A NUMERICAL STUDY ON THE EFFECTS OF SKYSCRAPERS ON FLOW AND DISPERSION IN A METROPOLIS

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Abstract

The aim of this study is to investigate the effects of skyscrapers on the flow and dispersion characteristics in metropolitan area. For this, a three-dimensional computational fluid dynamics (CFD) model with the renormalization group (RNG) k-ε turbulence model is employed. To examine the skyscrapers effects, two building configurations (with/without skyscrapers) are considered. For each configuration, three cases with different ambient wind directions (westerly, southwesterly and southerly) are examined. In the absence of the skyscrapers, monotonous wind patterns are shown. The results show that the skyscrapers affected the variation of flow field nearby significantly. Within the skyscrapers, wind speed increased compared with that in the case without the skyscrapers. The increase in wind speed, channeling effect, is caused to satisfy the mass continuity. On the other hand, at the downwind region, wind speed decreased compared with that in the case without the skyscrapers due to the drag effect of the skyscrapers. The results of the dispersion model assuming the line sources with the constant emission rate showed that increased at the downwind region after construction of the skyscrapers.

Key words : CFD model, Pollutant concentration, Skyscrapers

1. INTRODUCTION

The global proportion of urban polulation rose from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005 (World Urbanization Prospects : The 2005 Revision). In addition, it is prospected that urban population will reach 60% (4.9 billion) by 2030 and more than 6 billion people will reside in urban area. As the polulation density increases in urban area, the buldings located in a residential and commercial areas become higher. For identifying the effects of the skyscrapers on the surrounding atmospheric environment and preventing possible damages due to the construction of skyscrapers, assessments of environmental impact are needed. There are many studies that were performed on the flow and dispersion in urban street canyons by means of field measurements (Rotach, 1995), laboratory-scale physical experiments (Baik et al., 2000; Uehara et al., 2000; Liu et al., 2003; Kim and Baik, 2005), and numerical modelling (Lee and Park, 1994; Sini et al., 1996; Baik and Kim 1999; Kim and Baik 1999, 2001) during the last decades. Field and laboratory experiments have provided valuable data for numerical model validation, carried out under the limited condition. However, there are limitations to examine the effects of buildings in real urban areas on flow and dispersion. Numerical models are very useful in investigating more detailed characteristics of real urban flow and dispersion phenomena. In this study, the effects of the skyscrapers on flow and dispersion in a metropolis and examined using a computational fluid dynamics model.

2. EXPERIMENTAL SETUP

In this study, a computational fluid dynamics (CFD) model developed by Kim and Baik (2007) is used. The model assumes a three-dimensional, non-hydrostatic, non-rotating, and incompressible flow system and considers Reynolds averaged momentum equation, mass continuity equation and transportation equation. For investigating the effects of skyscrapers on urban flow and dispersion, a building congested area around the Konkuk university in Seoul is chosen. Recently, skyscrapers were constructed beside the Konkuk university. To examine the skyscrapers effects, two building configurations (with/without skyscrapers) are considered. For each building configuration, three numerical experiments are performed for different ambient wind direction (westerly, south-westerly, and southerly). The model domain sizes are 1700m, 1700m, and 960m in the x-, y-, and z-direction respectively. The horizontal grid sizes are 10m. The vertical grid sizes are uniform up to the 36^{th} layer (5m) and it increases with the expansion ratio of 1.1 up to the 52^{th} layer. Then, the vertical grid sizes are uniform as 20.89m.

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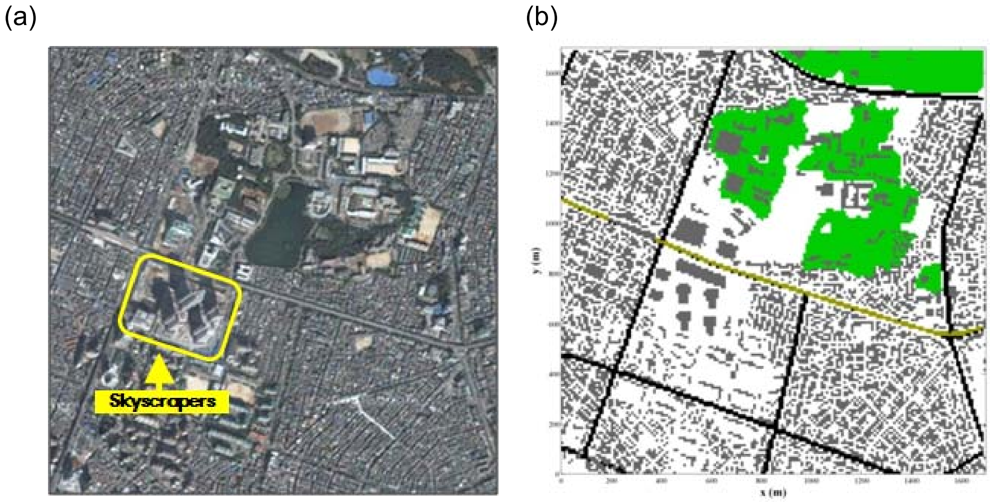

Fig. 1. (a) The picture of simulation area taken from the Google Earth (www.googleearth.com) and (b) top view of the topography and buildings constructed in the model.

The skyscrapers are located within the yellow box (Fig. 1a). Using geographic information system (GIS) data, topography and buildings are constructed in the CFD model (Fig. 1b). Numerical model is integrated for 3600s with the time step of 1s.

3. RESULTS AND DISCUSSION

Figs. 2a and b show the flow fields at z = 2.5 m in the westerly case. Although the inflow is westerly, flow in the domain has several wind directions after inflow bumped against the buildings. Wind speed and direction significantly changed near the buildings. Before skyscrapers are constructed, westerly is dominant in the region of the skyscrapers. Although westerly flow is passing through the apartment complex located at the south of the skyscrapers, southerly flow appears at the upwind and downwind regions. After the skyscrapers are constructed, there is significant increase in wind speed in the Konkuk university. Wind direction is changed from west to south-west in part. Note that wind speed significantly increases the spaces between the skyscrapers for satisfying the mass conservation law (so called channeling flow). At the downwind region of skyscrapers, wind speed becomes weak and double eddy circulations are formed. In the case without the skyscrapers, inflow from the apartment complex located in south is changed to the northerly after the skyscrapers are constructed.

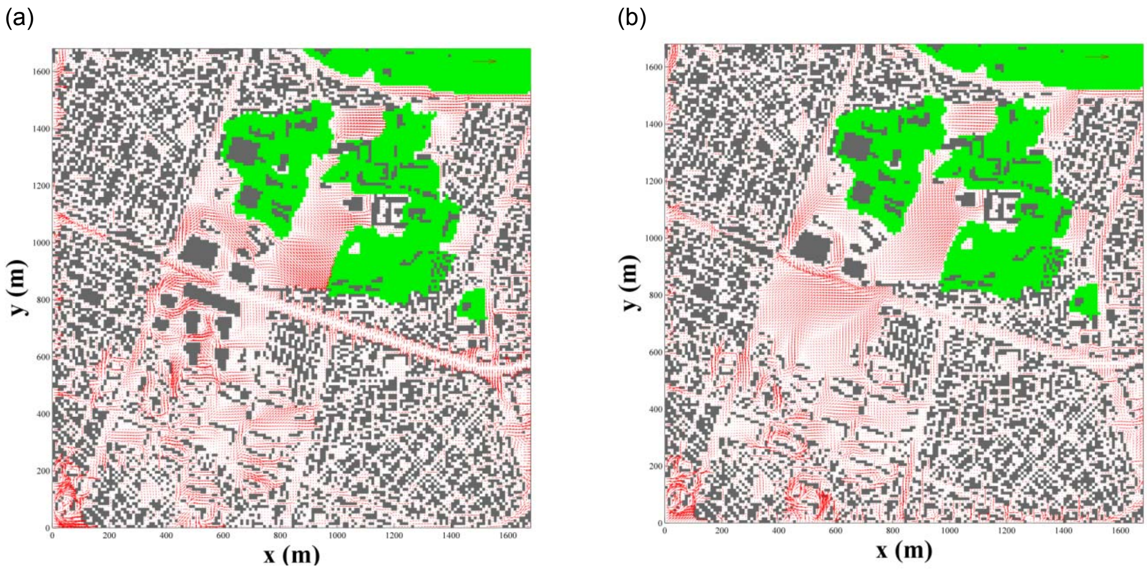

Fig. 2. Wind vector fields at z = 2.5 m (a) with / (b) without skyscrapers in cases of westerly wind

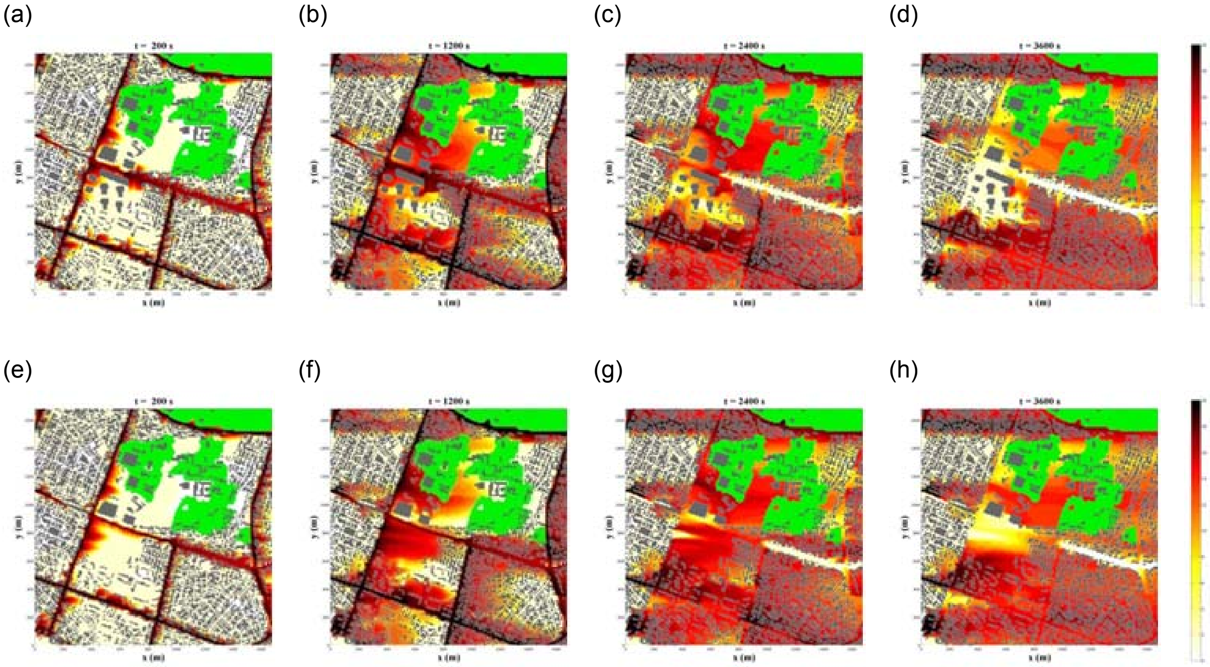

Fig. 3. Pollutant concentration fields (exponential scale) at z = 2.5 m in the case with/without the skyscrapers at t = 200s [(a) and (e)], 1200s [(b) and (f)], 2400s [(c) and (g)], and 3600s [(d) and (h)] under westerly wind.

Beneath the subway tracks, divergence flows to the north and south are shown. It is considered that the influence of inflow from the upper part is blocked by the tracks. Pollutant concentration at z = 2.5 m are presented in the case with/without skyscrapers under westerly wind in Fig. 3. Passive scalar pollutants are assumed to be emitted along the streets (line sources). In the first 30 minutes, pollutant are continuesly emitted from the line sources. Then, pollutant emission stops in the last 30 minutes. Comparison shows that the dispersion patterns and concentrations are overall similar to each other. However, distinct difference appears near the skyscrapers. In the case with the skyscrapers, horse-shoe vortex and separated flow at the upwind transport the pollutant to the apartment complex in the south and play an important role in decreasing pollutant concentration. On the contrary, it can be seen that pollutant concentration does not decreased after pollutant emission stopped in the case without skyscrapers. This is because pollutants are trapped within the recirculation zone. At the downwind region, pollutant concentration increases because of the decrease in wind speed caused by the drag effect of the skyscrapers. Fig. 4. shows the concentration difference between the cases with/without the skyscrapers at the eight circular zones. It is shown that the skyscrapers significantly affect the pollutant concentration within the (a), (b), and (c) zones. Since the wind speed near the skyscrapers increased due to the channeling effect, pollutant concentration decreased at the adjacent area. However, pollutant concentration increased after (d) zone.

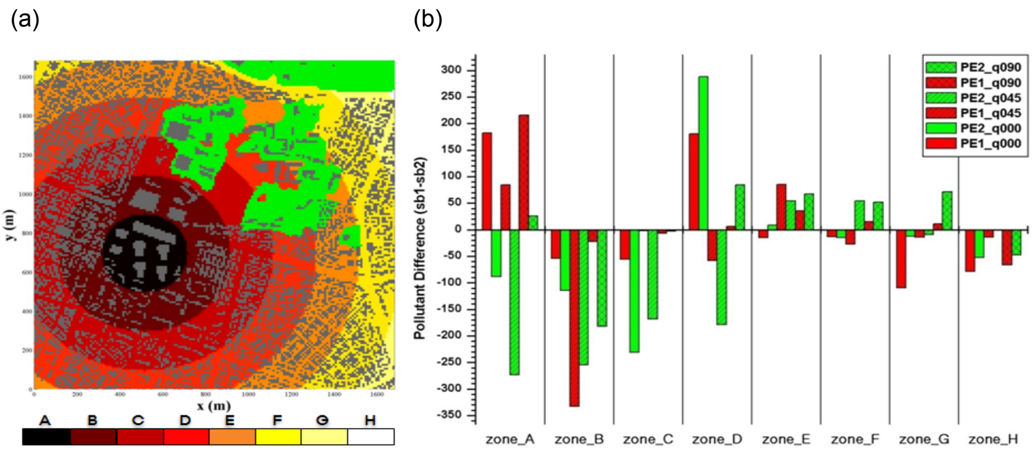

Fig. 4. (a) Eight circular zones and (b) concentration difference between the case with/without

the skyscrapers [PE1 = Pollutant Emission, PE2 = no Pollutant Emission]

4. CONCLUSIONS

In this study, the influence of the skyscrapers in a metropolitan area has been investigated with respect to flow and dispersion under three different wind directions (westerly, south-westerly, and southerly). Overall, wind speed decreased due to the drag effect of the skyscrapers in the whole domain. The characteristics of flow are represented at the region of the complex buildings and skyscrapers. The flow separation at the upwind region of the skyscrapers plays an important role in forming flow around the Konkuk university and apartment complex. Though the domain-averaged wind speed decrease about 20% after construction of the skyscrapers, the dilution rate of pollutant concentration is quite dependent on the inflow direction

Acknowledgement

This research was supported by a grant from Seoul R&D Program (GS070167).

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