MB3 Assessment of the Influence of Urban Parameters on Ventilation Efficiency in the Urban Environment

都市形状が都市の換気効率へおよぼす影響の評価

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Abstract: A suitable countermeasure to reduce the effect of the urban heat island (UHI) is to harness the wind by better urban spaces designs. In this study, ventilation efficiency (VE) indices are used to assess the ventilation performance within urban domains. The local age of air, the purging flow rate and the air exchange efficiency were the VE indices used. Computational Fluids Dynamics (CFD) simulations were carried out using OpenFOAM 4.0 for two systematic analyses. First, the VE indices of two actual urban environments with contrasting characteristics and second, three idealized urban models with symmetric geometry (regular urban environment) to evaluate their sensitivity of the urban parameters, were studied. The results illustrated that the height and number of buildings influence on the VE indices, and how wider streets are directly linked with better ventilation performance.

Keywords: Urban heat island, Natural wind, Ventilation efficiency indices, CFD

1. Background

The UHI is an issue of special interest, since half of the population of the world is currently living in urban areas and more people is expected to move in the following years. One of the strategies to countermeasure the UHI is by harnessing the wind, through suitable urban planning. However, how good the removal of heat or pollution is by the air hasn't been satisfactorily defined, so VE indices are used to evaluate the ventilation performance and air quality for outdoor [1)]. The VE indices represent a practical methodology, but their application in real scenarios requires further analyses. In this study, three VE indices namely the local age of air (LAA) defined as the time taken by fresh air to replace old air after it enters a given zone, the purging flow rate (PFR) net rate by which the pollutants are flushed out the domain and the air exchange efficiency (AEE) as the efficiency in providing rural air into the urban canopy, are considered. The aim of this research is by means of VE indices describe the behavior of the wind within the urban environment and to evaluate the urban ventilation based on different configurations of urban spaces.

2. Methodology

In this study, OpenFOAM version 4.0 was chosen as the Computational Fluids Dynamics (CFD) tool. The standard k-ε model was employed to simulate the turbulent flow, with assumptions such as incompressible, isothermal, steady state and no external forces. Also, the equation of passive scalar transport was presented but at unsteady state. The conservation equations of mass and momentum, and the scalar transport equation were discretized by finite volume method. To assess the VE of actual urban environments with contrasting characteristics, Hiranomachi (34.69N, 135.50E) and Maishima (34.66N, 135.40E) were selected (Figure 1): The calculation domain size was x: 1000 m, y: 1000 m, z: 180 m, analysis domain x: 177 m and y: 183 m and approx. 3.4 million hexahedral cells were generated. The systematic analysis was carried out, with three symmetric arrays (regular urban environment, Figure 2). The calculation domain size was x: 984 m, y: 984 m and z: 330 m, analysis domain x: 192

m and y: 192 m, and approx. 4.7 million of hexahedral cells were generated. The boundaries conditions were the same for the two urban environments: power law boundary condition in the inlet (west), with a reference wind velocity of 3 m/s at 10 m height. For all solid surfaces the no-slip boundary condition was used. For the east (outlet) boundary, the zero gradient boundary condition was employed. The concentration was set constant at zero for the inlet and a source of homogenous emission of 1 mg/m^3/s in the analysis domain from z: 0 m to z: 4 m.

3. Results and discussion

For the actual urban environment (Table 1), the LAA for Hiranomachi and Maishima indicate that the height and number of building influence on the capacity of the wind to refresh the urban area. The PFR results show that contaminants are removed at higher rate in Maishima because the concentration is lower than Hiranomachi. The AEE pointed out that the wind coming from the west is not able to flush away the contaminants in the analysis domain. For the regular urban environment (Table 2), the LAA results indicate that the wider the street the lower the LAA. The PFR show that narrower streets and higher number of buildings require more volume of air to purge the contaminants. Our AEE calculation results indicated the wind flow and mass rate from the top of the analysis domain influence on the VE.

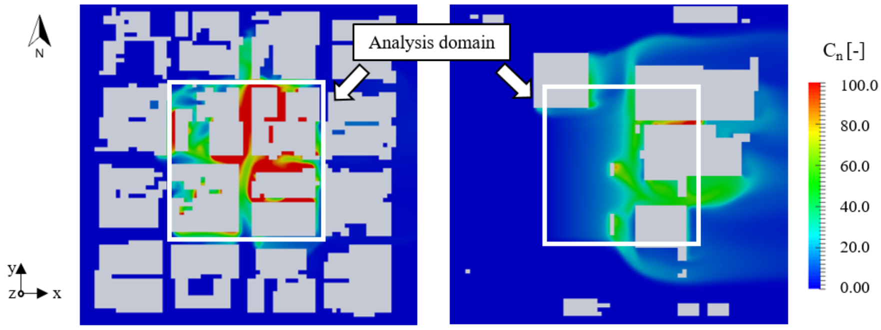

Figure 1 Actual urban environment, Hiranomachi (left), Maishima (right)
Concentration field at steady state, City domain view x:355 m y:365 m

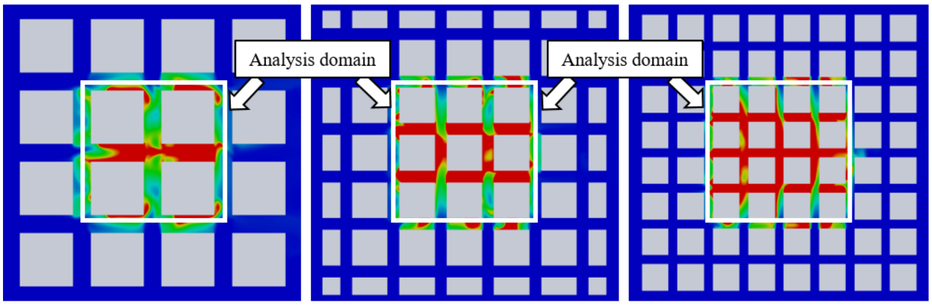

Figure 2 Regular urban environment, Case A (left), Case B (center), Case C (right)
Concentration field at steady state, City domain view x:384 m y:384 m

Table 1 Actual urban environment

	Local age of air (s)	**Purging flow rate (m^3/s)**	**Air exchange efficiency (%)**
Hiranomachi	65.34	712	7
Maishima	26.49	3324	14

Table 2 Regular urban environment

	Local age of air (s)	**Purging flow rate (m^3/s)**	**Air exchange efficiency (%)**
Case A	68.82	937	30
Case B	96.35	670	31
Case C	110.52	584	38

4. Conclusions

This work has demonstrated that the local age of air, the purging flow rate and the air exchange efficiency as VE indices can describe the relationship between geometrical characteristic of the urban environment and the wind, so they help develop countermeasures for the UHI.

Regardless of the advantages of VE indices, further research is required to clarify the AEE viability when it is applied to outdoor ventilation.

References

1) Bady, M., Kato, S., K., Huang, H., *Towards the application of indoor ventilation efficiency indices to evaluate the air quality of urban areas*. Building and Environment 43 (2008), pages 1991-2004.