Numerical Study of Pollutant Dispersion Within Urban Canyons

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Abstract— The purpose of this paper is to simulate different idealized configuration of Malaysian’s urban canyon to evaluate and determine which layout has the best natural ventilation. It is found that the porous region of the tree crown acts as obstacles that restrict air flow, preventing air pollutant to disperse into the above-roof environment and hence reducing the air quality within the urban canyons.

Keywords— Pollution dispersion, Computer simulation, Urban streets, Natural ventilation

1. Introduction

Natural air ventilation of urban canyons is becoming one of the most important factors to ensure a healthy air quality of urban canyon. The main source of air pollution in urban canyons is the ongoing traffic exhaust gas emitted from ground vehicles [1]. As the number of ground vehicles increases every year, the amount of air pollution emitted also increase drastically.

Therefore to ensure good air quality of those urban canyons, many studies have been done experimentally and numerically to determine the best natural ventilation of urban canyons and provide solutions to improve the air quality. For example, research done by Žajić, et al. illustrates the wind flow through an idealized urban canyons of different building height and distance between the buildings [2]. In his study, the vortex regimes formed in between different layout of idealized urban canyons are presented in Fig. 1a.

However, those studies fail to take into consideration the aerodynamics effect of tree crown [1]. Alternatively in studies done by Salim [1], number of simulation done numerically have provided evidences that due to the porous nature of tree crowns, air pollutions which suppose to disperse into the atmosphere, are trapped and accumulated instead. In his simulations, European layout – equivalent in height of the trees and buildings, was chosen to be his case for simulation as shown in Fig. 1b.

2. Methodology

An explanation of the meshing of computational domains and the different boundary conditions (with pollution emission) are shown and discussed in this section.

2.1 Boundary Condition

By referring to wind tunnel measurement data (CODASC data base,) [3] and research paper done by Salim [1] as benchmark, the computational domain of the area of interest has been designed as shown in Fig. 3. To enable the dispersion of air pollution to be capture easily, sulphur hexafluoride (SF6) was chosen as the “air pollutant” since its used as a tracer gas [1]. The figure below shows the meshes of the boundary condition. While the rectangle region represent trees species of Acacia Mangium [5], it is clear that most of the meshes focus around the building area. To determine whatever Asian trees are able to prevent the dispersion of air pollution, the pollutant concentration of the windward building are recorded and compare with 2 configurations, urban canyon with trees and another is without trees.

Fig. 1. Examples of European Urban Canyon Configuration (a and b)

In this paper, numerical simulations are done to study the aerodynamic aspect of Asian urban configuration which is referring to a Kuala Lumpur urban canyon shown in Fig 2. With the tree are much higher than the building, a study regarding if the height different between European and Asian trees configuration will affect the dispersion of air pollution within urban canyon.

After the simulations are done, recommendations are provided to improve the air ventilation of the urban canyons.
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The table below summarizes the boundary condition of this paper.

<table>
<thead>
<tr>
<th>Table 1. The Boundary Condition of the Computer Simulation [5]</th>
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<tr>
<td><strong>Parameters</strong></td>
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<tr>
<td>Inlet Velocity (ms$^{-1}$)</td>
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<td>Roughness Length, $Z_o$ (m)</td>
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<td>Turbulence Model</td>
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<td>Tree Height, $h$ (m)</td>
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<tr>
<td>Porosity, $P_{ref}$ (%)</td>
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</table>

2.2. User Defined Function

Therefore to increase the realism of the simulation, not only the meshes must be fine at the near-wall region, User Defined Function (UDF) is used to create a velocity profile. The profile is plotted by using power law equation:

$$\frac{u(z)}{u(z_{ref})} = \left( \frac{z}{z_{ref}} \right)^\alpha$$ (1)

Where $u(z)$ is the mean velocity at height of $z$ (m) while $u(z_{ref})$ is the mean wind speed at a certain reference height, $z_{ref}$ and $\alpha$ represent a constant of 0.3. [6]

3. Result and Discussion

Fig. 5. demonstrate the velocity contour of Large Eddy Simulation (LES) of the Asian urban canyons. As wind passes through obstacle such as buildings and porous region of the tree crown, the aerodynamic drag forces of those obstacles will causes the flow to lose its kinetic energy as work [7] as its used to overcome the aerodynamic drag force and shown in fig.6. By comparing the result, it is clear that the porosity of the trees diverged wind flow away from the building, causing a low velocity flow at the windward building. Due to this, the air pollutions emitted in between the building are trapped and hence cannot disperse into the atmosphere. This proves that even Asian trees prevent the dispersion of air pollutions.

4. Conclusion

The aerodynamic of the trees have direct impact on the natural ventilation of urban canyons. The porous region of the trees will act as an obstacle, directing air flow away from the urban canyons into the above-roof region and hence restricting the dispersion of air pollution. Therefore, tree-free urban canyons are much more likely to have a good quality of air compared to urban canyons with trees.

References