# EXPERIMENTAL AND NUMERICAL SIMULATION OF POLLUTANT DISPERSION IN A HIGH DENSITY RESIDENTIAL AREA

*Ayumu Sato[1], Takenobu Michioka[1] and Yoichi Ichikawa[1]*
[1] Central Research Institute of Electric Power Industry(CRIEPI), Chiba, Japan

## INTRODUCTION

Combined heat and power (CHP) systems have been installed for commercial use in buildings such as hotels, hospitals and office buildings in Japan to reduce energy consumption and $CO_2$ emissions. Most CHP systems operate by internal combustion using gas turbines or gas engines; thus, exhaust gases containing NOx are released from the building's rooftop in urban areas (*Sato, A., and Y. Ichikawa*, 2005). Field tracer experiments and wind tunnel experiments were conducted to simulate the atmospheric dispersion of gases within a high-density residential area of Komae-City, Tokyo, Japan, where houses are closely packed. Two atmospheric dispersion models used for practical purpose widely (an analytical solution model based on a normal distribution function (Gaussian plume model) and a computational fluid dynamics model based on two equation turbulence model ($k$-$e$ model)) were applied to calculate ground-level concentrations of a gas released from rooftop of a low-rise building.

## METHODOLOGY

Field tracer experiments were conducted in and around the Komae Research Laboratory of Central Research Institute of Electric Power Industry (CRIEPI) in Komae-City, Tokyo. Twenty-two trials of the field tracer experiments were carried out. A tracer gas, perfluoro-methyl cyclohexane (PMCH), was released at a steady rate from the rooftop of the highest laboratory building, which is 29.6m high (=Hb). Surface tracer concentrations were measured at five distances downwind of the source (50, 100, 150, 250 and 500 m). Air samples were collected using portable samplers deployed at 50 locations in an array of five sampling arcs. Sampling locations are shown in Figure 1. Instantaneous measurements of wind velocity components were recorded at 20 Hz using an ultrasonic anemometer mounted on a mast on the rooftop during tracer release periods.

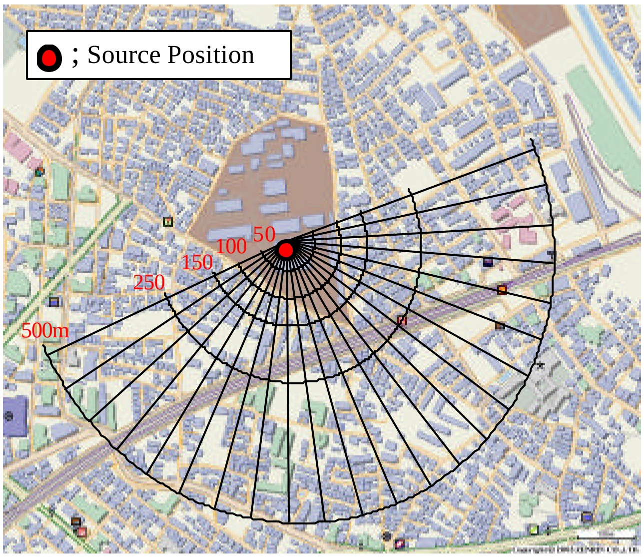



*Fig. 1; Map of research area and sampling arcs.*

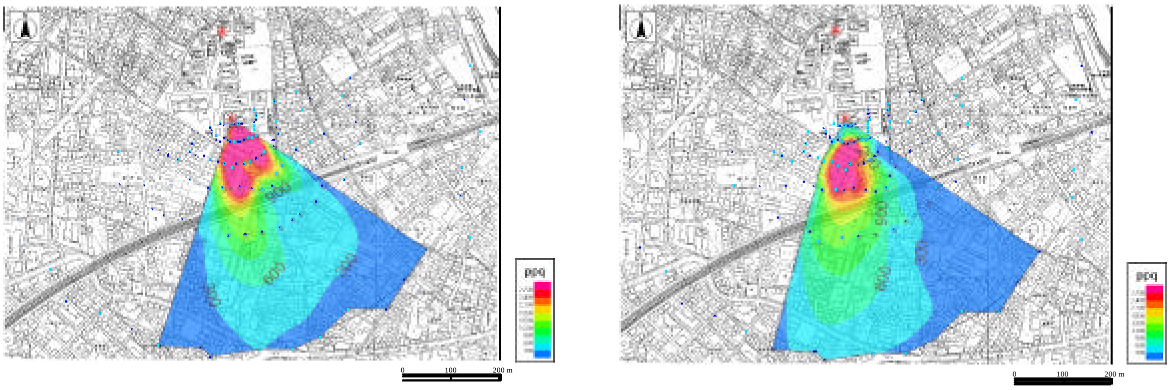
Wind tunnel experiments were performed in a wind tunnel at CRIEPI. The test section is 3 m wide, 1.5 m high and 17 m long. All measurements were carried out at a free stream wind speed of 3.0 m/s (=$U_{ref}$), and the power-law exponent of the mean velocity profile of the approach flow was 0.25. A scale model covering an area of 700 m x 700 m containing all the buildings surrounding the laboratories was constructed on a scale of 1:250 (Figure 2). A tracer gas, a mixture of ethylene and air, was released from the rooftop of the same building as that used for the field tracer experiments. A neutrally stratified boundary layer corresponding to the model scale was generated using a combination of vortex generators and roughness elements. Mean concentrations were measured using a flame ionization detector (FID), and the mean and fluctuation velocity components were measured using a laser Doppler velocimeter (LDV). Wind tunnel experiments were conducted in 16 wind directions in steps of 22.5 degrees by rotating the scale model.

*Fig. 2 ; View of a scale model in wind tunnel.*

Two types of atmospheric dispersion model, ISC-PRIME *(Schulman, et al.,* 1997, *U.S. EPA*, 1995) and a general-purpose fluid simulation code FrontFlow/red were used. In FrontFlow/red, the conservation equations of mass, momentum, energy, and chemical species are solved, and both the Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) models are used. In this study, the standard $k - e$ turbulence model was used to simulate wind flow and pollutant dispersion. A computational domain that included all the buildings modelled in the wind tunnel experiments was constructed from actual building coordinates and heights using the Geographical Information System (GIS) and commercially available electronic residential maps.

**RESULTS AND DISCUSSION**

Figure 3 shows the ground-level concentration profiles observed in the field tracer experiments for Run7 and Run22 (Table 1). At lower wind speeds, the plume was dispersed widely, and a contour plot shows a bimodal concentration profile. During trials with higher wind speeds, concentration profiles were found to be Gaussian and maximum ground-level concentrations of tracer gas were measured between 100 and 150 m downwind of the source, which is about 3 to 5 times the building height (Hb). Figure 4 shows the down wind distribution of the lateral plume widths for all the trials, in which the wind direction was north or north-northwest. Lateral plume widths were between 1.1 and 6.0 times larger than those of Pasquill- Gifford curves under slightly unstable conditions and neutral conditions.



*Run 7* *Run 22*

*Fig. 3 ; Ground-level concentration profiles observed in the field tracer experiments*

*Table 1. Meteorological conditions during air tracer experiments*

| Run | Date | Wind Direction | Wind Speed(m/s) | Stability | Temp. (℃) |
|---|---|---|---|---|---|
| 7 | 2/2/05 12:00-12:30 | NNW | 1.8 | A-B | 6.7 |
| 9 | 2/2/05 13:00-13:30 | NNW | 5.3 | C | 7.2 |
| 10 | 2/2/05 13:30-14:00 | NNW | 4.6 | B | 7.0 |
| 11 | 2/2/05 14:00-14:30 | NNW | 3.6 | B | 7.3 |
| 18 | 2/3/05 13:00-13:30 | N | 5.8 | C | 8.9 |
| 19 | 2/3/05 13:30-14:00 | NNW | 5.3 | C | 9.2 |
| 20 | 2/3/05 14:00-14:30 | NNW | 5.2 | C-D | 9.3 |
| 21 | 2/3/05 15:30-16:00 | NNW | 6.0 | C-D | 8.5 |
| 22 | 2/3/05 16:00-16:30 | N | 6.8 | D | 7.5 |

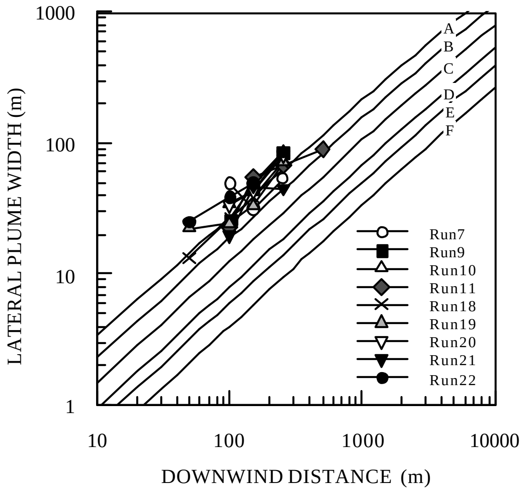



*Fig. 4; Lateral plume widths*

Although the calculated concentrations using ISC-PRIME tended to underestimate the observed tracer concentrations, the comparison between the calculations and the observations showed reasonably good agreement under slightly unstable conditions (Figure 5(a)). Figure 5(b) shows the vertical profiles of the u-component calculated using FrontFlow/red at different downwind positions in the calculation area. The predicted wind velocities downwind of the building on which the source was located showed good agreement with those obtained by the wind tunnel experiments, but the calculated velocities upstream of the building were larger than those obtained by the experiments. Horizontal profiles of the mean concentration calculated at the surface, normalized by the source strength and free stream wind speed, are shown in Figure 5(c) with those obtained in the wind tunnel experiments. Although the calculated peak concentrations were slightly smaller than those of the experimental results, the distribution of lateral plume shows good agreement. Figure 5(d) shows the predicted and observed ground-level concentrations versus downwind distance along the plume central line. The observed concentrations of the field experiments were converted using a power-law exponent in consideration of the sampling time. Both dispersion models tended to underestimate the concentrations obtained by the field and wind tunnel experiments close to the source, but the calculation results were in good agreement with the observed values further downwind.

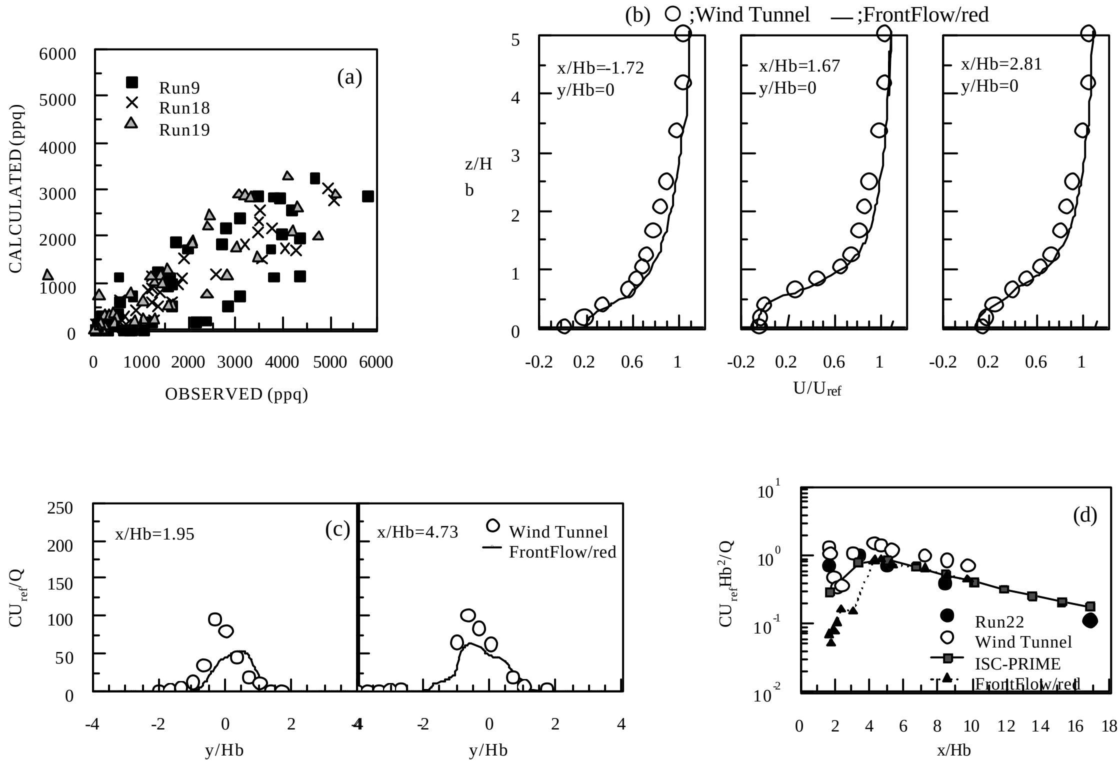



*Fig. 5 ; Comparison between measurements and model results.*

## CONCLUSIONS

Field tracer experiments and wind tunnel experiments were conducted to simulate the atmospheric dispersion of gases within a high-density residential area. A Gaussian dispersion model and a computational fluid dynamics model were applied to calculate pollutant concentrations released from the rooftop of a building. Observed tracer concentrations showed bimodal profiles at lower wind speeds and Gaussian profiles at higher wind speeds, and the maximum ground-level concentrations were measured at downwind distances about 3 to 5 times the building height. Calculated concentrations using ISC-PRIME showed reasonably good agreement with the experimental results. Although the standard $k - e$ model has a poor prediction accuracy for wind velocities at upstream of the building, the computational results of the horizontal distribution of the concentration near the surface were in good agreement with experimental results. It was found that the calculation results using the models for the maximum concentration further downwind were almost the same for both ISC-PRIME and the standard $k - e$ model.

## REFERENCES


*Sato, A. and Y. Ichikawa*, 2005: A gis-based dispersion model for predicting pollution from cogeneration systems in urban areas, Proceedings of the 10th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, pp 159-162.

*Schulman, L.L., Strimaitis, D.G. and Scire, J.S.*, 1997: The PRIME plume rise and building downwash model,"Addendum to ISC3 user's guide", Electric Power Research Institute.

*U.S. EPA*, 1995: User's guide for the Industrial Source Complex (ISC3) dispersion models, Volume II - Description of model algorithms, EPA-454/B-95-003B, EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC27711.