NUMERICAL ANALYSIS OF WIND EFFECT ON HIGH-DENSITY BUILDING AERAS

Bin ZHAO, Ying LI, Xianting LI and Qisen YAN
Department of Thermal Engineering, Tsinghua University
Beijing, 100084, P.R. China

ABSTRACT

In this paper a new method called TSM was presented to analyze wind effect on high-density building areas. With TSM, a software named WEATHER is developed based on STACH-3. The wind effect on a simple building is simulated to validate STACH-3 for outdoor airflow. The wind effect to a real zone with 9 buildings is analyzed with WEATHER. It shows that TSM is an effective method to deal with high-density building areas. It takes an acceptable CPU time to get convergence.

KEYWORDS: CFD, Wind effect

INTRODUCTION

Wind velocities and wind-induced pressure on buildings have been considered as important design parameters. There are two main ways to obtain these parameters. One is from experiment, the other is from numerical analysis. It is expensive to do either full-scale experiment or wind tunnel experiment. And it is hard to get detailed data as well. With the development of computer and the advancement of CFD (Computational Fluid Dynamics) modeling, numerical analysis is becoming more and more important to evaluate wind effect on buildings.

Early investigation on wind effect with CFD is focused on a single building with simple geometry. There are few papers that simulate wind effect on buildings with complicated geometry, especially the buildings in high-density building areas. As the number of grids is great in these cases, it will take an unacceptable CPU time to get meaningful results.

METHODOLOGY

A new method called TSM (Two Step Method) was presented to deal with the problem. In TSM, the computational process is divided into two orders. In the first order, the chosen computational domain is large enough, maybe several times larger than the building area. Thus the boundary conditions are easy to describe, as the buildings have no influence on it. Complicated-geometry buildings are simplified as regular blocks. In the second order, the computational domain is just the area we concerned. The boundary conditions are provided by the results of the first order. As the grids in the first order is much larger than the grids in the second order, u,v,w (velocity in x,y and z direction respectively) of every grids on the boundary is given with interpolation method. Some other parameters, such as k (turbulent kinetic energy), ε (dissipation of turbulence) and pressure of every grid in computational domain are give with interpolation for the results of the first order as well. The geometry of buildings can be described in detail. This process can be repeated until satisfied results are obtained. With TSM, a software named WEATHEBT (Wind Effect Analysis Tool for High dEnsity Buildings with TSM) is developed based on the CFD software STACH-3.

This process can be schematically illustrated by figure 1.

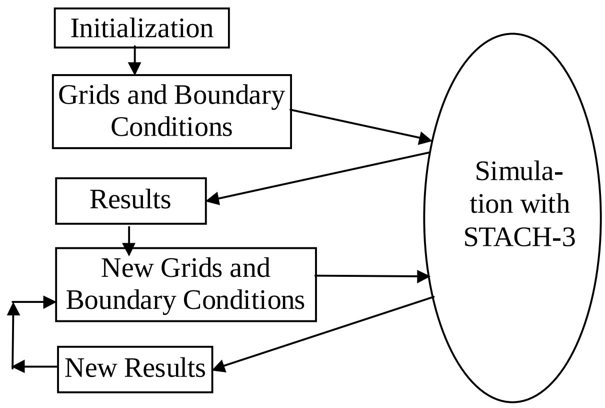


Fig. 1 Flowsheet of TSM method

VALIDATION OF STACH-3

STACH-3[1] is a three-dimensional CFD software developed by HAVC group at Tsinghua University. The standard k-ε turbulence model and finite volume method are adopted in this package. The algorithm is SIMPLE and the discretization scheme is staggered-grid system. The CFD equations are shown in appendix. Many experiences prove that it can simulate indoor airflow very well.

To validate STACH-3 for outdoor airflow simulation, the wind effect on a simple building is analyzed with STACH-3 package. And the predicted results are compared with those of wind tunnel experiment by SHUZO MURAKAMI *et al* [2]

A cube-shaped model, 200 mm in height, was used as the model of a building in the wind-tunnel experiment (See figure 2). The Reynolds number of the experiment was about 7×10^4.

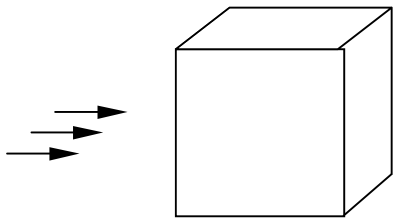
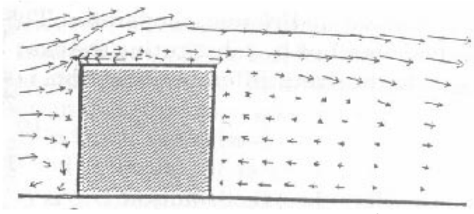


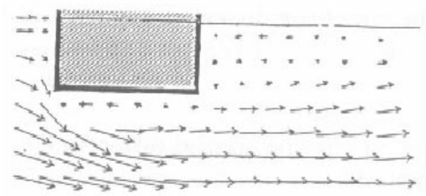
Fig.2 Cube-shaped building in wind tunnel experiment

The building in computation is the same as that of wind tunnel experiment. Upper stream direction is set as horizontal. And the profile of velocity is assumed to obey a power law [4] expressed as $U/Ug=(Z/Zg)^{0.28}$. The computation domain is 7, 4 and 3 times of the building's length, height and width, respectively.

Figure 3 shows the results of wind tunnel experiment [2] and figure 4 shows results of numerical simulation.

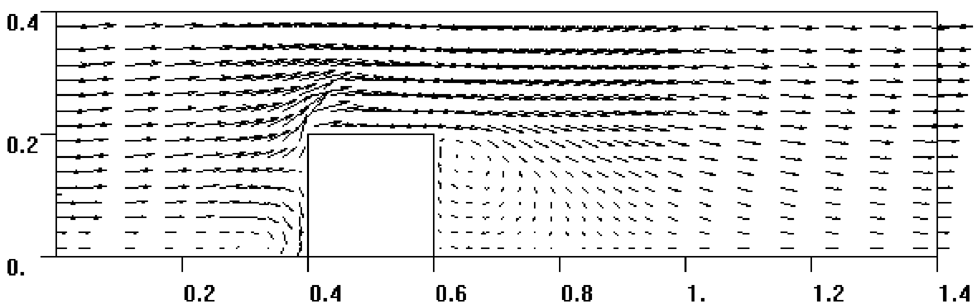


(a) Vertical section at the middle of building's width

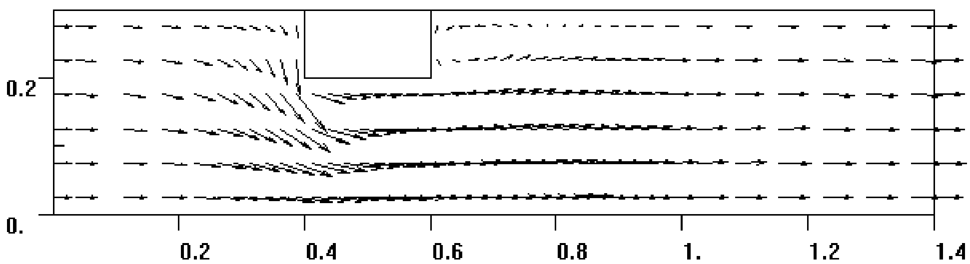


(b) Horizontal section at the middle of building's height

Fig. 3 Velocity field of wind tunnel experiment [2]



(a) Vertical section at the middle of building's width



(b) Horizontal section at the middle of building's height

Fig 4. Predicted wind velocity

Figure 3 (a) is the velocity field of the vertical section obtained from the wind tunnel experiment [2]. The figure shows that there is a stagnation point at about 2/3 of the building's height. There is a recirculation zone below the point. Above the point, air moves up and flows over the building. And there is a recirculation zone behind the building. Figure 4 (a) is the predicted velocity field of this section. And it shows a great similarity with figure 3 (a). The same thing happens between figure 3 (b) and figure 4 (b). That is to say, predicted results agree well with the experimental results.

This case study proves that STACH-3 can simulate outdoor airflow as well as indoor airflow.

SIMULATION AND ANALYSIS

Normally there are several arrangement styles of buildings in a zone: (1) array arrangement; (2)

stagger arrangement; (3) perimeter arrangement [3]. Here a real zone with 9 buildings arranged in array is analyzed with WEATHER (See figure 5).

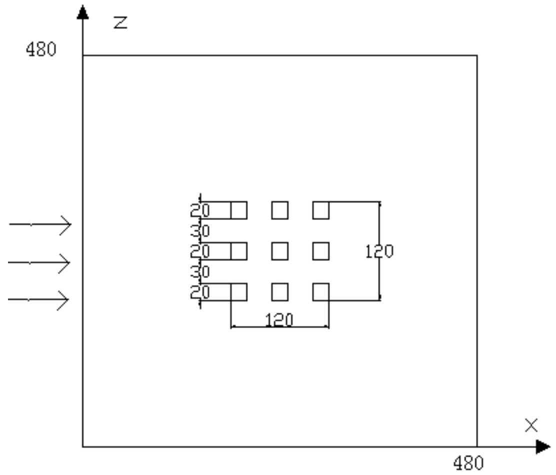


Fig.5 Computational domain

According to TSM, the computational domain is large enough and the buildings in the domain are simplified as regular blocks in the first order. In this case, the computational domain is 480m×240m×60m and the buildings are simplified as 20m×20m×40m blocks. Large windward length is to eliminate the effect of buildings on wind velocity and direction. It's a common method to solve this kind of problems. Thus the boundary conditions are easy to describe. Because of the roughness of ground and some other things, subaerial wind is exponential distribution, which is known as gradient wind (See figure 6). The inflow boundary conditions are from local weather data. The wind velocity is 5m/s at 10m height and the wind velocity at other height can be computed by $U/Ug=(Z/Zg)^{0.28}$ [4].

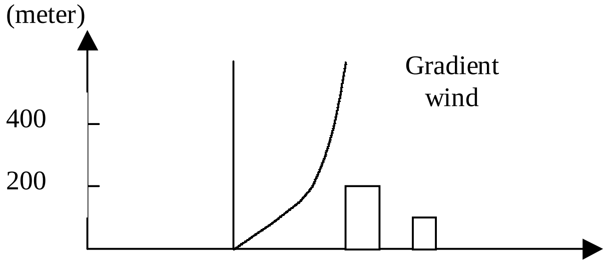
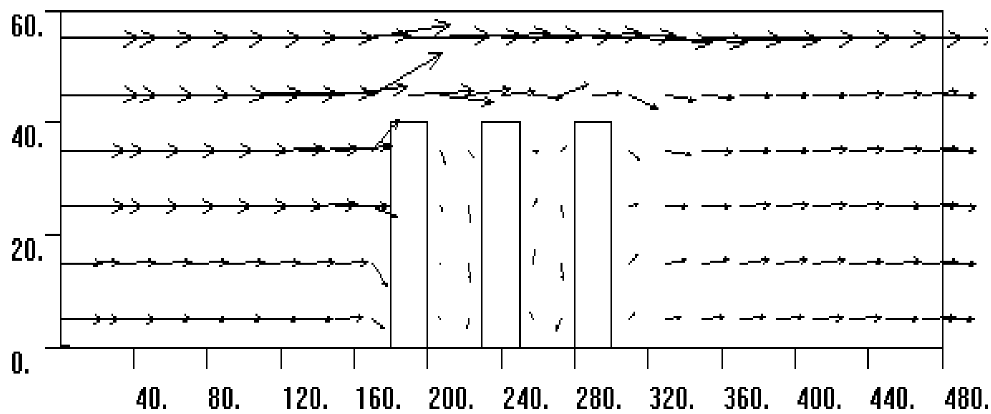
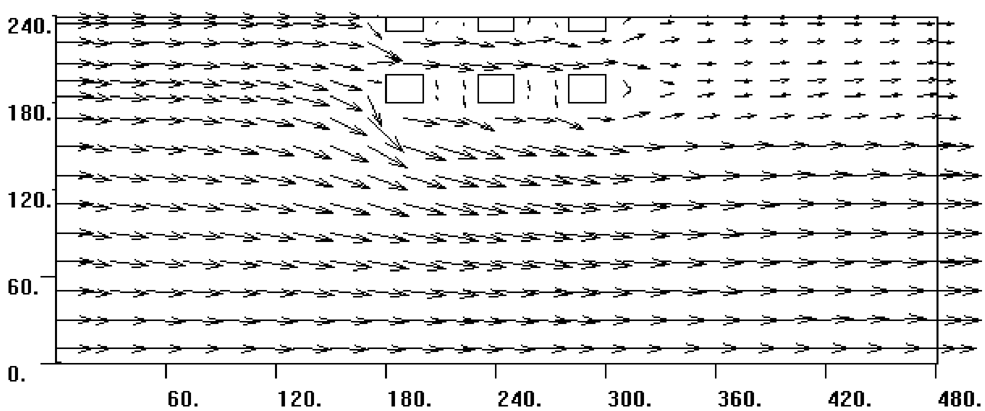


Fig.6 Gradient wind

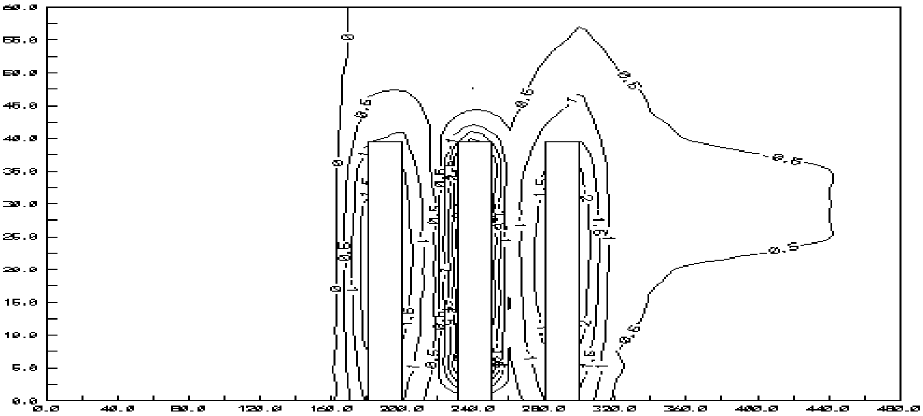
Figure 7 shows the results of the first order.



(a) Predicted velocity field (Vertical section at Z=190m)



(b) Predicted velocity field (Horizontal section, Height=5m)



(c) Predicted pressure field (Vertical section at Z=190m)

Fig.7 Predicted velocity field and pressure field of the first order

In the second order, the computational domain is reduced to the area around the building that is concerned. The geometry of the building can be described in detail to be closer to the real case. The boundary conditions in the second order are provided by the results of the first order with WEATHER package.

In this case, the computational domain is 80m×80m ×60m, which is much smaller than that of first order. The geometry of the building (See figure5, the building that have the symbol "A") is described in detail only to imitate the real building.

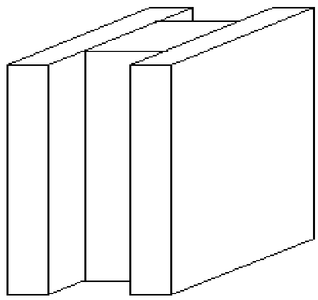
Figure 8 shows the geometry of the building.

The followings are grid number and CPU time of the two orders:

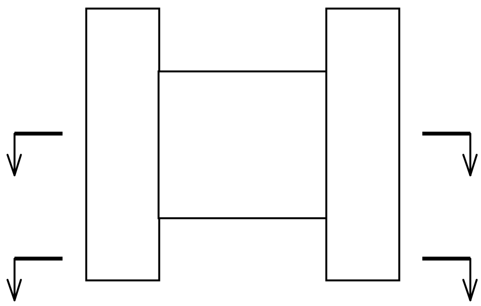
	grid number	CPU time
first order	27×8×16	1 hours
second order	22×14×22	2 hours

The computation is processed on a Pentium III PC with 128M RAM.

Figure 9 and figure 10 show the results of this step. Figure 7, figure 9 and figure 10 indicates that the recirculation before the building and the ambient flow around it in the second step are similar with those obtained in the first step. It shows that the results are reasonable and they agree well with the feeling of those people who live in the zone.

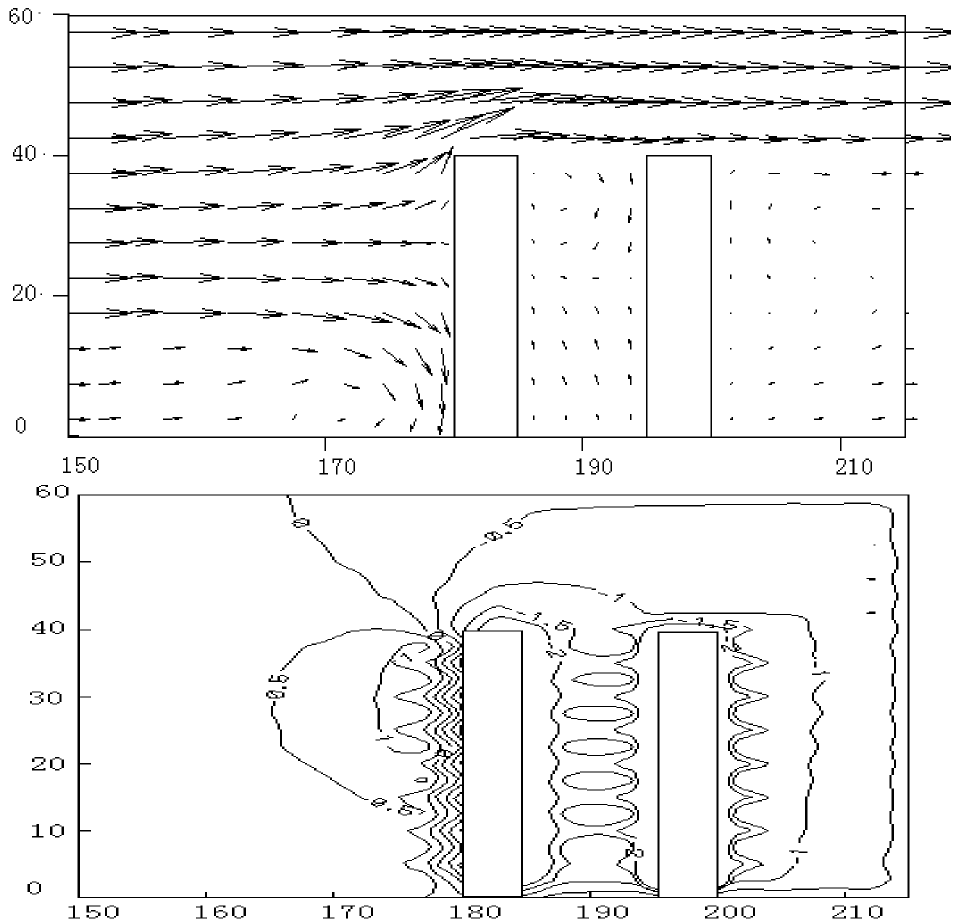


(a) Three-space graph

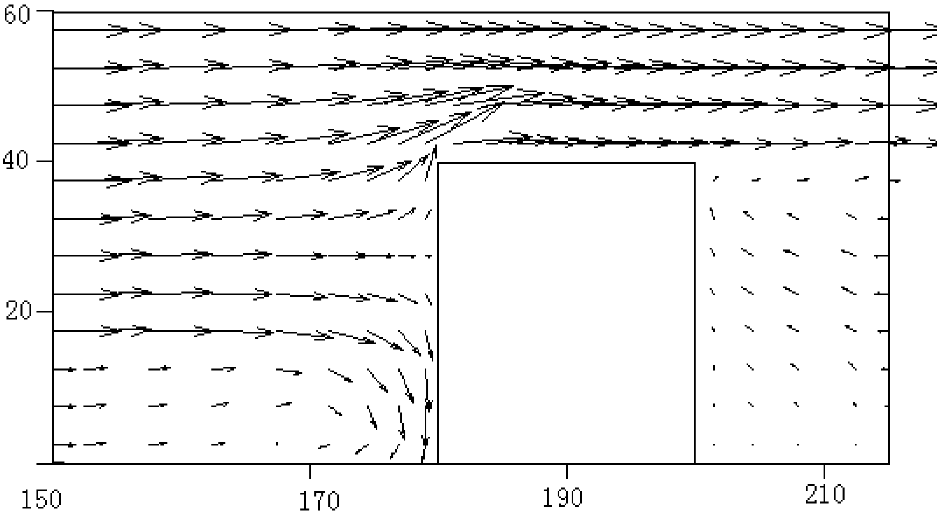


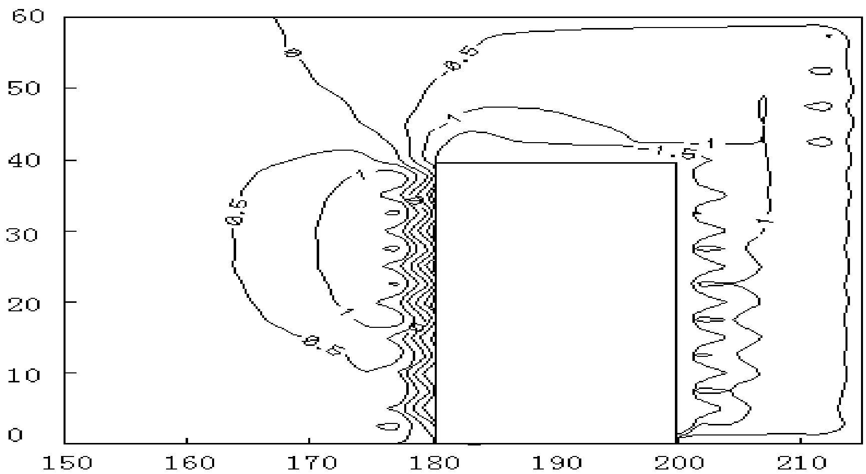
(b) Horizontal cutaway view

Fig.8 Geometry of the building



(a) Profile section 1-1(at Z=182.5m)





(b) Profile section 2-2(at Z=190m)

Fig.9 Predicted velocity field and pressure field around building (vertical section)

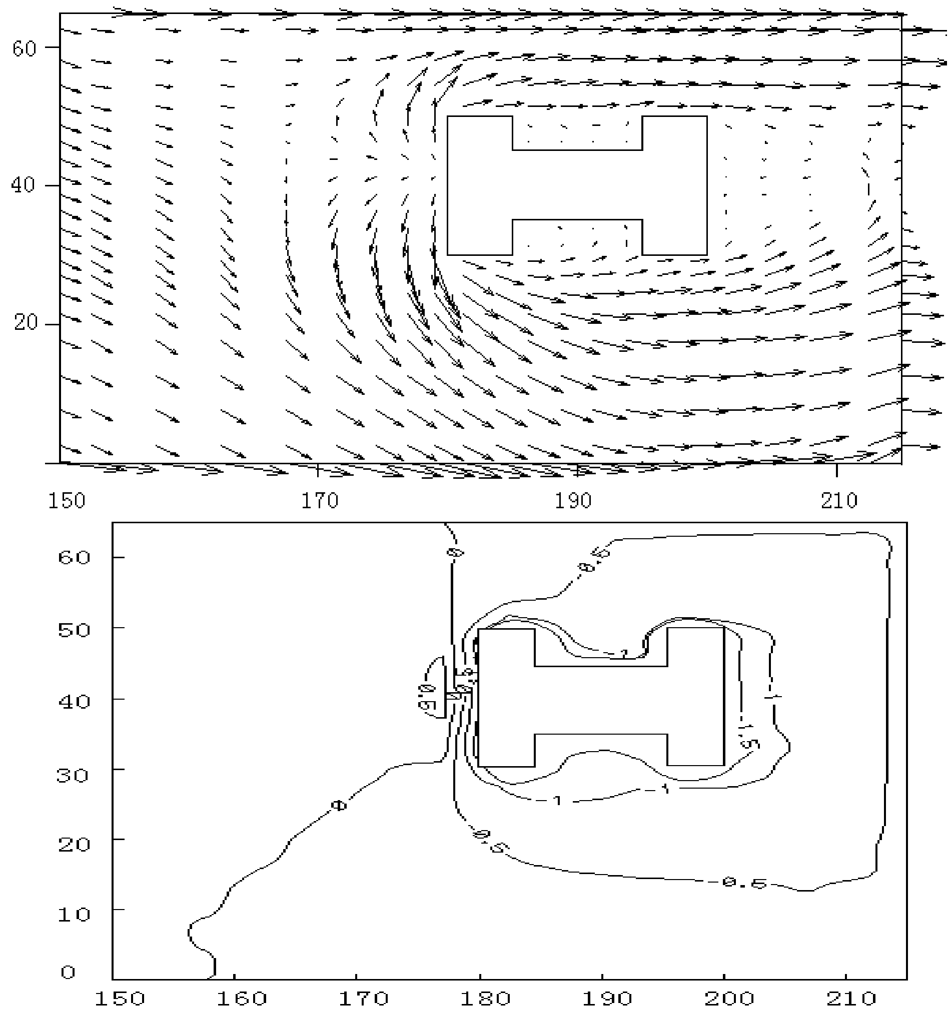


Fig.10 Predicted velocity field and pressure field around building (horizontal section, at the height=5m)

CONCLUSIONS

It shows that TSM is an effective and economical method to deal with high-density buildings. It takes an acceptable CPU time to get the parameters such as wind velocity distribution and wind-induced pressure. We can consider it a possible approach to analyze the wind effect to high-density buildings with complicated geometry.

As it is very difficult to make experiment in a zone with high-density buildings and the test results are strongly affected by the boundary conditions, the validation work is not easy to take. However, some experiments are needed to validate the TSM method and WEATHER. It will be done in future.

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[4] ZHOU, shuzheng and ZHANG, Chao, 1985. City Climate, East China Teaching University Press

APPENDIX

The CFD equations can be written in general format as following, which include mass, momentum, energy conservation equations.

$$\frac{\partial}{\partial t}(\rho\varphi) + div(\rho \vec{u} \varphi - \Gamma_\varphi grad\varphi) = S_\varphi$$

The details are as following:

φ	Γ_φ	S_φ
1	0	0
u	μ_{eff}	$-\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial x}) + \frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial x}) + \frac{\partial}{\partial z}(\mu_{eff}\frac{\partial w}{\partial x}) + g_x(\rho - \rho_{ref})$
v	μ_{eff}	$-\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial y}) + \frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial y}) + \frac{\partial}{\partial z}(\mu_{eff}\frac{\partial w}{\partial y}) + g_y(\rho - \rho_{ref})$
w	μ_{eff}	$-\frac{\partial p}{\partial z} + \frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial z}) + \frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial z}) + \frac{\partial}{\partial z}(\mu_{eff}\frac{\partial w}{\partial z}) + g_z(\rho - \rho_{ref})$
k	$\frac{\mu_{eff}}{\sigma_k}$	$G_k - \rho\varepsilon$
ε	$\frac{\mu_{eff}}{\sigma_\varepsilon}$	$\frac{\varepsilon}{k}[G_k C_1 - C_2\rho\varepsilon]$
h	$\frac{\mu_{eff}}{\sigma_h}$	S_h
$\mu_{eff} = \mu_l + \mu_t \qquad \mu_t = C_D\rho k^2 / \varepsilon$		
$G_k = \mu_t\{2[(\frac{\partial u}{\partial x})^2 + (\frac{\partial v}{\partial y})^2 + (\frac{\partial w}{\partial z})^2] + (\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x})^2 + (\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z})^2 + (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})^2\}$		
$C_1 = 1.44, C_2 = 1.92, C_D = 0.09, \sigma_k = 1.0, \sigma_\varepsilon = 1.3, \sigma_h = 1.0, \sigma_Y = 1.0, \sigma_\tau = 1.0$		