ADMS 4 Buildings Validation
Snyder Wind Tunnel Experiments

Cambridge Environmental Research Consultants
December 2010

1 Introduction

Experiments were conducted in a simulated boundary layer representative of rural terrain with a few shrubs and trees in neutral conditions. Vertical profiles of concentration were measured downstream of a rectangular building for various stack heights, emission characteristics and building positions.

The model scale in the wind tunnel was 1/200 of full scale. Full details of the building and source parameters are given in Snyder (1993) [1].

Model runs for comparison with the experimental data have been carried out using ADMS 4.2 (version 4.2.2.0), ADMS 4.1 (version 4.1.0.0), and ISC-Prime (version 3). ISC-Prime contains the same buildings model that is in the AERMOD model which is why it is included here.

Section 2 describes the input data used for the model. The results are presented and discussed in Section 3.

2 Input data

2.1 Source parameters and buildings

The wind tunnel experiments consisted of a ‘base case’ and a number of variations in which stack height, diameter and exit velocity and building position were varied. The data used as input to the dispersion models for the base case are given in **Tables 1** and **2**.

In the wind tunnel experiments, a mixture of air and helium was used to simulate a high-temperature emission. The calculation of the equivalent emission and ambient temperatures is given in the Section 4.

Centre (m)	Height (m)	Length (m)	Width (m)	Angle (°)
(-25,0)	50	100	40	0

Table 1 − Building dimensions. The centre is given relative to the source. The angle is the angle between north and the building length measured clockwise from north.

Height (m)	Exit V (m/s)	Exit T (°C)	Diameter (m)	Emission rate (g/s)
75	20	145	6	1

Table 2 – Source input parameters. T is the temperature, V the velocity.

Details of variations from the base case are given in **Table 3**. For the model runs, all parameters except those in the table were identical to the base case for each experiment.

Experiment number	Variation from base case
3_1	stack height = 12.5 m
3_2	stack height = 50 m
3_3	stack height = 125 m
5_2	centre of building = (-100,0)
5_3	centre of building = (-250,0)
5_4	centre of building = (-375,0)
6_2	building centre = (-17.7,17.7), angle = 135°
6_3	building centre = (0,25), angle = 90°
6_4	building centre = (17.7,-17.7), angle = 45°
6_5	building centre = (25,0), angle = 0°
7_1	exit velocity = 15
7_2	exit velocity = 25
7_3	exit velocity = 40
8_1	stack diameter = 6.68
8_2	stack diameter = 3.34
8_3	stack diameter = 1.67
8_4	stack diameter = 0.1

Table 3 – Range of input data.

2.2 Meteorological data

The meteorological data were the same for all experiments (see **Table 4**). Wind speed was measured at the stack height. Hence in the model runs, the height of the wind speed measurements was set equal to the stack height.

Wind speed (m/s)	13.4
Wind direction (°)	270
Boundary layer height (m)	360
Temperature (°C)	20
1/Monin-Obukhov length (m^{-1}) (ADMS only)	0
Stability category (ISC-Prime only)	D
Surface roughness (m) (ADMS only)	0.2
Site characteristics (ISC-Prime only)	rural

Table 4 – Meteorological data.

3 Results

3.1 Output

In each case, concentrations were calculated 750 m downstream of the source, at a number of heights corresponding to the receptor heights in the wind tunnel. The heights varied slightly from experiment to experiment. Non-dimensional concentrations K were then calculated as follows:

$$K = \frac{C \; U \; H_b^2}{Q}$$

where C is concentration (μg/m^3), U is the wind speed at the stack height (m/s), H_b is the height of the building (m) and Q is the emission rate (μg/s).

In analysing the results, data points where the observed or modelled concentration was less than 0.01 were removed. In Section 3.2, results are presented as scatter plots and quantile-quantile plots of model results versus observed data, for each model. The data were also processed using the BOOT statistical package. The results are given in Section 3.3.

3.2 Scatter and quantile-quantile plots

Figure 1 shows scatter plots and quantile-quantile plots of all the results for each model.

The scatter plots were created by plotting each modelled concentration against the corresponding observed value. For all of these plots, concentrations are given as the non-dimensional value multiplied by 10^3. When all values are considered, ADMS results are closest to observed values, and ISC-Prime has a tendency to over predict. The quantile-quantile plots were created by plotting the highest modelled concentration against the highest observed concentration, the second highest modelled concentration against the second highest observed concentration, and so on. For the high observed values, ADMS gives a better prediction than the other models, but for the lower observed values, ISC-Prime is more accurate.

The results from ADMS 4.2 and ADMS 4.1 are graphically indistinguishable.

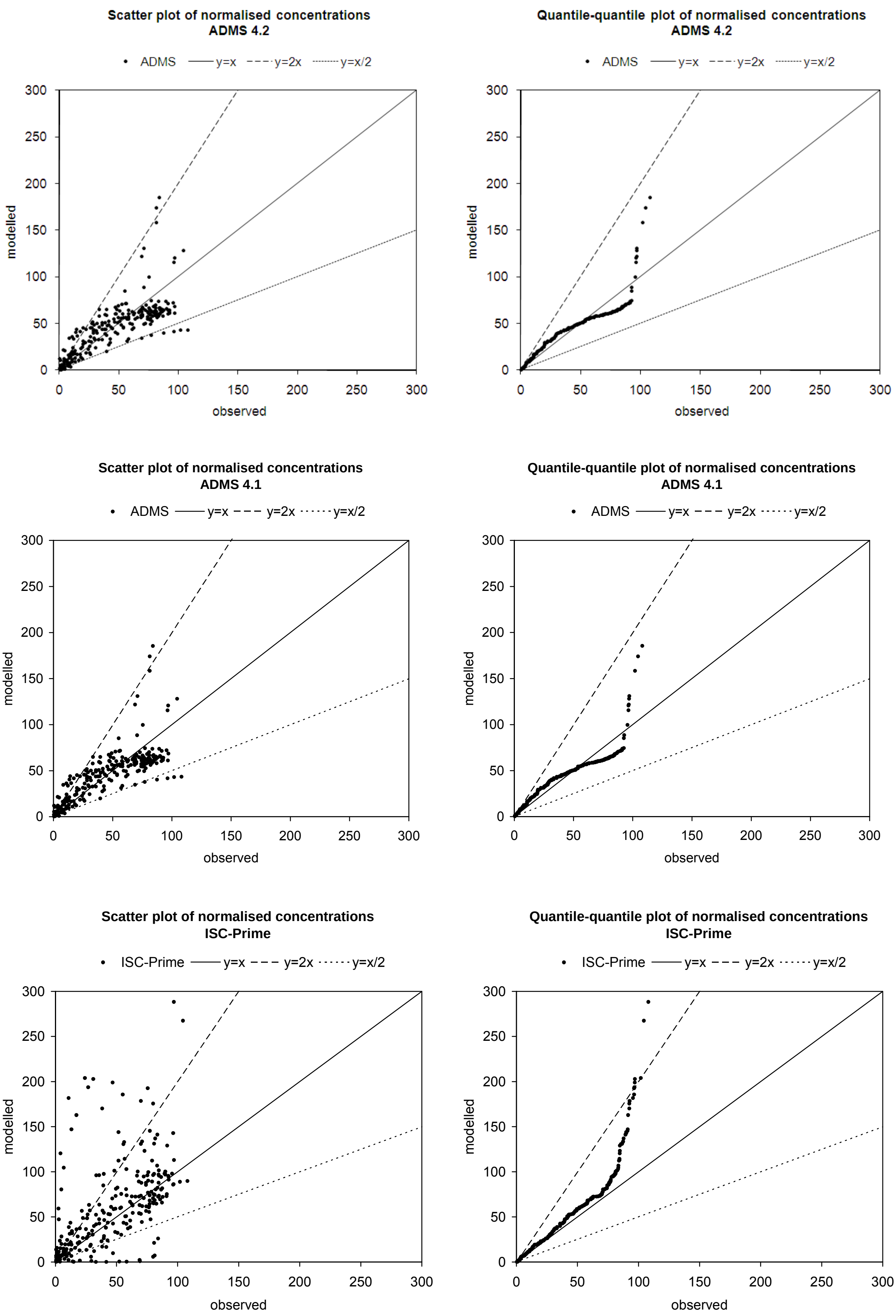

Figure 1 – Scatter and quantile-quantile plots of each model against observed data. (ug/m³).

3.3 BOOT statistics

The BOOT package produces statistics of the data that are useful in assessing model performance. Statistics calculated include mean, standard deviation (sigma), bias, normalised mean square error (NMSE), correlation (cor), fraction of results where the modelled and observed concentrations agree to within a factor of two (fa2), fractional bias (fb) and fractional standard deviation (fs).

The data were analysed in two ways. Firstly the observed concentrations were compared directly with the modelled values. The results are shown in **Table 5**.

Data	Mean	Sigma	Bias	NMSE	Cor	Fa2	Fb	Fs
observed	45.16	31.28	0.00	0.00	1.000	1.000	0.000	0.000
ADMS 4.2	43.91	29.31	1.26	0.19	0.795	0.862	0.028	0.065
ADMS 4.1	43.91	29.31	1.26	0.19	0.795	0.862	0.028	0.065
observed	46.19	31.15	0.00	0.00	1.000	1.000	0.000	0.000
ISC-Prime	59.77	50.48	-13.58	0.71	0.550	0.648	-0.256	-0.473

Table 5 – BOOT statistics comparing observed and modelled concentrations.

This method of analysing the data gives extra weight to the higher concentrations, so that for example, under predicting the highest concentration by 10 % will have a much larger effect on the standard deviation than under predicting the lowest concentration by 10 %. Hence the data were also analysed by normalising each concentration by the observed value. The results are shown in **Table 6**.

The ADMS model gives the best results for all statistics, and there is no difference in results between ADMS 4.2 and ADMS 4.1.

Data	Mean	Sigma	Bias	NMSE	Fa2	Fb
observed	1.00	0.00	0.00	0.00	1.000	0.000
ADMS 4.2	1.32	1.50	-0.32	1.77	0.862	-0.279
ADMS 4.1	1.32	1.50	-0.32	1.77	0.862	-0.279
ISC-Prime	2.16	3.61	-1.16	6.67	0.648	-0.734

Table 6 – BOOT statistics comparing observed and modelled concentrations, normalised by the observed values.

The BOOT package was also used to produce box and whisker plots to assess how model performance varies as each input parameter varies. The 5th, 25th, 50th, 75th and 95th percentile normalised concentrations for each value of each input parameter were calculated. **Figures 2** to **6** illustrate the variation with stack height, stack diameter, stack exit velocity, upstream position of building relative to the source, and position and orientation of the building.

Figure 5 shows that the performance of ISC-Prime worsens as the stack moves further from the building; this is not the case for ADMS. Considering the orientation of the building (**Figure 6**), the performance of ISC-Prime is worst when the building is located due south of the stack (with the wind from the west).

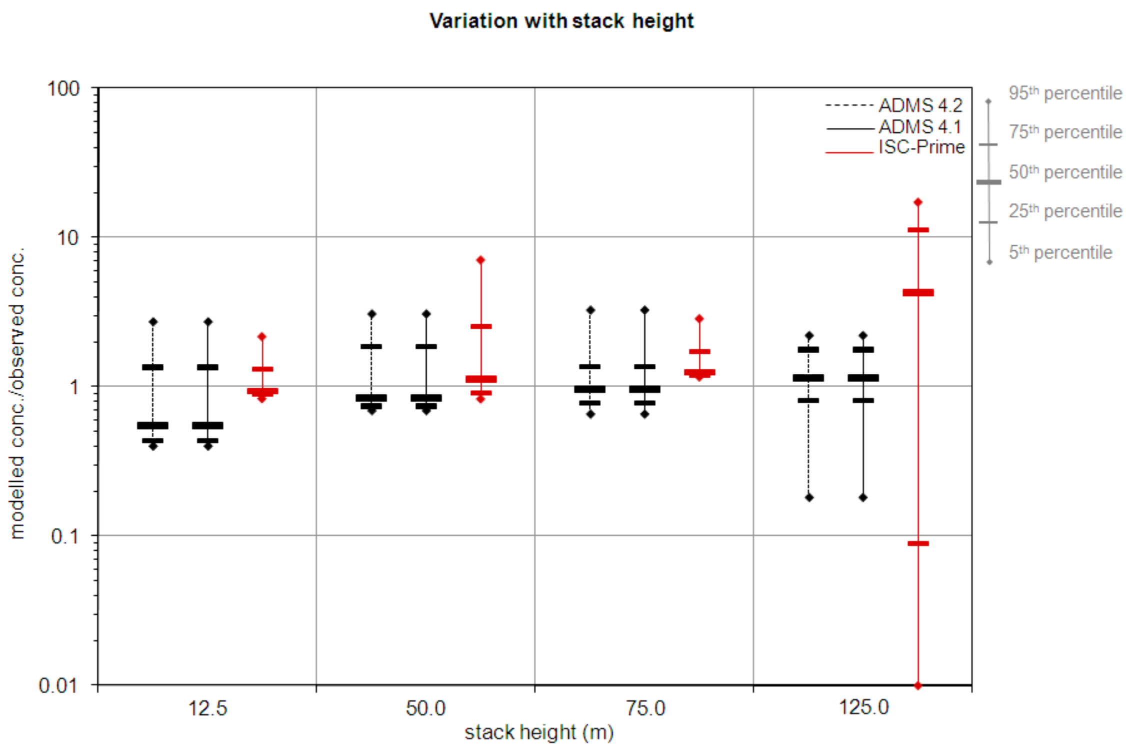

Figure 2 − Box and whisker plot of model results, variation with stack height.

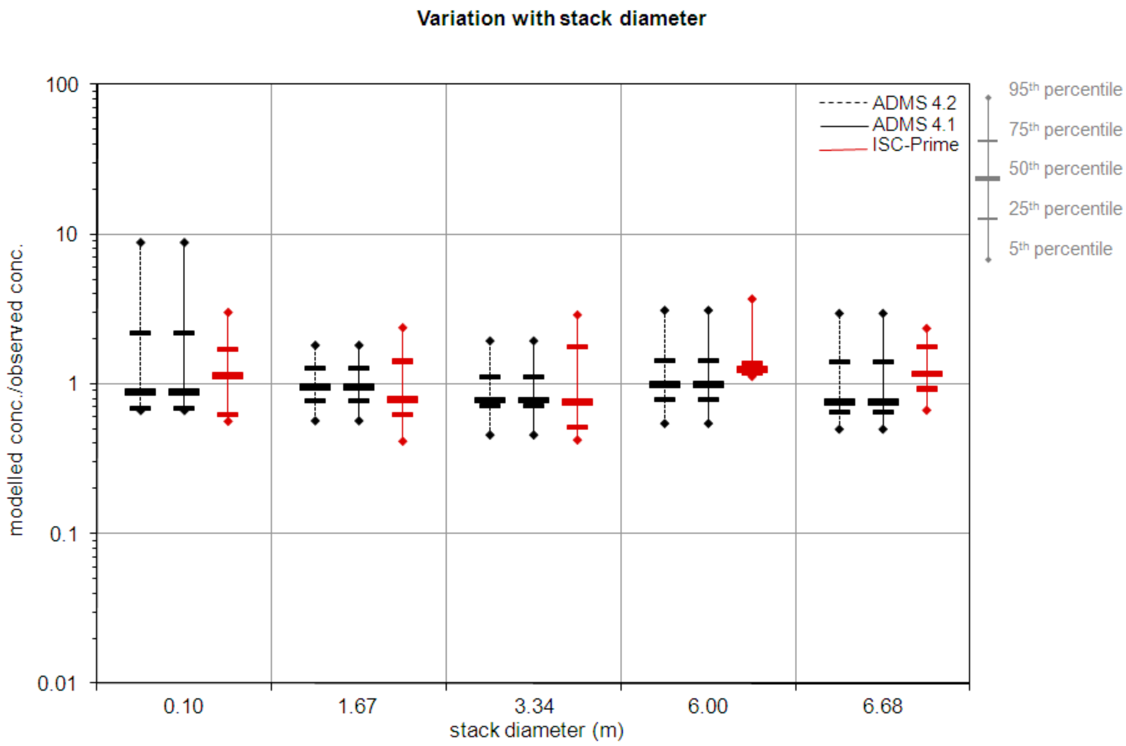

Figure 3 − Box and whisker plot of model results, variation with stack diameter.

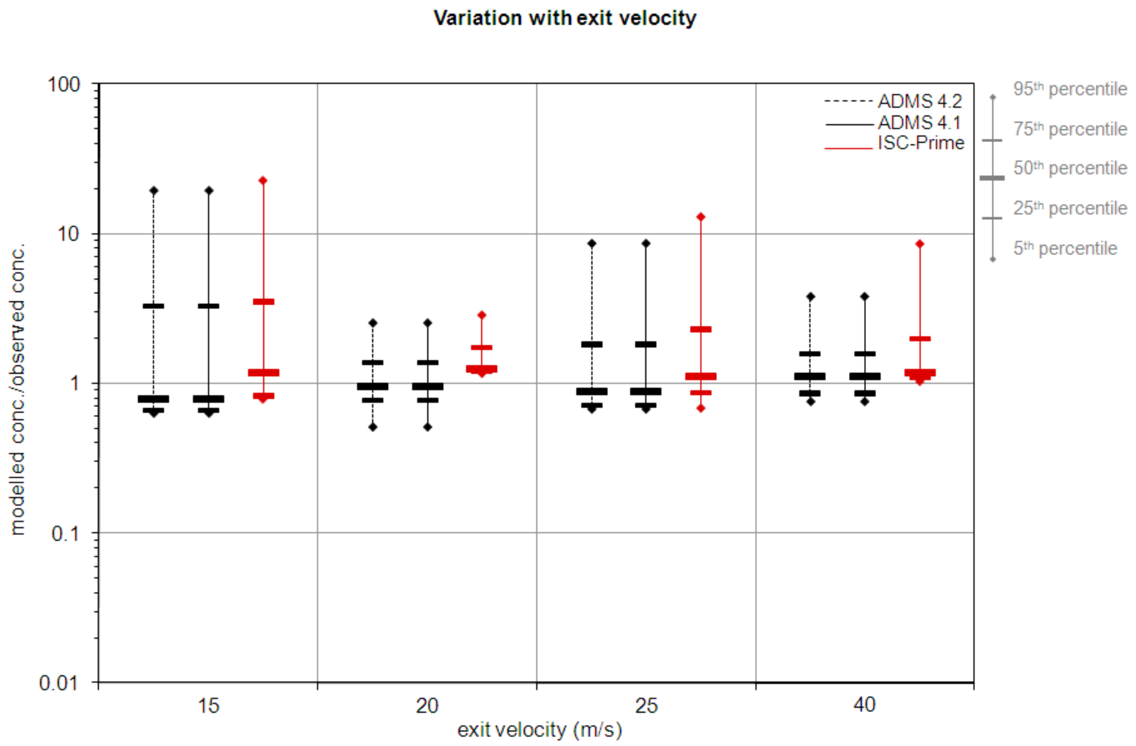

Figure 4 − Box and whisker plot of model results, variation with exit velocity.

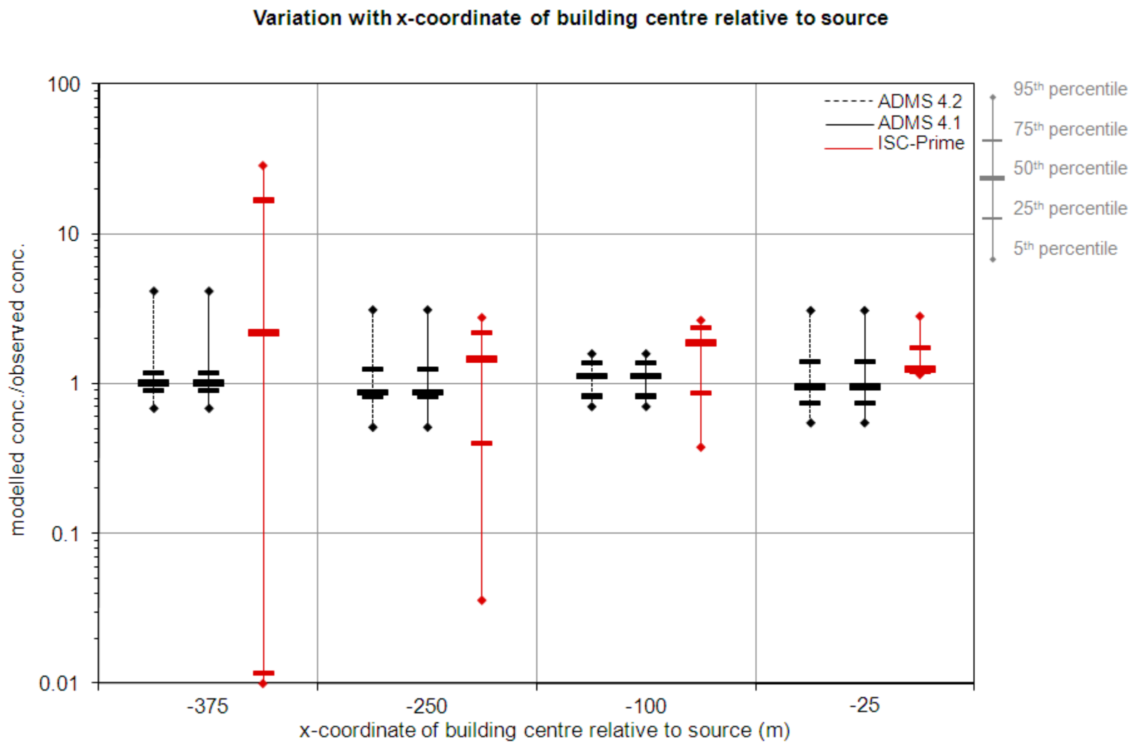

Figure 5 − Box and whisker plot of model results, variation with x-coordinate of building centre relative to source (y-coordinate = 0).

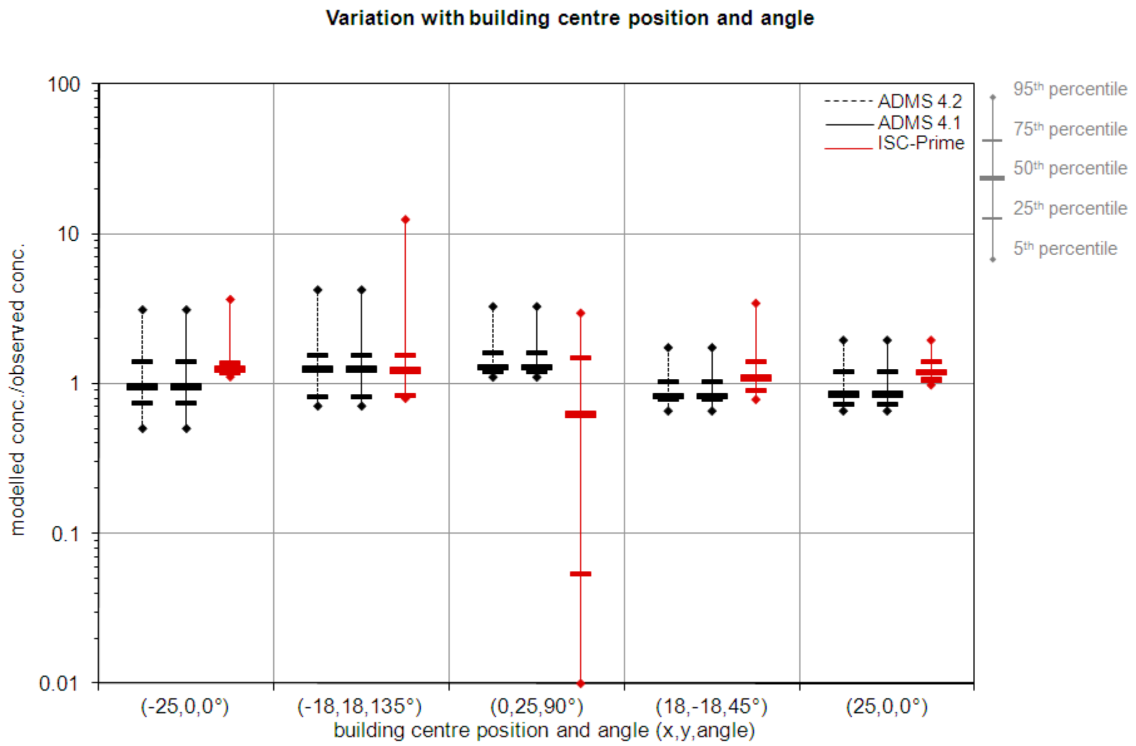

Figure 6 − Box and whisker plot of model results, variation with building centre position and angle.

4 Additional information: calculation of emission characteristics

Snyder considered a steam boiler with the characteristics as a base case shown in **Table 7**.

l (m)	w (m)	H_b (m)	L (m)	D_s (m)	H_s (m)	W_s (m/s)	T_s (K)	U_s (m/s)
100	40	50	25	6	75	20	418	13.4

Table 7 − Parameters of the steam boiler for the base case (at full scale) with l the building length, w the building width, H_b the building height, L the distance from the building centre to the stack centre (L is positive if the stack is downstream of building), D_s the source diameter, H_s the source height, W_s the exit velocity, T_s the emission temperature, and U_s the wind speed at top of stack.

The parameters were formed into non-dimensional variables. The table below shows the base-case values, ranges of parameter variations, and number of values of each parameter tested in Snyder's original study.

	H_s/H_b	L/H_b	θ (°)	W_s/U_s	Fr_a	ρ_s/ρ_a
Minimum	0.25	-5.0	0	1.5	8	0.7
Base	1.5	0.5	0	1.5	16	0.7
Maximum	2.5	7.5	180	4.0	∞	0.7

Table 8 − Values of dimensionless groups used in Snyder's original study. The meaning of θ,

Fr_a, ρ_s and ρ_a is explained below; see caption of **Table 7** for meaning of the other variables.

In the wind tunnel experiments, a mixture of air and helium was used to simulate the full-scale high temperature emissions. For the model runs T_s was specified explicitly, giving the same ratio of source density to ambient (see below).

Here θ is the building orientation (defined as zero when the wind direction is perpendicular to the long face of building). ρ_s and ρ_a are effluent and ambient density respectively. Fr_a is the Froude number expressed as follows:

$$Fr_a = \frac{W_s^2}{gD_s(\Delta T / T_a)},$$

where T_a is the ambient temperature (in K) at the stack top, $\Delta T = T_s$-T_a.

For the base case $Fr_a = 16$, $W_s = 20$ m/s, $D_s = 6$ m and $T_s = 418$ K, substituting these values into the expression for the Froude number gives the ambient temperature $T_a = 293$ K.

Emission density

For a perfect gas,

$$P = \frac{\rho RT}{M},$$

where P is pressure, ρ is the density, R = 8.314 J kg^{-1}mol^{-1} is the universal gas constant, T is the absolute temperature and M is the molecular weight.

For a particular gas, at a fixed pressure this gives

$$\rho_1 T_1 = \rho_2 T_2 .$$

Hence, if $T_1 = 418$ K and $T_2 = 293$ K,

$$\rho_1 = 0.7 \rho_2 .$$

Hence for the model runs, the gas released may be assumed to have the properties of air (i.e. $c_p = 1012$ J/kg^{-1}K^{-1}, $M = 28.96$ g), with $T_s = 418$ K (= 145°C) and $T_a = 293$ K (= 20°C).

5 References

[1] Snyder, W.H., 1993: *Downwash of Plumes in the Vicinity of Buildings − A Wind Tunnel Study*. In proceedings of the NATO Advanced Research Workshop: "Recent Research Advances in the Fluid Modeling Mechanics of Turbulent Jets and Plumes", Viano do Castelo, Portugal, June 28 - July 2, 1993.