A GIS-BASED DISPERSION MODEL FOR PREDICTING POLLUTION FROM COGENERATION SYSTEMS IN URBAN AREAS

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INTRODUCTION

Cogeneration systems have been installed for commercial use in buildings such as hotels, hospitals and offices to reduce energy consumption and CO_2 emissions since the 1980s in Japan. Cogeneration systems produce not only electric power but also heat. The heat produced when energy is generated can be used for hot water supply and air conditioning; thus, cogeneration systems are located near sites where the heat is required. Most cogeneration systems operate by internal combustion, such as gas turbines, gas engines and diesel engines that burn fossil fuel; thus, most cogeneration systems exhaust gases containing NO_x emissions from rooftops of buildings in which the cogeneration systems are installed. When air-quality impact assessments for such facilities are undertaken, the building downwash effect on pollution dispersion should be considered. In Gaussian dispersion models such as ISC3 of U.S. EPA, the dimensions of buildings around a pollution source that may affect plume dispersion should be specified. In urban areas, however, it is difficult to specify building dimensions because there are many buildings and some of them have complicated shapes. In this study, we developed an air dispersion modeling system that can consider the building downwash effect using a geographic information system (GIS) to specify building dimensions automatically. Using this system, we calculated the annual mean ground-level concentrations of NO_x discharged from the cogeneration systems installed within the Tokyo Metropolis.

MODEL DESCRIPTION

To determine the building dimensions, commercially available electronic residential maps containing detailed information about buildings and homes were used. These maps indicate the planar shape and number of stories of each building, as well as the names of all buildings and residential houses. First, the planar shapes of buildings adjacent to emission sources were transformed into rectangles that envelope all polygonal vertices, and the length and projected width of each rectangle were determined in the wind directions of 16 (22.5 degree) sectors used in Japanese standard meteorological data acquisition systems, such as an AMeDAS (Automated Meteorological Data Acquisition System). Moreover, the building height was calculated by multiplying the number of stories of each building by the given floor height. Then the dominant buildings affecting plume dispersion were selected, and their heights and projected widths in each direction were calculated using the Good Engineering Practice Stack Heights (*U.S. EPA*, 1985) formula.

The METI-LIS developed by the Ministry of Economy, Trade and Industry of Japan was used as a dispersion model for calculating the ground-level concentrations of NO_x discharged from cogeneration systems in urban areas. METI-LIS is a steady-state Gaussian plume model, which was developed by improving the ISC to predict the dispersion of hazardous air pollutants discharged from industrial establishments. In METI-LIS, dispersion parameters on the lee side of buildings were modified to predict not only the maximum concentration but also the annual mean concentration accurately, and these parameters were treated as functions

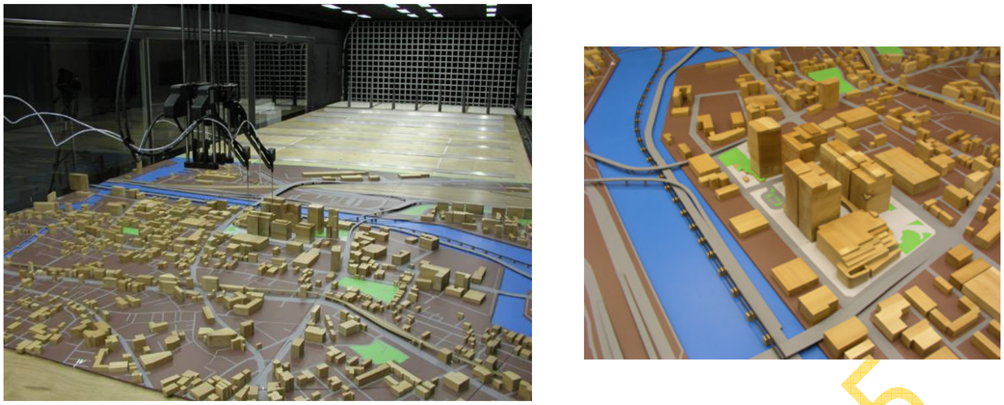

Fig. 1; View of a scale model in wind tunnel.

of source height, building aspect ratio and so on. The modifications of these parameters were mainly based on the results of wind tunnel experiments of dispersion from a point source through regularly arranged identical obstacles (*Kouchi and Okabayashi*, 2001). Input parameters, such as calculation grids, source locations, emission rates and building dimensions, can be configured readily using a graphical user interface.

WIND TUNNEL EXPERIMENTS

To evaluate the performance of the system developed in this study, a series of wind tunnel experiments simulating plume dispersion around buildings in urban areas were carried out. The experiments were performed in a wind tunnel at the Komae Research Laboratory of Central Research Institute of Electric Power Industry. The test section is 3 m wide, 1.5 m high and 17 m long. All measurements were carried out at a free stream wind speed of 3.0 m/s, and the power low exponent of the mean velocity profile of an approach flow was 0.25. A scale model of Shinagawa City, Tokyo, was constructed on a scale of 1:750 (Figure 1). There are nine high-rise buildings, which are between 60 and 100 m in height, and one low-rise building about 30 m in height. A tracer gas, a mixture of ethylene and air, was released from the rooftop of one of the high-rise buildings. A neutrally stratified boundary layer corresponding to the model scale was generated using a combination of vortex generators and roughness elements. Wind tunnel experiments were conducted in 16 wind directions in steps of 22.5 degrees by rotating the scale model.

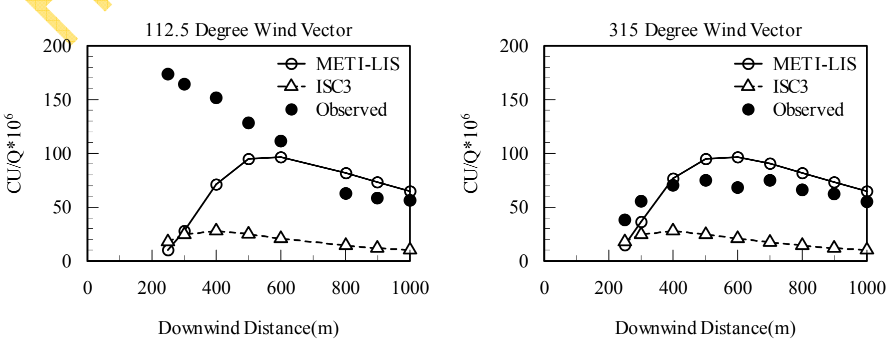

Fig. 2; Downstream distributions of ground level concentrations at the plume central line.

Figure 2 shows the downstream distributions of ground-level concentrations at the plume central line. Although the calculated value was in good agreement with the observed value at any downwind distance from the source when winds were blown from northwest (315 degree wind vector), the calculated value underestimated wind tunnel observations considerably near the source for wind from east-southeast (112.5 degree wind vector). This is probably due to the plume discharged from the stack dispersed vertically significantly due to the high-rise buildings located downwind of the source building when winds were blown from the east side. The maximum concentrations predicted for each wind vector normalised by the observed concentrations in the wind tunnel are shown in Figure 3. It was found that the maximum concentrations predicted using the system developed in this study are lower than those obtained in the wind tunnel experiments, particularly for wind vectors 45 through 180 degrees, but the calculated maximum concentrations are within a factor of two of wind tunnel observations for most wind vectors.

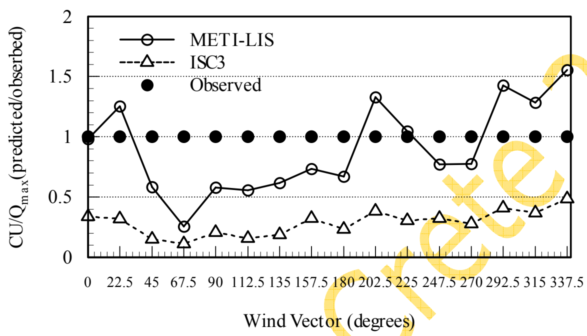

Fig. 3; Maximum concentrations predicted for each wind vector.

MODEL APPLICATION

The system was used to calculate the spatial distribution of annual mean ground-level concentrations of NO_x released from cogeneration systems actually installed in urban areas of Tokyo. To estimate NO_x emissions of cogeneration systems a questionnaire survey and an interview of users within the Tokyo Metropolis were conducted. Questionnaires were sent to commercial and industrial consumers with total power generation capacities of 1,000 kW or higher. In the survey, exhaust heights, discharged NO_x concentrations, operation hours, and so forth were determined. On the basis of the results of the survey, it was determined that many establishments direct exhaust gases from underground where cogeneration systems are installed to the rooftop and that the discharged NO_x concentrations are approximately 50% of those indicated in the regulations issued by local governments. The amount of NO_x discharged from all cogeneration systems installed within the Tokyo Metropolis area was estimated to be approximately 1,100 tons/year.

The calculation domain included 23 wards of Tokyo. The number of buildings with cogeneration systems within the domain was 266, and the total electric power generation capacity was 215 MW. We calculated the hourly concentrations of NO_x using the hourly meteorological data obtained from the surface meteorological observations made at manned stations and a mesoscale observation network, and averaged the hourly concentrations over a year. Only the increments in the concentrations of NO_x discharged from the cogeneration systems within the domain were estimated, and the background concentrations of pollutants generated by other sources including industry and traffic were not considered.

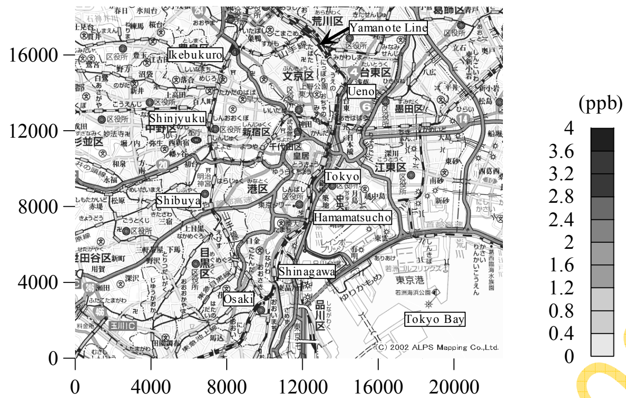

Fig. 4; Annual ground-level concentrations of NO_x discharged from cogeneration systems.

Figure 4 shows the estimated annual ground-level concentrations of NO_x discharged from the cogeneration systems actually installed. The calculated NO_x concentrations of the center of Tokyo (the area inside the Yamanote Line), where many cogeneration systems are introduced, were higher than those of surrounding areas and the annual mean concentration within that area was about 2 ppb, which was equivalent to approximately 3.1 % of the ambient air pollution level.

CONCLUSION

A GIS-based dispersion modeling system was developed to estimate the effects of pollutants discharged from cogeneration systems in urban areas. The building dimensions required in calculating downwash were automatically determined using electronic residential maps. To evaluate the performance of the system, a series of wind tunnel experiments simulating plume dispersion around building models in urban areas were carried out. It was found that the concentrations calculated using the system are lower than those obtained in wind tunnel experiments, but for the maximum ground-level concentration, there was a good agreement between the theoretical and experimental values. The spatial distribution of annual concentrations of NO_x released from cogeneration systems actually installed in urban areas of Tokyo was calculated. The calculated annual mean concentrations within the center of Tokyo were equivalent to approximately 3.1 % of the ambient air concentrations.

REFERENCES

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