect ratio criteria.[1] Street canyon can be classified according to A.R as *regular/uniform* street canyon (A.R =1), *wide/shallow* street canyon (A.R ≤ 0.5) and *deep* street canyon (A.R ≥ 2).

According to the length to height ratio (L/H) street canyon can be classified as *long* street canyon (L/H ≥ 7), *medium* street canyon (L/H=5) and *short* street canyon (L/H = 3).

Street canyon can also be classified as *symmetric* for even building height and *asymmetric* for uneven building height.

According to the direction of wind flow the upward side of the canyon is known as *leeward* and downward side is known as *windward*. According to height variation of building of leeward and windward, street canyons are classified as *a step up* for the height of windward side is greater than the height of leeward side and *step down* in height of leeward side is greater than the height of windward side. [2]

Flow of Wind

Wind flow is possible in street canyons in three conditions. First is the flow of wind is *parallel* to the street (Zero degree angle), second flow is *perpendicular* flow (flow at 90 degree to the street) and third is *oblique* (flow at any angle excluding 0 and 90 degrees). [3]

Oke (1988) has reported that there are basically three flow regimes in the street canyons. For perpendicular wind flow of magnitude 1.5 – 2 m/s, flow can be described in three regimes as (a) *Isolated roughness flow*, (b) *Wake interference flow*, and (c) *Skimming flow*. Generally in the regular canyon (A.R = 1) skimming flow pattern is formed in which there is a single vortex turbulence formed.

If the height and spacing of the building blocks are such that they disturb the bolster and cavity eddies (due to the deflection caused by downward flow passing over the cavity), the flow regime changes and is known as *'Wake interference flow'*.

At a greater H=W, the circulatory vortex is established inside the street canyon. This may be due to the transfer of momentum across the shear layer at the roof height. In this situation, the bulk of the flow does not enter inside the street canyon and forms single vortex within the canyon [4]. This type of flow regime is known as *'Skimming flow regime'*.

2. EXPERIMENTAL SETUP

Street Canyon Design Configuration

In this study, we have considered symmetrical dome shaped buildings. The average height of building is taken to be 50 m. Three Aspect Ratios are considered, i.e. AR=1 (Uniform Street Canyon), AR=2 (Deep Street Canyon) and AR=0.5 (Wide Street Canyon).

ANSYS DesignModeler was used to create the two-dimensional design featuring air as the fluid and aluminium as the wall material. Dimensions and constraints were given as and when required. For our ease at further working, we gave names to the edges. Named Selection makes it easy to work upon with the names defining Inlet, Outlet, Wall and Symmetry.

Inlet and Outlet are, as the name suggests, inlet and outlet regions for flow of air. Wall is the edges pertaining to the obstacle in the flow i.e. buildings. Symmetry is the top edge beyond which the properties are assumed to be symmetrical.

Meshing of the design

Meshing is a very important aspect for the accurate calculation of the design. The mesh should be fine enough to give good results and coarse enough to not take much of the time for meshing. For two dimensional structure, we take quadrilateral mesh.

In this case, we took the mesh size to be 0.5 m. The comparison of meshes among three aspect ratios is tabled below.

	Aspect Ratio=0.5	Aspect Ratio=1	Aspect Ratio=2
Number Of Nodes	962190	309262	308396
Number of Elements	479611	153566	153127
Number of Wedges	548	185	174
Number of Hexahedra	479063	153381	152953

Table 1: Comparison between the meshing values of three difference geometrical configurations.

Problem Setup

After the meshing is done, the geometry is run on ANSYS FLUENT for the calculations. Single precision and serial processing setting is used to launch FLUENT to get fast results. Pressure-Based Solver was used with planar 2D space. Gravitational acceleration was considered to be 9.81 m/s^2 in negative y-direction. Standard SI units were used.

The model we used for calculations is K-Ɛ model and sub-model selected was Realizable with enhanced wall function. Heat and energy related inputs were kept off. The material considered are Air for fluid and Aluminium for edges i.e. solid. The named selection done earlier automatically allotted the type for the boundary conditions. The reference values were kept default values with change in velocity. Initial velocity was taken to be 2 m/s from the inlet.

Solution Setup

SIMPLE solver algorithm was taken for quick calculations. Moreover, not much turbulence is considered in just two buildings forming one street canyon. So, SIMPLE was taken rather than PISO Scheme.

Green-Gauss Node Based gradient was taken for more accurate calculations as it minimizes false diffusion. Pressure was taken to be Linear for accurate and quick calculations and to achieve convergence easily as Standard setting was making it difficult to achieve convergence. Momentum, Turbulent Kinetic Energy and Turbulent Dissipation Rate were calculated with Second Order Upwind for better results.

The residuals were edited for convergence criteria to be kept 0.00003 or 3×10^{-5}. This value was considered after some trials. Over the time, the values would limit them to form a linear result. Hence, achieving convergence became difficult. So, in order to converge the solution, such value is taken.

Solution Initialization is done with velocity 2 m/s in X-direction and default values for Turbulent Kinetic Energy and Turbulence Dissipation Rate.

3. Results and Discussion

The results were obtained and they were analyzed to find better way of enriching the air inside the street canyon. These results obtained are of Aspect Ratios 0.5, 1 and 2. From the iterations onwards only, the difference could be observed in the three types of configurations.

To achieve convergence in aspect ratio 0.5, 5880 iterations were run, to achieve convergence in aspect ratio 1, 3480 iterations were run and to get convergence in aspect ratio 2, 2338 iterations were run.

When the iterations were completed and the solutions were well under the convergence criteria, the results were analyzed in CFD-POST. Velocity, turbulent kinetic energy (TKE) and static pressure values were taken into account in the street canyon.

Velocity is plotted using vectors whereas contours are used to show the Static Pressure and Turbulent Kinetic Energy.

Result for Aspect Ratio 0.5

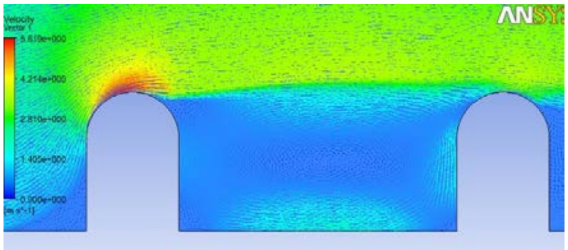

Fig. 1: Velocity vector profile for Aspect Ratio 0.5

The velocity profile generated in the case of aspect ratio 0.5 shows the flow of air in the street canyon. Inlet velocity is 2 m/s. The vortex is created at the center. The velocity at the building at windward side experiences highest velocity of the wind i.e. 5.81 m/s. However in the canyon, the velocity decreases to 1.4 m/s at the leeward side of the canyon and at the base. In this result, it is clearly shown that the velocity is present at the base of the canyon. Hence, flow of wind is present to provide replenishment.

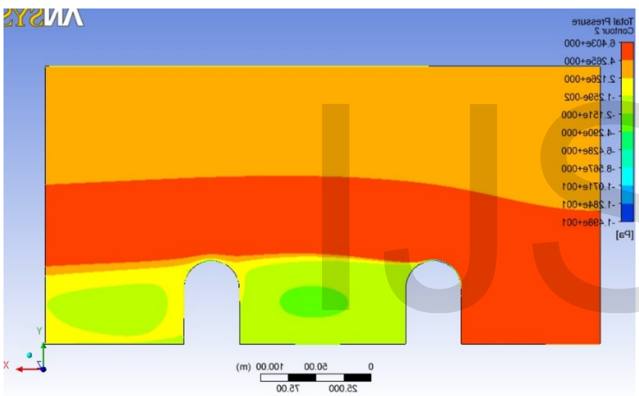

Fig 2: Total Static Pressure Contour for Aspect Ratio 0.5

The initial pressure condition is taken to be 0 Pa. Here it is evident that pressure of around 6.4 Pa is created at the bottom surface before the first building. It can be seen clearly that slightly low pressure exists in the street canyon of about 0.0012 Pa but at the center of vortex, the pressure is about -4.2 Pa. This means creation of vacuum region inside the street canyon at the center of the vortex.

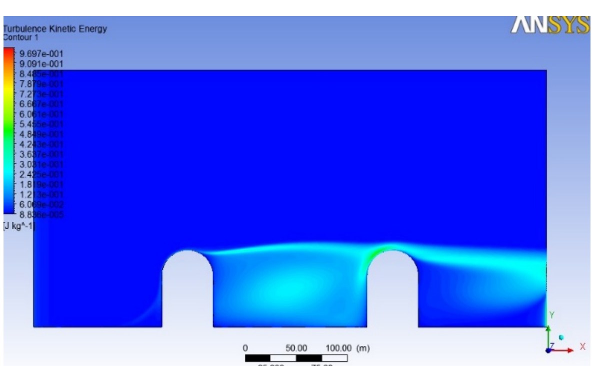

Fig 3: Turbulence Kinetic Energy Contour for Aspect Ratio 0.5

In this result, we see that throughout the free region, very little turbulence is present. But in the canyon, on the leeward side, there is turbulence of about 0.3 – 0.36 j/kg. Such a turbulence is only present on the side of the wall of second building. On the windward side, at the bottom, the turbulence is negligible. At the corners on the base, the turbulence kinetic energy is again absent.

Results for Aspect Ratio 1

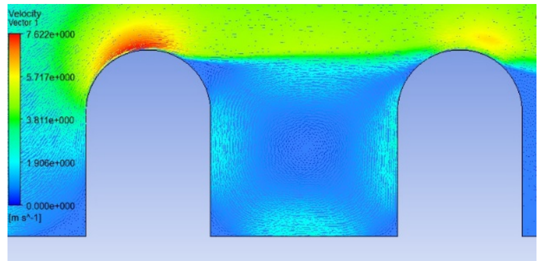

Fig 4: Velocity Vector Profile for Aspect ratio 1

In Aspect Ratio 1, the velocity vector profile is created in such a manner. Here the flow of velocity vector lines clearly show the formation of a single vortex at the center of the canyon. This facilitates the proper mixing of the air inside the canyon. The flow lines at the four sides on the walls and upper surface represent the velocity to be around 1.9 m/s. whereas, at the upper and lower corners of the canyon, the velocity is negligible. However, air from outside is covering more area with its flow.

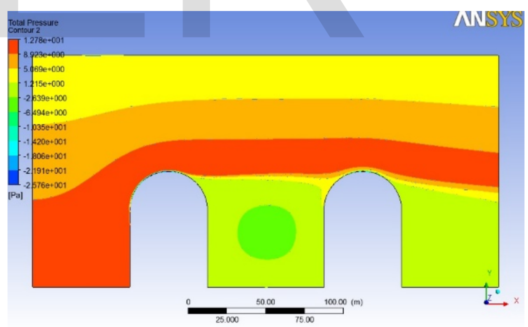

Fig 5: Total Static Pressure Contour in Aspect Ratio 1

The pressure in the canyon forms the similar structure as in aspect ratio 0.5. But, higher pressure or lower vacuum is found at the center of the vortex i.e. -2.6 Pa. At the surrounding of the canyon, the static pressure is found to be 1.215 Pa which is higher than the result in case of aspect ratio 0.5.

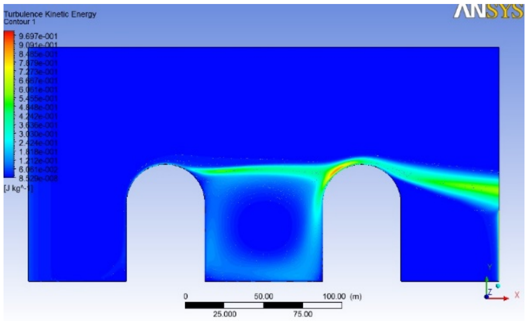

Fig 6: Turbulence Kinetic Energy Contour for Aspect Ratio 1

Turbulence Kinetic Energy takes a twist in the case of aspect ratio 1. In case of aspect ratio 0.5, more TKE was present at the center of the vortex, but in this case, negligible TKE is found at the center of the vortex in the street canyon and higher TKE is found at the surrounding. Some turbulence is found at the base as well.

Results for Aspect Ratio 2

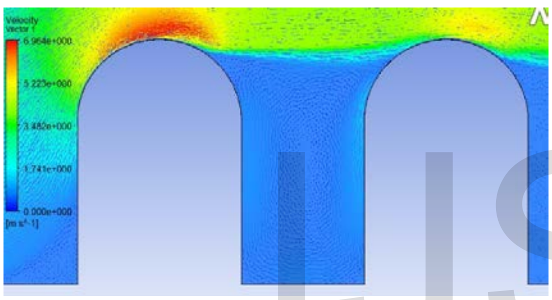

Fig 7: Velocity vector Profile for Aspect Ratio 2

Very low velocity is found inside the street canyon in the case of aspect ratio 2. The vortex takes form of an ellipse inside the canyon. With constant negligible velocity inside. Though, on the upper leeward side, on the wall, small increase in velocity is observed.

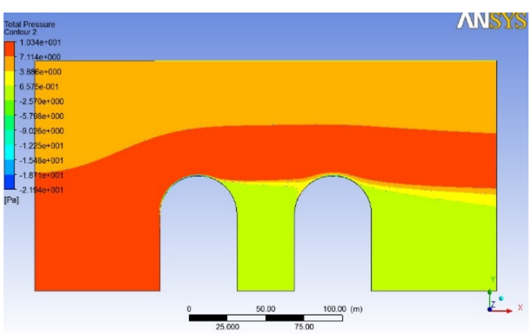

Fig 8: Total Static Pressure Contour for Aspect Ratio 2

The pressure inside the canyon is constant at approximately 0.26 Pa. There is no difference of pressure anywhere inside the street canyon as seen in the results for aspect ratios 0.5 and 1.

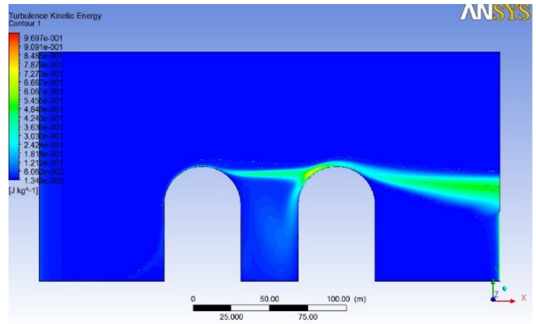

Fig 9: Turbulence Kinetic Energy Contour for Aspect Ratio 2

The turbulence kinetic energy is found to be negligible for most of the part of the street canyon. However, in the leeward side, there is some turbulence present. This turbulence is also at the upper level and is not effective in enriching the air inside the street canyon at greater depth.

4. Summary and Conclusions

This article elaborately discussed about the analysis of wind flow in street canyons of three different geometrical configurations i.e. Aspect ratios 0.5, 1 and 2. The buildings are taken to be dome shaped. Different values of velocity, total static pressure and turbulence kinetic energy were analyzed using ANSYS FLUENT software. The model used for solving the problem was K-e model with realizable subgroup. Salient results were found and conclusions are drawn on their basis.

Through this analysis, we can see that in aspect ratio 2, the enriching of air is very difficult due to negligible velocity and turbulence inside the street canyon. Moreover, in case of aspect ratio 0.5 also, the enriching is difficult at the corners of the street canyon. But, best result is acquired in the case of aspect ratio 1. In the case of aspect ratio 1, the velocity vector profile is quite supportive to the requirement of the adequate flow of air inside the canyon. Hence, for correct replenishment of the air in street canyon, aspect ratio should be kept as close to 1 as possible.

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