CFD Simulation On The Pressure Distribution For An Isolated Single-Story House With Extension: Grid Sensitivity Analysis

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Abstract. Damage due to wind-related disasters is increasing due to global climate change. Many studies have been conducted to study the wind effect surrounding low-rise building using wind tunnel tests or numerical simulations. The use of numerical simulation is relatively cheap but requires very good command in handling the software, acquiring the correct input parameters and obtaining the optimum grid or mesh. However, before a study can be conducted, a grid sensitivity test must be conducted to get a suitable cell number for the final to ensure an accurate result with lesser computing time. This study demonstrates the numerical procedures for conducting a grid sensitivity analysis using five models with different grid schemes. The pressure coefficients (Cₚ) were observed along the wall and roof profile and compared between the models. The results showed that medium grid scheme can be used and able to produce high accuracy results compared to finer grid scheme as the difference in terms of the Cₚ values was found to be insignificant.

1. Introduction

Currently in Malaysia, people are not aware of the wind-related disasters. Therefore, they did not take into consideration the possibility of wind-related disasters when constructing a building especially in rural areas. However, there is an increase in the number of wind-related disasters [1] due to the global climate change. This phenomenon climate has resulted in significant increase in the numbers of very unusual windstorms in Malaysia. According to Goldman et al. [2], windstorm is a storm in which the primary hazard comes from the speed of the wind. It is categorized into three types namely cyclone (including tropical and extra-tropical storms), local windstorm (tornadoes and thunderstorm) and downslope windstorm. The roof of a house generally receives the largest wind load thus most vulnerable to wind damage. The slope of the roof, overhang roof and gap height between the core house and the kitchen house is some of the factors that might cause severe damage to the roof based on the survey conducted by Zaini et al. [3].

The effect of wind flow over a structure can be investigated using laboratory tests (full scale and wind tunnel) and numerical simulation (Computational Fluid Dynamics). Experimental investigation produced immediate results but the assembly and the instrumentation can be very costly. The use of
numerical simulation is relatively cheap but requires very good command in handling the software, acquiring the correct input parameters and obtaining the optimum grid or mesh. Good quality grid reduces the errors, produces high order accuracy [4] but at the same maintain a reasonable computational time [5]. The use very fine grids generally resulted in highly accurate result but can consume extremely longer computational time. As such, the sensitivity of the grid must be tested accordingly. This paper demonstrates the numerical procedures and the results from a grid sensitivity analysis.

2. Computational Method
The computational method was divided into two parts. Firstly, the construction of building models using Gambit 4.6, followed by the analytical part using ANSYS Fluent 14.

2.1. Construction of Building Models
The basic model consisted of an isolated single storey gable-roof house with extended kitchen house as shown in Figure 1. The dimensions of the basic model were obtained from Zaini et al. [3] and reflected the general dimensions of rural houses in the Northern region of Peninsular Malaysia. Franke et al. [6] suggested that a grid sensitivity test should be conducted to quantify the influence of the grid resolution on the solution. They also recommend that at least three systematically and substantially refined grid should be conducted. However, in order to have a better understanding on the effect of the sensitivity analysis, five different grid resolutions were generated. The differences between all models were reflected in the number of computational grids. The models were labeled as having either very coarse, coarse, medium, fine and very fine grid representing 2177280, 3339600, 4528800, 5692500 and 7044800 number of grids, respectively.

2.1.1. Computational Domain and Boundary Condition. The surrounding of the models was cut off by the computational domain and represented as a boundary condition as shown in Figure 2. The top boundary was extended 9H vertically from the ground of the model and 9H from the side walls. H is the height of the house model and set to be 4 m. On the other hand, the inlet and outlet boundary were extended 6H and 16H from the wall, respectively. The size of the domain was built based on recommendation by Franke et al. [6] and Tominaga et al. [7]. The blockage ratio for this arrangement was calculated to be 2.97%. This value is below than 3% as recommended by Tominaga et al. [7] and Baetke et al. [8].
Symmetrical boundary conditions were applied to the top and lateral boundaries in order to create a parallel flow. In CFD simulations, the roughness length was expressed as equivalent to sand-grain roughness where the roughness height, \( k_s \) and roughness constant, \( C_s \) were taken as 0.035 mm and 0.5, respectively.

Figure 2. Computational domain and boundary condition for CFD analysis a) Side view, b) Plan view

2.1.2. Meshing. A structured grid with hexahedra cells was developed for the computational domain. Hirsh et al. [9] reported that hexahedra cells were more preferred over tetrahedral cells as the former were known to generate smaller truncation errors and display better iterative convergence.

For efficient computation of turbulence, the computational grid must be in good quality especially around the area of interest since the computational results depend crucially on the grid hence. As such, the mesh arrangement was made finer at the house. This approach ensures the correct reproduction of the characteristics of separating flow near the roof and walls [7]. High meshing smoothness and fine quality meshing produces more accurate result for the simulation but it takes a longer computational time. To overcome this issue, the region located away from building was meshed with a coarser structured mesh. A growth factor ranging from 1.06 until 1.13 was used to increase the cell size away from the building. A ratio between two conservative cells should not exceed 1.2 [10][11] and 1.3
[6][7] when the cells are stretched were suggested. Figure 3 shows the example of the overall mesh of the model.

![Mesh arrangement within the computational domain showing a) 3D view, b) Side view, c) Plan view](image)

**Figure 3.** Mesh arrangement within the computational domain showing a) 3D view, b) Side view, c) Plan view
2.2. Computational Analysis
The wind velocity was set to be 26.4 m/s representing the equivalent speed for storm at 10 m above ground, as stated in the Beauford Scale. For a flow through a rectangular domain, the appropriate boundary condition at the inlet was governed by Equation (2.1), (2.2), (2.3) and (2.4) [11].

\[ U(z) = U_h \left( \frac{z}{z_h} \right)^\alpha \] (2.1)

where,
- \( U(z) \) = Wind speed
- \( U_h \) = Wind speed at height, \( z_{ref} \)
- \( z \) = Height
- \( z_h \) = Reference height
- \( \alpha \) = Wind shear exponent

\[ k(z) = \frac{u_*^2}{\sqrt{C_\mu}} \] (2.2)

where,
- \( k(z) \) = Turbulent kinetic energy
- \( u_* \) = Friction velocity
- \( C_\mu \) = Constant, 0.09

\[ \varepsilon(z) = \frac{u_*^2}{K(z + z_o)} \] (2.3)

where,
- \( \varepsilon(z) \) = Turbulent dissipation
- \( u_* \) = Friction velocity
- \( K \) = Von Karman constant, 0.4
- \( z \) = Height
- \( z_o \) = Roughness length

\[ u_* = \frac{KU_h}{\ln \left( \frac{h + z_o}{z_o} \right)} \] (2.4)

where,
- \( u_* \) = Friction velocity
- \( K \) = Von Karman constant, 0.4
- \( U_h \) = Reference height
- \( h \) = Height
- \( z_o \) = Roughness length

The mean stream wise velocity of the approaching flow obeyed a power law with an exponent of 0.25, corresponding to an open terrain. Turbulence model of RNG k-\( \varepsilon \) was used in following the recommendation by Tominaga et al. [13] and Quan et al. [14] due to its better performance and computational time saving. For all the transport equations (pressure, momentum and turbulence) second-order differencing was used together with a “SIMPLE” pressure-velocity coupling approach.
This setting was recommended by Abohela et al. [10], Montazeri & Blocken [11], Tominaga et al. [13] and Irtaza et al. [15]. A total of 5000 steps of iteration were used in this study. The computational results were considered as converged when all the scaled residuals levelled off and reached a value ranging from $1 \times 10^{-4}$ until $1 \times 10^{-7}$.

3. Result and Discussion

In this grid sensitivity analysis, five models with increasing number of grid were generated and analysed. The static pressure obtained from ANSYS Fluent 14 was converted into pressure coefficient $C_p$ following the recommendation by Tominaga et al [13]:

$$C_p = \frac{P_S}{0.5 \times \rho \times U_h^2}$$

where,
- $C_p$ = Pressure Coefficient
- $P_S$ = Static Pressure
- $\rho$ = Air Density
- $U_h$ = Reference Height

The $C_p$ obtained from all five models is tabulated in Figure 4. It can see that all five models showed a similar trend of $C_p$ distribution along the profile of the wall and roof. In Zone A, B and C the $C_p$ showed positive values. Lower pressure was observed in Zone B due to the suction effect. A sudden drop in $C_p$ values occurred to the development of high suction in Zone D. However, the suction effect reduced in Zone E.

Due to the difference in the total grid numbers, the differences in terms of the magnitude of $C_p$ values are noted especially in Zone A, C and D. In general, the medium, fine and very fine grid scheme showed consistent values compared to the very course and course grid scheme. This finding suggests that medium grid scheme can be used in further analysis instead of the finer grid scheme because the difference in terms of the $C_p$ values was found to be insignificant.
4. Conclusion
From this grid sensitivity test that has been conducted, it can be concluded that a medium grid scheme was acceptable to be used in further analysis. This finding is particular true because with a moderate number of cells, it can produce a similar result with a model that has a larger number of cells and at the same time reduce the computational time.

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6. References
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