

## Development of Atmospheric Dispersion Model for Environmental Impact Assessment of Complicated Industrial Area

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### 1 Introduction

In Japan, with amendment of the Air Pollution Control Law in May 1996, materials such as benzene, trichloroethylene were newly designated as hazardous air pollutants and environmental standards were established as annual averaged concentrations. Consequently, the need for an effective and efficient atmospheric dispersion model which is applicable to environmental impact assessment of industrial area with complex of factory buildings has increased. The ISC<sup>[1]</sup> model is one of the useful dispersion model which can take the downdraft effect due to building wake into account. However ISC model is good at predicting maximum concentration during some period, but not at predicting horizontal distribution of 1 hr averaged concentrations.

To overcome this problem, the development of the improved ISC's downdraft model has been undertaken by the Ministry of Economy, Trade and Industry (METI) and Japan Environmental Management Association for Industry (JEMAI). This improvement is based on the data set of newly conducted wind tunnel experiments simulating downdraft due to wake of buildings.

### 2 Wind Tunnel Experiments

For the purpose of investigating the features of gas dispersion around buildings and for obtaining the data needed for the modification and validation of the model, two types of wind tunnel experiments were carried on. One type is the 'Simple-buildings experiments' and the other one is the 'Factory-buildings experiments'.

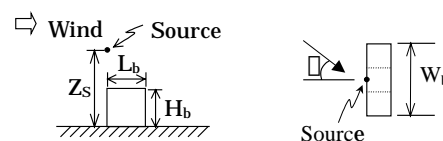
#### 2.1 Simple-buildings experiments

In the simple-buildings experiments, 1/200 scale models of simple cubic or squat buildings were used. The data were collected under a total of 44 different conditions, i.e. different source height, aspect ratio of the building, wind directions, arrangements of buildings and so on. The summary of the experimental condition is shown in Table 1 and Figure 1, while an example of the arrangement of buildings is shown in Figure 2(a). The ground level concentrations, vertical profiles of concentration and wind speed were measured and the obtained data from these measurements such as the lateral standard deviation ( $\sigma_y$ ), the vertical standard deviation ( $\sigma_z$ ), etc. were used for the modification of the downdraft model.

**Table 1** Summary of simple buildings experiments conditions.

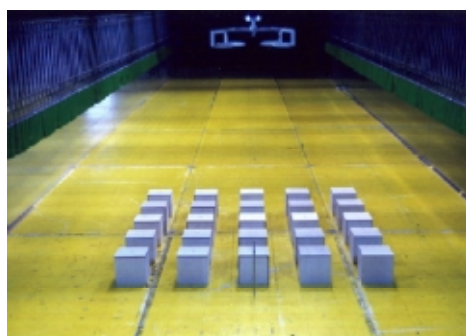
Shape of buildings	$W_b/H_b=1, 3, 5$ $L_b/H_b=1$
Number of buildings (Arrangement : Row * Line)	1, 2, 3, 9(3*3), 25(5*5), 35(5*7)
Wind direction	$\theta = 0, 20, 40$ [deg]
Source height	$Z_s/H_b=0.5, 1.0, 1.5$

Where ,  $W_b$ ,  $H_b$ ,  $L_b$  : width, height and length of buildings,  
 $Z_s$ : Source height,  $\theta$ : wind direction.

**Figure 1** Parameters of building shape.

## 2.2 Factory-buildings experiments

In the factory-buildings experiments, 1/200 scale models of three different chemical factories were used. The data were collected under a total of 5 tests. An example of a factory-buildings model is shown in Figure 2(b). In these tests, the ground level concentrations were measured. The obtained data set was used for the validation of the model itself and of the methods for the model application to actual industrial areas, which are composed of many different types of buildings.



(a) Simple-buildings experiments (Buildings arrangement : 5\*5)



(b) Factory-buildings experiments

**Figure 2** Examples of scale models used in the experiments .

## 2.3 Experimental facilities

The Large Scale Dispersion Wind Tunnel was used for all the wind tunnel experiments described above and the experiments were newly conducted by the Nagasaki Research & Development Center of Mitsubishi Heavy Industries in 1998 and 1999.

The wind tunnel has 3 m wide, 2 m high and 25 m long working section. The neutral atmospheric condition was simulated in the working section by using surface roughness and spires located at the upstream section of the wind tunnel.

Ammonia was used as the tracer gas for ground level concentration measurements and methane was used for vertical concentration profile measurements. The tracer gas was emitted as a point passive source. The sampling points are almost 300 for ground level concentrations and almost 100 for vertical concentration profile (at 4 different downwind distance, 25 points per each distance) .

## 3 Modification of ISC model

The model we want to develop should be able to predict not only the maximum concentration occurred in a short period, but also annual average concentration. Therefore the model is expected to be able to effectively simulate the concentration distribution in the cross-wind ( $y$ ) direction and not only the maximum concentration. This means the model must treat dispersion parameter ( such as  $\sigma_y$ ,  $\sigma_z$ ,  $H_e$ , etc.) correctly as a function of building arrangement and source position etc..

The ISC model is based on plume model (Equation 1) :

$$C = \frac{Q}{2\pi\sigma_y\sigma_z u} \cdot \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \cdot \left\{ \exp\left[-\frac{(He-z)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(He+z)^2}{2\sigma_z^2}\right] \right\} \quad (1)$$

where  $C$  is the concentration,  $He$  is the effective stack height,  $Q$  is the source strength,  $u$  is the wind speed. In case the source height is low and the gas dispersion can be influenced by the building wake, the downdraft must be taken into account. In original ISC model the H-S (Huber-Snyder)<sup>[1]</sup> model is used as prediction methods for downdraft. The second column in Table 2 describes the original H-S model, where  $Cz_1$ ,  $Cz_2$ ,  $Cy_1$  and  $Cy_2$  have constant value, while the third column in Table 2 reports an outline of our modification, where we tried to model  $Cz_i$ ,  $Cy_i$  ( $i=1,2$ ) as functions of building width and height, building arrangement, source position etc. Not only  $Cz_i$ , and  $Cy_i$ , but also the following parameters were modelled in the same manner.

- Effective plume height  $He$ .
- Wind speed used in the plume model.
- Introduction of virtual source position which is  $\Delta y_s$  away from an actual source positions in  $y$  direction. This displaced source position is applied in case the wind direction is not perpendicular to the building wall.

All the modelled parameters are based on the data obtained from simple-buildings experiments.

**Table 2** Outline of parameter modification.

Source Height	ISC model	Parameter to be modified
$Z_s \leq 2.5H_b$ (without downdraft model)	$\sigma_y = 465.1 \cdot x \cdot \tan(TH)$ $TH = 0.1745 \cdot [c - d \cdot \ln(x)]$ $\sigma_z = a \cdot x^b$ where a, b, c and d are the constants determined by atmospheric stability .	Same as ISC model
$Z_s < 2.5H_b$ (Use downdraft model)	<p><b>H-S model ( ex. for squat building)</b></p> $\begin{cases} \sigma_z' = Cz_1 \cdot h + Cz_2 \cdot (x - 3h) & 3h \leq x < 10h \\ \sigma_z' = \sigma_z(x + x_z) & 10h < x \end{cases}$ $\begin{cases} \sigma_y' = Cy_1 \cdot W_b + Cy_2 \cdot (x - 3H_b) & 3H_b \leq x < 10H_b \\ \sigma_y' = \sigma_y(x + x_y) & 10H_b < x \end{cases}$ where, $h = \text{Min}(H_b, W_b)$ , $Cz_1 = 0.7$ , $Cz_2 = 0.067$ , $Cy_1 = 0.35$ , $Cy_2 = 0.067$ and $x_z$ , $x_y$ are virtual downwind distance from a source.	(1) $Cz_i$ , $Cy_i$ ( $i=1,2$ ) (2) Effective plume height $He$ (3) Wind speed used in the plume model. (4) Source position displacement $\Delta y_s$  These parameters are modified as functions of building width, height, building arrangement and source position etc.

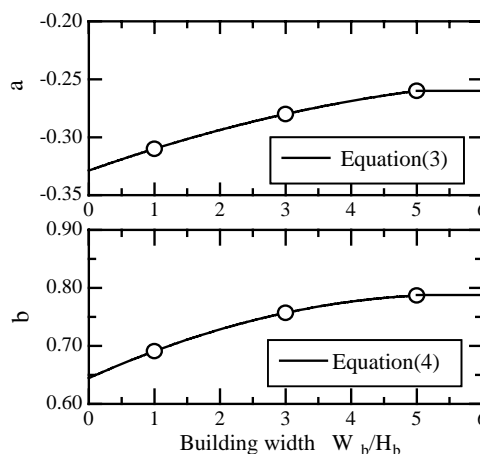
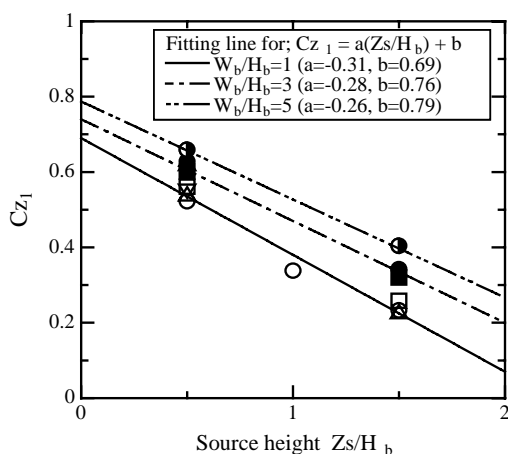
The experimental results showed that most of the parameters to be modified have obviously different characteristics when considering a small group of buildings or a large group, where ‘large (small) group’ means that a large (small) area is occupied by buildings. Therefore, as a first step of modelling, we classified the type of buildings in two major categories, i.e. ‘large group type’ and ‘small group type’, and then, for each group, model formulas of every parameter were determined. For conciseness reasons, we present only an example of the formulas at the base of the model, like equations (2)-(4) for

$C_{z1}$ . The  $C_{z1}$  is one of the rare parameters that are not dominated by group type as shown in Figure 3, and it was modelled as a function of only source height and building width.

$$C_{z1} = a \cdot (Z_s/H_b)^2 + b \quad [\text{for } \theta = 0] \quad (2)$$

$$\begin{cases} a = -0.00125 \cdot (W_b/H_b)^2 + 0.02 \cdot (W_b/H_b) - 0.329 & [\text{for } W_b/H_b \leq 5] \\ a = -0.26 & [\text{for } W_b/H_b > 5] \end{cases} \quad (3)$$

$$\begin{cases} b = -0.045 \cdot (W_b/H_b)^2 + 0.051 \cdot (W_b/H_b) + 0.645 & [\text{for } W_b/H_b \leq 5] \\ b = -0.788 & [\text{for } W_b/H_b > 5] \end{cases} \quad (4)$$



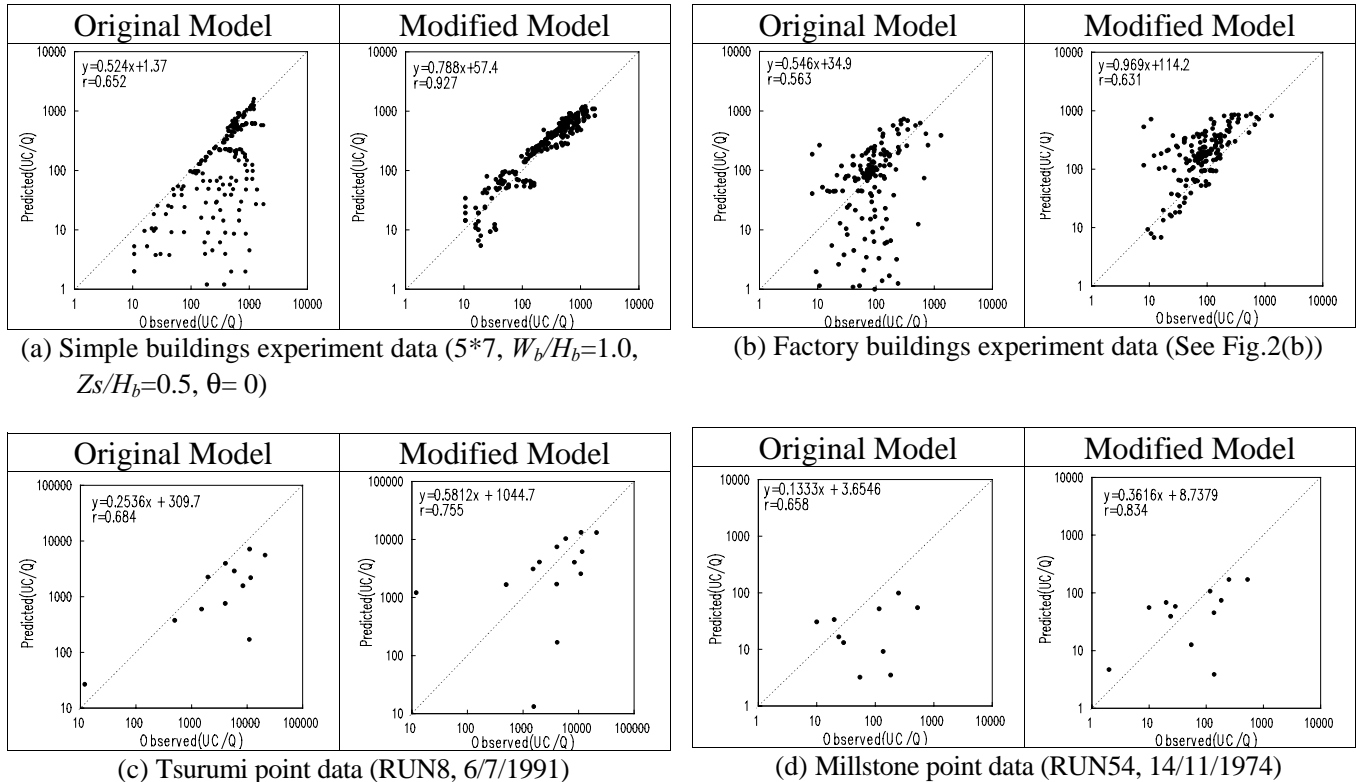
**Figure 3(a)**  $C_{z1}$  as a function of source height      **Figure 3(b)** Model of coefficient  $a, b$   
 (Symbols in Fig.3(a):  $W_b/H_b = 1$ ,  $\circ$ : number of buildings = 1,  $\Delta$ : 2,  $\square$ : 5\*5,  $\nabla$ : 5\*7.  
 $W_b/H_b = 3$ ,  $\bullet$ : 1,  $\blacktriangle$ : 2,  $\blacksquare$ : 5\*5.       $W_b/H_b = 3$ ,  $\odot$ : 1.)

Next task is to establish rules for the application of the model to actual factory buildings. A goal of this task is to describe methods indicating how to determine the type of the factory (i.e. small group or large group), and how to choose one building, which is the most dominant in gas dispersion, among many different types of buildings in a factory. The former method was invented and examined by comparing the correlations among simple buildings experiments. The latter was carried out with many calculation tests simulating the factory buildings experiments. The rules are as follows.

- (1) If the distance between the source and the nearest part of the building is within  $5L_i^*$  in wind direction and within  $L_i^*$  in crosswind direction, the building is listed as an influential building in gas dispersion, where  $L_i^*$  is the smallest value of  $H_{bi}$  or  $W_{bi}$  and subscript  $i$  means each building around the source.
- (2) For each influential building, calculate  $H_{Gi} (= H_{bi} + 1.5L_i^* : \text{i.e., GEP Stack Height}^{[2]})$  and choose the building which has the largest  $H_{Gi}$  value as the most dominant building.
- (3) Width and height of the most dominant building ( $W_b$  and  $H_b$ ) are to be used in the downdraft model.
- (4) If the area occupied by group of buildings is larger (smaller) than a rectangle composed of lines which have  $5H_b$  length in wind direction and  $6H_b$  in crosswind direction, the group is defined as 'large (small) group'.

#### 4 Simulation Results

Performances of two models (Original ISC's downdraft model and modified model) were compared. The data sets used in this comparison are based on two types of wind tunnel data described in Section 2, and several field experiments carried on at Millstone nuclear power station<sup>[3]</sup>, Tsurumi point<sup>[4]</sup> in Japan, etc.. Several comparison results are shown in Figure 4 and we can see that the performance of the modified model is better than original model. The same tendency is observed in almost all other comparisons we have done.



**Figure 4** Comparison between modified model and original model (r: correlation factor).

#### 5 Summary

For the purpose of developing the dispersion model which is applicable to the environmental impact assessment of industrial area, the ISC's downdraft model was improved based on the data of 'simple buildings experiments' and the rules to apply this model to actual factories was examined using 'factory buildings experiments'. The model was tested using wind tunnel experiments and several field experiments and proved to have better performances than the original model.

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