International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Effect of Temperature on Wind Forces on Tall Building using Numerical Approach - Computational Fluid Dynamics (CFD)

Jigar K. Sevalia*[a], Atul K. Desai[a] and S. A. Vasanwala[a]

[a]Applied Mechanics Department, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India.

Accepted 05 July 2013, Available online 01 August 2013, **Vol.3, No.3 (August 2013)**

Abstract

In this paper an attempt has been made for comprehensive numerical study of wind effects on tall building considering temperature effects. For that a tall structure having different geometric plan configuration of same plan area have been considered. All the tall buildings with different plan configuration have been modeled in CFD Code namely Fluent / Gambit and then comparative study has been executed. Distribution of the fluctuating surface pressure and the wind forces acting on bluff-shaped bodies are of great practical interest in the field of structural design in wind engineering because much civil and industrial structure can be assimilating to this shape. Computational wind engineering as a new branch of computational fluid dynamics (CFD) has been developed recently to evaluate the interaction between wind and buildings numerically. The techniques of Computational Fluid Dynamics (CFD), such as Standard k-ε Simulation, were adopted in this study to predict wind loads on and wind flow around the building. For the study, commercial Computational Fluid Dynamics (CFD) code Fluent has been used to generate computational domain around building then effect of temperature on static pressure, drag force and wind force coefficient on tall building has been examined.

Keywords: *Tall Building; Computational Fluid Dynamics (CFD); Numerical Simulation; Temperature; Wind; Wind Force; Wake Region*

1. Introduction

Modeling the wind atmosphere around buildings is of great importance for the Wind Engineering, Civil Construction sectors as well as Structural Engineering Sectors. The potential market for wind engineering studies around buildings is very large.

Computational Wind Engineering (CWE) as a branch of Computational Fluid Dynamics (CFD) has been developed rapidly over the last three decades to evaluate the interaction between wind and structures numerically, offering an alternative technique for practical applications (Shenghong Huang *et al*,2007).

CFD simulations can provide information on all flow parameters in the entire computational domain. Moreover, a reliable numerical evaluation of the interaction between fluids namely winds and buildings can be achieved with CFD modeling in a time- saving as well as economic manner. Thus, CFD can offer more flexibility when exploring a variety of building designs and modifications and their impact on the flow around them. CFD could also potentially supersede traditional wind tunnel studies as a more cost-effective and powerful design tool for wind engineering studies. However, wind tunnel studies have been proved quite useful for development, evaluation, validation and general performance assessment of CFD methods.

Distribution of the fluctuating surface pressure and the wind forces acting on bluff shaped bodies are of great practical interest in the field of structural design in wind engineering (Swaddiwudhipong S *et al*,2002) especially when building is located in different atmospheric condition i.e. under different temperature conditions. Any increase in building height increases the effect of wind loading. Wind loads on tall structures cause concerns about the integrity of the structure envelope and safety of the whole structural system. Under the influence of the dynamic wind loads, typical high-rise buildings vibrate in the along wind, across wind, and torsional directions. Modern high-rise buildings designed to satisfy static lateral drift requirements still might oscillate excessively during windstorms. The level of these oscillations may be significant enough to cause discomfort to the occupants. An assessment of building motion is an essential prerequisite for serviceability.

2. Methodology

In order to study the effect of Wind on Tall Building with respect to Wind Force Coefficient (Cf), Drag Force, Lift Force, Across wind force etc., a tall building with different

---

*Corresponding author **Jigar K. Sevalia** is a Research Scholar, **Dr. Atul K. Desai** and **Dr. S. A. Vasanwala** are Professors.

geometric plan shapes having dimensions as shown in fig. 1 has been considered. The plan area of all geometric plan shapes of tall building is same. The height of the tall building considered is 300 m. To execute study, Computational Fluid Dynamics Code namely Fluent and Gambit have been used. The different geometric plan shapes of tall building considered are as follows,

1. Circular Plan Shape of Building (Model – 1)
2. Square Plan Shape of Building (Model – 2)
3. Swastik Plan Shape of Building (Model – 3)
4. Hexagonal Plan Shape of Building with Sharp Windward Edge (Model – 4)
5. Hexagonal Plan Shape of Building with Blunt Windward Edge (Model – 5)
6. Octagonal Plan Shape of Building with Sharp Windward Edge (Model – 6)
7. Octagonal Plan Shape of Building with Blunt Windward Edge (Model – 7)

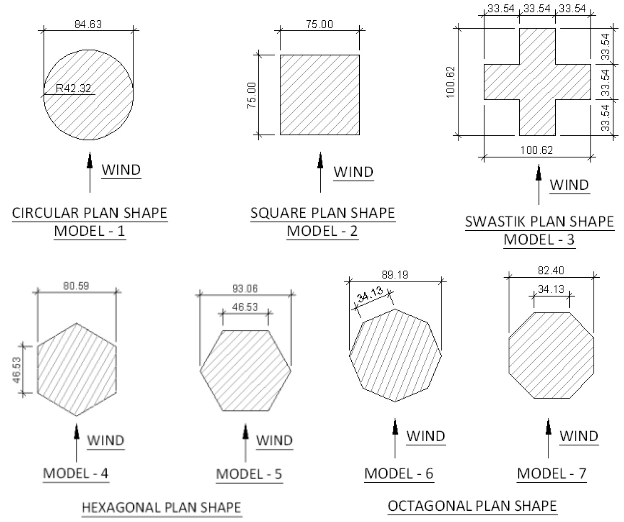


Fig. 1 Tall Building Geometry with Different Plan Shapes with Same Plan Area

2.1Governing Equations

The wind in the atmospheric boundary layer is turbulent and the wind velocity profile and its scale of turbulence are determined by the surface roughness of the ground (Cheng-Hu Hu *et al*,2005). A common practice of studying the turbulent wind is to decompose it into a quantity of mean wind velocity and its fluctuating components. Statistically, an instantaneous wind velocity at one direction can be considered as consisting of a mean value (U) with a fluctuating component (u') in which its mean value (u') is zero. With this manipulation, the time-averaged mean flow equations can be derived from the time-dependent Navier–Stokes equations.

The approaching wind was created from a power-law model to approximate the mean velocity profile (Cheng-Hu Hu *et al*,2005):

$$U(z) = U_G * \left[\frac{Z}{Z_G}\right]^{0.25} \tag{1}$$

The gradient height Z_G was assumed to be 900m and the mean wind velocity U_G at the gradient height was 57.91 m/s.

Since the *k*-ε model was used, the values of *k* and ε were required to account for the turbulence in the approaching wind. The turbulence intensity was assumed to be 12% at 20 m above ground. The root-mean-square value of the fluctuating wind at the longitudinal direction (Cheng-Hu Hu *et al*,2005) was obtained by

$$\sqrt{\overline{(u_1')^2}}=I*300 \tag{2}$$

Where I = 12 %

The other components u_2' and u_3' were assumed as following as no relevant experimental data is available.

$$\overline{(u_1')^2} = \overline{(u_2')^2} = \overline{(u_3')^2}$$

Therefore, turbulence kinetic energy (*k*) was calculated from

$$k = \tfrac{3}{2}(U \times I)^2 \tag{3}$$

This estimation can be crude though, it is one of the methods often suggested when the k–e model is used. Another suggestion to determine k is

$$k = (U \text{ X } I)^2 \tag{4}$$

Which is based on the assumption that

$$\overline{(u_2')^2} = \overline{(u_3')^2} = 0.5 * \overline{(u_1')^2}$$

The two Eqs. (03) and (04) are often used to calculate k if lacking the experimental data. Eq. (03) is a more conservative estimate, as it implies a higher level of turbulence in the approaching flow. In this study, the k was calculated from Eq. (03), since the conservative estimation was preferred for the external flow simulations (Cheng-Hu Hu *et al*,2005).

The other important value required is the dissipation rate ε; which can be obtained from the assumption that the wind is neutrally stratified and homogeneous in the surface layer, where the rate of energy production is approximately equal to its dissipation rate (Cheng-Hu Hu *et al*,2005), therefore

$$\varepsilon(z) = \frac{u_*^3}{\kappa z}, \tag{5}$$

Where, k = Von Ka´ma´n constant (=0.41)
u_* = Friction Velocity

The friction velocity can be calculated from,

$$k = \frac{u_*^2}{\sqrt{C_\mu}} \tag{6}$$

Where, Cμ = Constant = 0.09

2.2 Boundary Conditions

The boundary conditions for the computational domain is considered as follows,

- The ground at the bottom of the computational domain was simulated with a smooth wall using log law wall function.
- The free slip boundary conditions are applied to top and side surfaces of computing domain. The flux normal to the boundary is considered zero.
- The no slip boundary conditions are applied to the surfaces of Building Model.

2.3 Domain Size

There are no explicit rules dictating the size of a computing domain. Many researchers determine their domain size by a trial-and-error approach because the domain size does influence the computed results (Cheng-Hu Hu *et al*,2005). For this study, size of the computational domain considered is 1875 m X 1275 m X 900 m in the longitudinal (X), lateral (Z), and vertical (Y) directions, respectively.

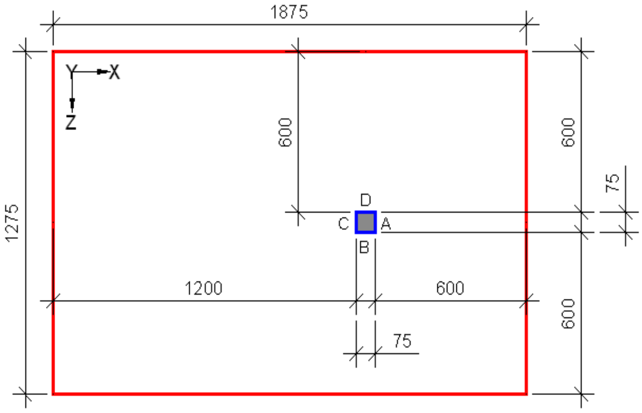


Fig. 2 View of Computational Domain along with Square Plan Shaped Tall Building in X-Z Plane (Horizontal Plane)

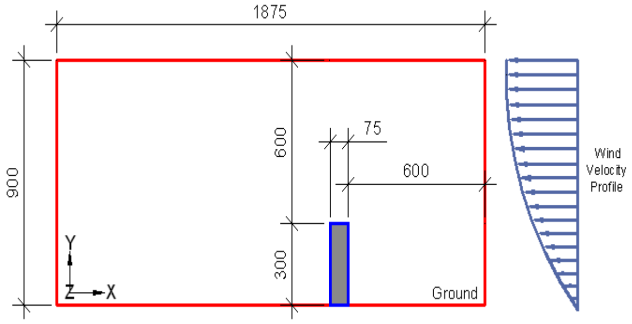


Fig. 3 View of Computational Domain along with Square Plan Shaped Tall Building in X-Y Plane (Vertical Plane)

2.4 Computational Grid

The computational grid is a key element in CFD since it determines the level of resolution of a flow field. 3-D Structured grids are created in the testing domains and 3-D unstructured meshes are arranged in the vicinity of Building Model (Shenghong Huang *et al*,2007). The grids in vertical plane are closely spaced near ground and coarser mesh is modeled away from ground. The Computational Grid Patterns for the Building Unit situated in computational domain is shown in fig. 4 and fig. 5,

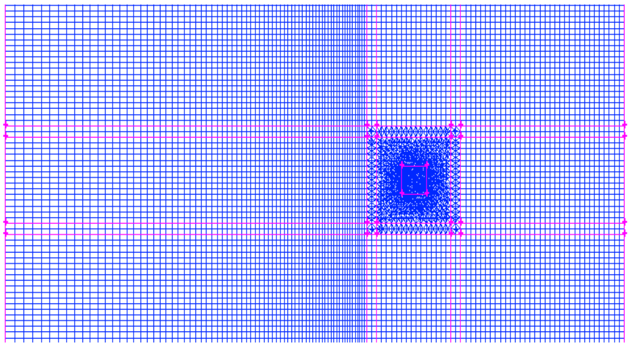


Fig. 4 Computational Grids in X-Z Plane (Horizontal Plane)

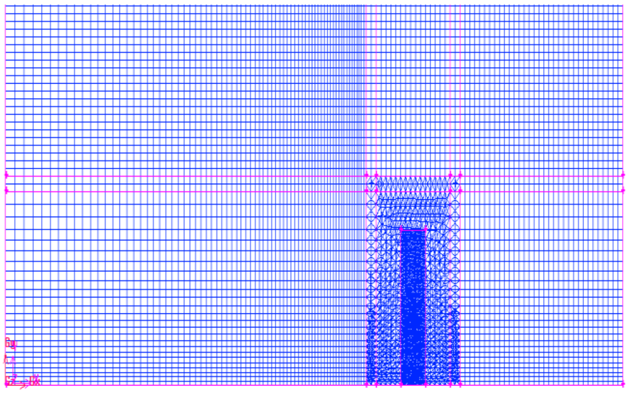


Fig. 5 Computational Grids in X-Y Plane (Vertical Plane)

2.5 Properties of Air

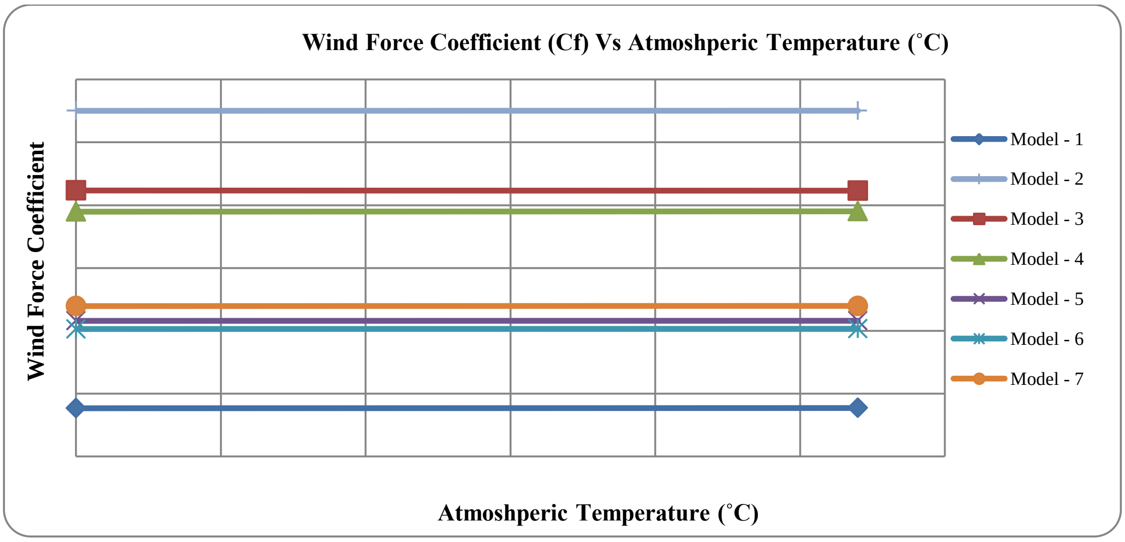
Different properties of air considered is as shown in table 1,

Table 1 Air Properties

Properties	**Temperature**	
	0° C (273 k)	27° C (300 k)
Density (ρ) - kg/m^3	1.293	1.1777
Specific Heat Capacity (Cp) – J/kg.K	1005	1005
Thermal Conductivity (W/m-K)	0.0243	0.0262
Kinematic Viscosity (kg/m.s)	1.33E-05	1.58E-05

Table 2 Wind Force Coefficient for Different Temperature Condition

Building Geometry	**Force Coefficient** 0˚ C (273 k)	27˚ C (300 k)	**% Difference**
Circular Plan Shape – Model 1	0.57667	0.57706	0.067
Square Plan Shape – Model 2	1.05021	1.05043	0.021
Swastik Plan Shape – Model 3	0.92334	0.92304	-0.032
Hexagonal Plan Shape with Sharp Windward Edge – Model 4	0.88962	0.89019	0.064
Hexagonal Plan Shape with Blunt Windward Edge – Model 5	0.71583	0.71596	0.018
Octagonal Plan Shape with Sharp Windward Edge – Model 6	0.70287	0.70317	0.043
Octagonal Plan Shape with Blunt Windward Edge – Model 7	0.73933	0.73964	0.042



Graph 1 Wind Force Coefficient (Cf) Vs Temperature (˚C)

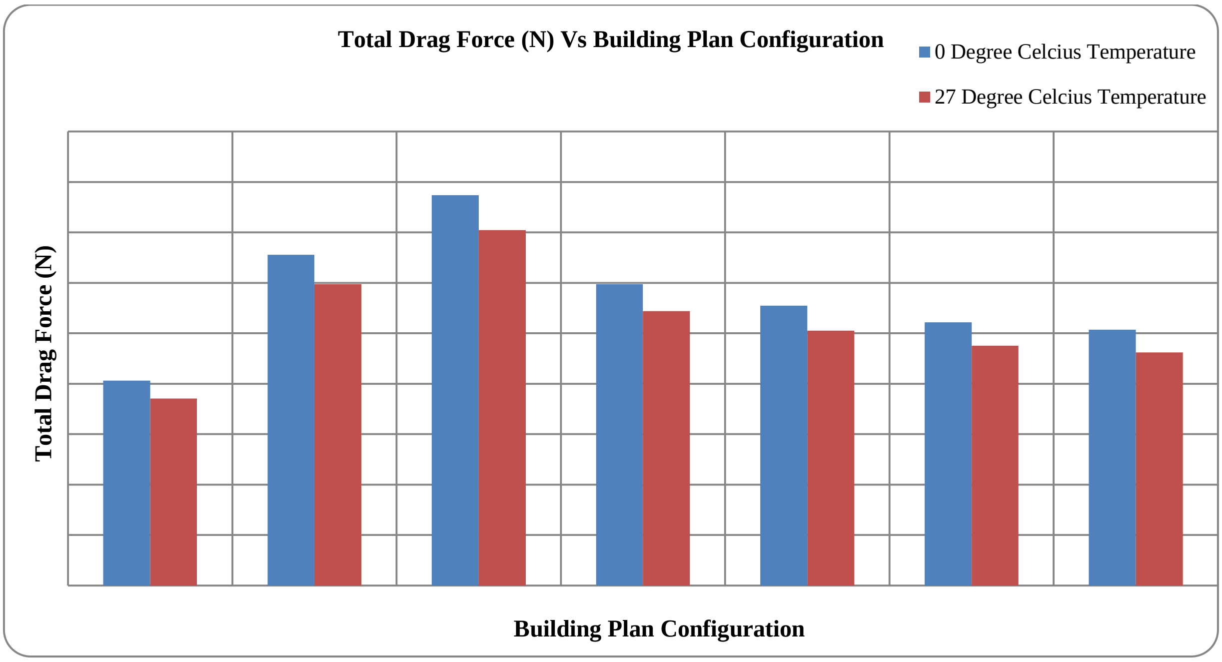
Table 3 Total Drag Force on Tall Building Geometry for Different Temperature Condition

Building Geometry	Total Drag Force 0˚ C (273 k)	27˚ C (300 k)	% Difference
Circular Plan Shape – Model 1	20323.34	18524.17	8.85
Square Plan Shape – Model 2	32800.59	29882.87	8.90
Swastik Plan Shape – Model 3	38689.25	35228.83	8.94
Hexagonal Plan Shape with Sharp Windward Edge – Model 4	29855.79	27211.82	8.86
Hexagonal Plan Shape with Blunt Windward Edge – Model 5	27740.48	25272.43	8.90
Octagonal Plan Shape with Sharp Windward Edge – Model 6	26105.77	23788.76	8.88
Octagonal Plan Shape with Blunt Windward Edge – Model 7	25369.28	23117.60	8.88

Results

The result consists of Wind Force Coefficient (Cf) and Drag Force on Tall Building due to interaction between wind and building under different temperature conditions.
The two different temperature conditions have been considered i.e. 0˚C and 27˚C for different Building Plan Shape Geometry. The Plan Area of each Tall Building Geometry is Constant i.e. 5625 square meter and Height of each Tall Building Unit is 300 meter.

The variation of Wind Force Coefficient for each Tall Building Geometry for different temperature condition as obtained by using CFD Code Fluent is tabulated in table 2 and also shown graphically in Graph 1.



Graph 2 Total Drag Force (N) Vs Building Plan Configuration

Table 4 Suggested Design Wind Pressure Equation for Different Atmospheric Temperature Condition

Atmospheric Temperature (°C)	Suggested Equation for finding Design Wind Pressure on Structures (*Pz*)
-30	$0.719 * Vz^2$
-20	$0.695 * Vz^2$
-10	$0.671 * Vz^2$
0	$0.646 * Vz^2$
10	$0.624 * Vz^2$
20	$0.602 * Vz^2$
30	$0.583 * Vz^2$
40	$0.563 * Vz^2$
50	$0.548 * Vz^2$
60	$0.533 * Vz^2$

From table 2 and table 3, it can be seen that increase in temperature from 0° C to 27° C doesn't make any more difference in wind pressure coefficient value. But it affects the total drag force acting on the building. Hence, it is necessary to develop an equation to calculate design wind pressure on surfaces of tall building considering properties of air in different atmospheric temperature conditions. Accordingly the suggested equation for design wind pressure (N/m^2) for the given design wind velocity (m/sec) will be as follows in table 4,

Conclusion

The study of effect of temperature on Wind Force Coefficient has been executed. The two different atmospheric temperature conditions have been considered to study the effect of temperature.

It has been found that the change in the value of wind force coefficient (Cf) is very negligible due to change in temperature. The reason is that due to change in temperature both static pressures on the surfaces of tall building and properties of air are changing simultaneously and according to definition of wind force coefficient, the change in the value of wind force coefficient is very negligible.

$$\text{Wind Force Coefficient} = \frac{\text{Static Pressure}}{{}^{1}\!/_{2} * \rho * v^2}$$

From the study, it can also be concluded that even though the change in temperature is not affecting the value of wind force coefficient (Cf), the total drag force acting on the tall building is changing along with temperature as shown in table 3. At low temperature, the total drag force on tall building is high due to the reason of high density of air at low temperature. At the same time, the total drag force on tall building is less due the low density of air at high temperature. Hence, the structural engineer has to consider the change in properties of air with respect to temperature to calculate the wind forces on the surfaces of building.

The equation for finding wind pressure on surfaces of structure based on research work shall be as mentioned in table 4 which take care of properties of air at different atmospheric temperature conditions.

References

Aishe Zhang, Cuilan Gao and Ling Zhang (2005), Numerical simulation of the wind field around different building arrangements, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 93, pg. 891–904.

Alexandre Luis Braun and Armando Miguel Awruch (2009), Aerodynamic and aeroelastic analyses on the CAARC standard tall building model using numerical simulation, *Computers and Structures*, Vol. 87, pg. 564–581.

Appupillai Baskaran and Ahmed Kashef , Investigation of air flow around buildings using computational fluid dynamics techniques, *Engineering Structures*, Vol. 18, No. 11, pg. 861-875.

Baskaran T. and Stathopoulos T.(1989), Computational Evaluation of Wind Effects on Buildings, *Building and Environment*, Vol. 24 , No. 4, pg. 325-333.

Cheng-Hu Hu and Fan Wang (2005), Using a CFD approach for the study of street-level winds in a built-up area, *Building and Environment* 40, pg. 617-631.

Gloria Gomes M., Moret Rodrigues A. and Pedro Mendes (2005), Experimental and numerical study of wind pressures on irregular-plan shapes, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 93, pg. 741–756.

Hoxeya R. P., Robertsona A. P., Basarab B. and Younisb B. A. (1993), Geometric parameters that affect wind loads on low-rise buildings: full-scale and CFD experiments, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 50, pg.243-252.

Lien F.S., Yee E. and Cheng Y. (2004), Simulation of mean flow and turbulence over a 2D building array using high-resolution CFD and a distributed drag force approach, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 92, pg. 117-158.

Swaddiwudhipong S. and Khan M.S.(2002), Dynamic response of wind-excited building using CFD, *Journal of Sound and Vibration*, pg. 735-754.

Shenghong Huang, Q.S. Li and Shengli Xu(2007), Numerical evaluation of wind effects on a tall steel building by CFD, *Journal of Constructional Steel Research*, Vol. 63, pg. 612–627.

Tore Wiik and Ernst W. M. Hansen(1997), The assessment of wind loads on roof overhang of low-rise buildings, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 67 & 68 , pg. 687-696.

Yoshie R., Mochida A., Tominaga Y., Kataoka H., Harimoto K., Nozu T. and Shirasawa T.(2007), Cooperative project for CFD prediction of pedestrian wind environment in the Architectural Institute of Japan, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 95, pg. 1551–1578.