#5264

Building Research Establishment PD 123/91

ASSESSING INTAKE CONTAMINATION FROM ATMOSPHERIC DISPERSION OF BUILDING EXHAUST

by M D A E S Perera, R G Tull, M K White and R R Walker

SUMMARY

The possibility of unacceptable internal air pollution levels can cause concern at the design stage given the potential for cross contamination between building exhausts and ventilation intakes is there. The complexity of airflows around buildings, however, makes it extremely difficult to predict the contamination levels at the intake locations. This paper reports a wind tunnel technique using a model of a proposed building to determine the pollutant levels expected at various inlet locations due to the re-ingestion of noxious emissions from its two stacks.

Tests were carried out in the BRE environmental wind tunnel on a 1 in 200 scale model of the proposed building with the approach wind simulated to correspond to the flow over a suburban terrain. Two tracer gases, sulphur hexafluoride and nitrous oxide, were injected separately, and at known concentrations, from the stacks at an efflux velocity corresponding directly to that required at full scale. Tests were carried out over a range of wind directions and speeds expected to occur for over 95% of the time. Air samples were taken at various locations on the model surface through brass tubes fitted from the inside. The concentration of the sampled air was measured using infrared gas analysers and the results presented as pollutant fractions in grams of pollutant measured to a kilogram of emitted pollutant.

Comparison of the measured maximum concentration levels with those predicted from an ASHRAE procedure showed in general good agreement. However, the wind tunnel test procedure was able to provide detailed information on the contaminant levels that would be expected at these intake locations for the range of wind speeds and directions anticipated at the site.

This paper is to be presented at the 12th AIVC Conference on Air Movement and Ventilation Control Within Buildings

July 1991
Project: GW551
BRE/66/7/6

Building Research Establishment
Garston, Watford, WD2 7JR
Telephone: 0923 894040
FAX: 0923 664010

INTRODUCTION

The possibility of unacceptable internal air pollution levels can cause concern at the design stage if there is a potential for cross contamination between building exhausts and ventilation intakes. There is a considerable body of work, notably by Wilson [1], and incorporated in the 1989 ASHRAE Fundamentals [2], which provides general guidance to the expected levels of contamination. However, by necessity, this guidance addresses 'isolated' buildings, i.e. where there is no strong and direct airflow interaction with neighbouring buildings. On occasions when interactions are expected, e.g. a building of similar height in close proximity, the complexity of airflows around buildings makes it extremely difficult to predict the levels of contamination. In such instances, wind tunnel studies can provide the nearest approximation to that expected at full scale.

This paper reports a wind tunnel study carried out on a model of a proposed 30 m high research laboratory building (Building A) to be erected in a suburban environment and adjacent (Fig. 1) to an existing laboratory building (Building B) of approximately the same height. A major part of the study was to determine distribution of fume cupboard effluent by two 4 m high stacks (Stacks I and II) on the roof of the proposed building and the resulting levels of contamination at fresh air intakes and windows in both the new and existing adjacent building. Although contamination levels were measured at 14 locations on various facades of the two buildings, measurements made in only three of these locations (Fig. 1) are described in this paper.

This paper describes the wind tunnel modelling arrangements, the testing procedure and the results obtained. The measured contaminant levels, presented as pollutant fractions in grams per kilogram, are compared with those derived from ASHRAE predictions for isolated buildings.

EXPERIMENTAL ARRANGEMENTS

Model

A 1:200 scale model of the proposed building A, the nearby existing building B and some surrounding low-rise buildings was mounted on the 1.75 m diameter turntable of the BRE environmental wind tunnel. Each of the two 4-metre high stacks consisted of 10 individual flues, each modelled by 1.5 mm internal diameter (ID) brass tubing. Apart from the flue outlets, each stack was constructed as an air-tight manifold box with a connector at the base. A 6 mm outer diameter (OD) nylon tube was attached to each of these connectors through which a mixture of air and tracer gas could be supplied (Fig. 2).

At each of the sampling locations, short lengths of 1.5 mm ID brass tubes were fitted from the inside, one end flush with the external building surface. Internally, these were individually connected (Fig. 2) to 300 mm lengths of flexible plastic tubing. These, in turn, were connected (by purpose-built push-fit brass adaptors) to 6 mm OD nylon sampling lines which were then brought together to a multiway valve connected to a sampling system (Fig. 2).

Wind tunnel modelling of the natural wind

The tests were carried out in the BRE environmental wind tunnel with a simulation for the approaching wind corresponding to a suburban terrain at a scale of 1:200. The wind simulation was generated by a bi-planar grid and a 300 mm high saw-tooth wall to start the required boundary layer, followed by a fetch of about 7 metres of 30 mm tall roughness elements (Fig. 3). Fuller details of the simulation are given in Reference 3. Tests were carried out at a 1:1 velocity scale so that air speeds measured in the wind tunnel corresponded to those at full scale.

Ratio of exhaust velocity to mean wind speed

To simulate the atmospheric dispersion of building exhausts, it is also necessary to match (equal in model and full-scale) the ratio V_E/U_H, where V_E is the exhaust velocity and U_H is the mean undisturbed upwind speed at the height of the proposed building A. During the tests, V_E was maintained at a specified full scale speed of 7 m/s.

The mean wind speed, U_H, was measured with a hot-wire anemometer in the free undisturbed flow upstream of the model at 150 mm (30 m in full scale) above the base of the wind tunnel. Tests were conducted at four wind speeds (1, 2, 4 and 8 m/s) to cover a sufficient range of ratios of efflux velocity to wind speed, excluding calm conditions. To relate these speeds to those expected at the site, meteorological wind data were obtained from the UK Meteorological Office for the weather station nearest to the site. Figure 4 summarises the essential features of this data.

For a suburban site, as for the present investigation, Penwarden and Wise [4] have shown that U_H can be related to the open-site meteorological wind speed u_{10} (measured at a height of 10 m) by,

$$U_H = u_{10}\,(0.315\,H^{0.28})$$

$$= 0.82\,u_{10} \qquad \text{for } H = 30 \text{ m}$$

Hence, the wind speed range covered during the tests correspond to a u_{10} range between 1.2 and 9.8 m/s. Figure 4 shows this covers about 95% of the range of expected wind speeds.

TEST PROCEDURE AND CONCENTRATION MEASUREMENTS

The tests involved injecting tracer gas at a known concentration from the two stacks (Fig. 2) and measuring the resulting concentrations at each sampling location. To identify the separate effect of each stack emission, two tracer gases were used. Nitrous oxide (N_2O) was emitted from Stack I located at the south-east end and sulphur hexafluoride (SF_6) from Stack II at the north-west end.

For each stack, an exhaust velocity of 7 m/s meant a flow rate of 7.4 litres/min of the air/tracer gas mixture. The uncontaminated air used in the mix was obtained from compressed air cylinders. The proportion of tracer gas used in this mix was dictated by the need:

(a) to bring its flow rate within the range of the available flow meter, and
(b) to ensure that the maximum concentration sampled at any location is within the range (0 to 200 parts per million by volume) of the infra-red gas analysers used during the tests.

Before each test, these analysers were zeroed and then calibrated using gas/air mixtures of known concentrations.

At each wind speed, contaminant concentration measurements were made at the sampling locations for winds from each of 12 principal wind directions at 30° intervals. Wind directions are given in the conventionally accepted form; 0° is wind from the North, 90° is wind from the East etc..

Taking account of the settling time required from the analysers when switched from one location to another, each measurement took approximately three to four minutes per location for any one wind speed and direction. The resulting analogue signals from the analysers were digitised and processed using an on-line analogue-to-digital convertor linked to an IBM PC. Fluctuations were smoothed out and the average concentration of each of the gases (at that location) evaluated.

Background concentration levels were also monitored throughout the tests to take account of any build-up of tracer gases within the wind tunnel. These levels were, however, found to be negligible. This is possibly because the wind tunnel being an open-jet type has no return circuit and is housed in a building which is well-vented to the outside.

RESULTS AND DISCUSSION

The measurements were noted and the ratio of sample concentration to emitted concentration calculated. This ratio, termed the pollution fraction, is expressed as grams sampled per kilogram emitted. Figure 5 shows the results plotted in a graphical form for each of the three locations.

The concentration measured at these or any other measurement location did not, on any occasion, exceed 3 g/kg (i.e. 0.3% of the emission concentration). In addition, the following salient features were observed at the three locations:

Location 1:

From both Stacks I and II, there is a relatively high level of contamination but is confined to a narrow band of wind directions between 90 and 150°N. This is due to re-entrainment of the stack exhausts to the leeward edge and face of the building. It should be noted, however, that winds from these directions occur only for about 10% of the time (Fig. 4).

Interestingly there is low contamination with a 1 m/s wind, rising to high contamination at the intermediate winds of 2 and 4 m/s and then decreasing to medium contamination at the highest 8 m/s wind. This is because at low wind speeds, the exhaust jet rises well above the building (and the wind region influenced by it) so that concentrations at the building intakes are low. At higher wind speeds, a given amount of exhaust plume is proportionately stretched out by the wind which again results in low concentrations. Between these two extremes, there is a critical wind speed, U_{crit}, at which the highest concentration (C_{max}) occurs. Other locations show similar features.

Location 2:

Emissions from Stack I for wind directions 90 and 120° show low levels at this location - otherwise levels are negligible. Since the sampling point is located approximately mid-way between Stacks I and II (Fig. 1), similar pollutant fractions - but at a higher level - occur (in a symmetrical manner) from Stack II emission for winds from 0 and 330°N. Winds come from these two directions for only about 10% of the time (Fig. 4).

Location 3:

This position (which is on the north-west face of building B) appears to be affected by emissions only for those winds blowing from 330°, i.e. when this location is directly in the lee of the two stacks. Figure 4 shows winds from this direction only for about 5% of the time. Note that pollutant fractions are higher for emissions from Stack II (which is further away from the sampling location) than Stack I and may be a result of the exhaust plume from Stack II being entrained between the two buildings.

COMPARISON WITH ASHRAE PREDICTIONS

ASHRAE [2] provides empirical equations which can be used not only to estimate the expected maximum concentration (C_{max}) levels at intakes affected by emissions from exhaust stacks but also to identify the critical wind speed, U_{crit}, at which this occurs. For an uncapped stack of height h, and which is well clear of local recirculation regions, these equations are given by,

$$C_{max} = \frac{\beta - 3.55\alpha}{\left[1 + 7B^{0.67}\gamma^{1.33}\right] . \exp\left(12.6\alpha^2 + 3.55\alpha\beta\right)}$$

and

$$U_{crit} = \frac{2.9\ V_e}{B^{0.33}\ \gamma^{0.67}\ (\beta - 3.55\alpha)}$$

where $\alpha = h/S$ in which h (m) is the height of the stack above roof level and S (m) is the 'stretched string' distance between exhaust to intake measured along building surface

$\beta = (1 + 12.6\alpha^2)^{0.5}$

and $\gamma = S/A^{0.5}$ in which A (m^2) is the face area of the exhaust outlet.

In the above equations, B is a distance-dilution parameter. ASHRAE [2] recommends values of 0.0625 for flat-roofed buildings in low-rise surroundings when exhaust and intake locations are on the same building wall or on the roof. For roof exhausts with wall intakes, a value of about 0.2 is suggested.

Using values of V_e = 7 m/s, h = 4 m and A = 0.71 m^2, the predicted maximum levels and critical wind speeds have been calculated and tabulated below. For comparison, measured values are shown alongside. Similar comparisons, between measured and predicted, have also been made elsewhere [5].

Emission from Stack I							
Location	**Stretched -string distance**	**Measured**		**Predicted with B=0.0624**		**Predicted with B=0.2**	
	S *m*	**C_{max}** *g/kg*	**U_{crit}** *m/s*	**C_{max}** *g/kg*	**U_{crit}** *m/s*	**C_{max}** *g/kg*	**U_{crit}** *m/s*
1	30	2.3	2	2.4	7	1.1	5
2	14	0.8	all	0.7	19	0.3	13
3	42	0.9	2	2.3	5	1.0	4

Emission from Stack II							
Location	**Stretched -string distance**	**Measured**		**Predicted with B=0.0624**		**Predicted with B=0.2**	
	S *m*	**C_{max}** *g/kg*	**U_{crit}** *m/s*	**C_{max}** *g/kg*	**U_{crit}** *m/s*	**C_{max}** *g/kg*	**U_{crit}** *m/s*
1	13	2.5	> 8	0.6	21	0.3	14
2	20	2.1	> 8	1.8	12	0.8	8
3	58	2.2	2	1.9	4	0.9	3

The above comparison shows acceptable order-of-magnitude agreement between measured and predicted maximum concentration levels. With two exceptions, agreement is particularly good when the distance-dilution parameter is set at B=0.0624, i.e. when there is an implicit assumption of a clear interaction between exhaust and intake. The exceptions, an over-prediction for Location 3 (from Stack I) and an under-prediction for Location 1 (from Stack II), probably result from the airflow interactions between the two buildings.

Comparison between predicted and measured critical wind speed is not good. However, this parameter is of limited value in any contamination assessment and therefore merits little concern.

GENERAL CONCLUSIONS

The pollutant levels expected at various inlet locations on two adjacent buildings as a result of exhaust-stack emissions was measured in a wind tunnel using a tracer gas technique. Measurements over a range of wind speeds and directions showed the variation of concentration levels with these parameters. These measurements also enabled the identification of the wind parameters that would result in maximum contaminant levels at these locations.

The measured maximum concentration levels were compared with an ASHRAE prediction procedure for the case of isolated buildings. In general, there was an acceptable order-of-magnitude agreement but this improved considerably with the choice of the distance-dilution parameter used in the prediction procedure.

To summarise, in the absence of a wind tunnel test, ASHRAE procedures could be used to provide guidance as to expected maximum contaminant levels at intake locations. However, wind tunnel tests provide more detailed and accurate estimates, e.g when there is the possibility of airflow interactions with neighbouring building, or when it is necessary to consider the specific effects of local wind speeds and directions.

ACKNOWLEDGEMENTS

The methodology described in this paper was developed as a result of a specific study carried out under Building Research Establishment's (BRE) technical consultancy work and we are grateful to the Client for permission to present the generic results. The assistance of Alan Penwarden in the experimental work is also gratefully acknowledged. This paper is published by permission of the Chief Executive of BRE.

REFERENCES

1. Wilson, D J, A design procedure for estimating air intake contamination from nearby exhaust vents, ASHRAE Transactions, Vol. 89 (2), pp 136-52, (1983).

2. ASHRAE, Chapter 14: Airflow around buildings, 1989 Fundamentals Handbook (SI), ASHRAE, Atlanta, USA, (1989).

3. Perera, M D A E S, Shelter behind two dimensional solid and porous fences, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 8, pp 89-104, (1981).

4. Penwarden, A D and Wise, A F E, Wind Environment Around Buildings, Building Research Establishment Report, HMSO, (1975).

5. Schuyler, G D, Comparison of wind tunnel test results with empirical exhaust dilution factors, ASHRAE Transactions, Vol 95(2), (1989).

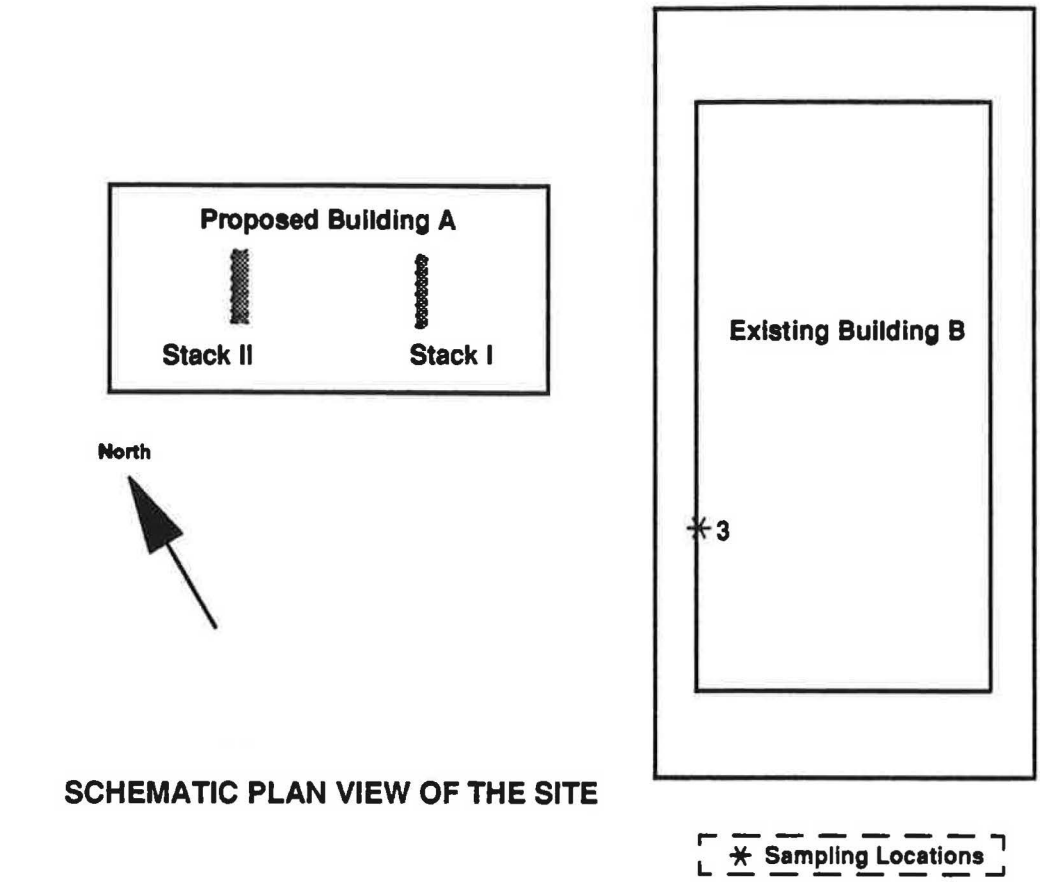

FIGURE 1 - SCHEMATIC OF BUILDINGS

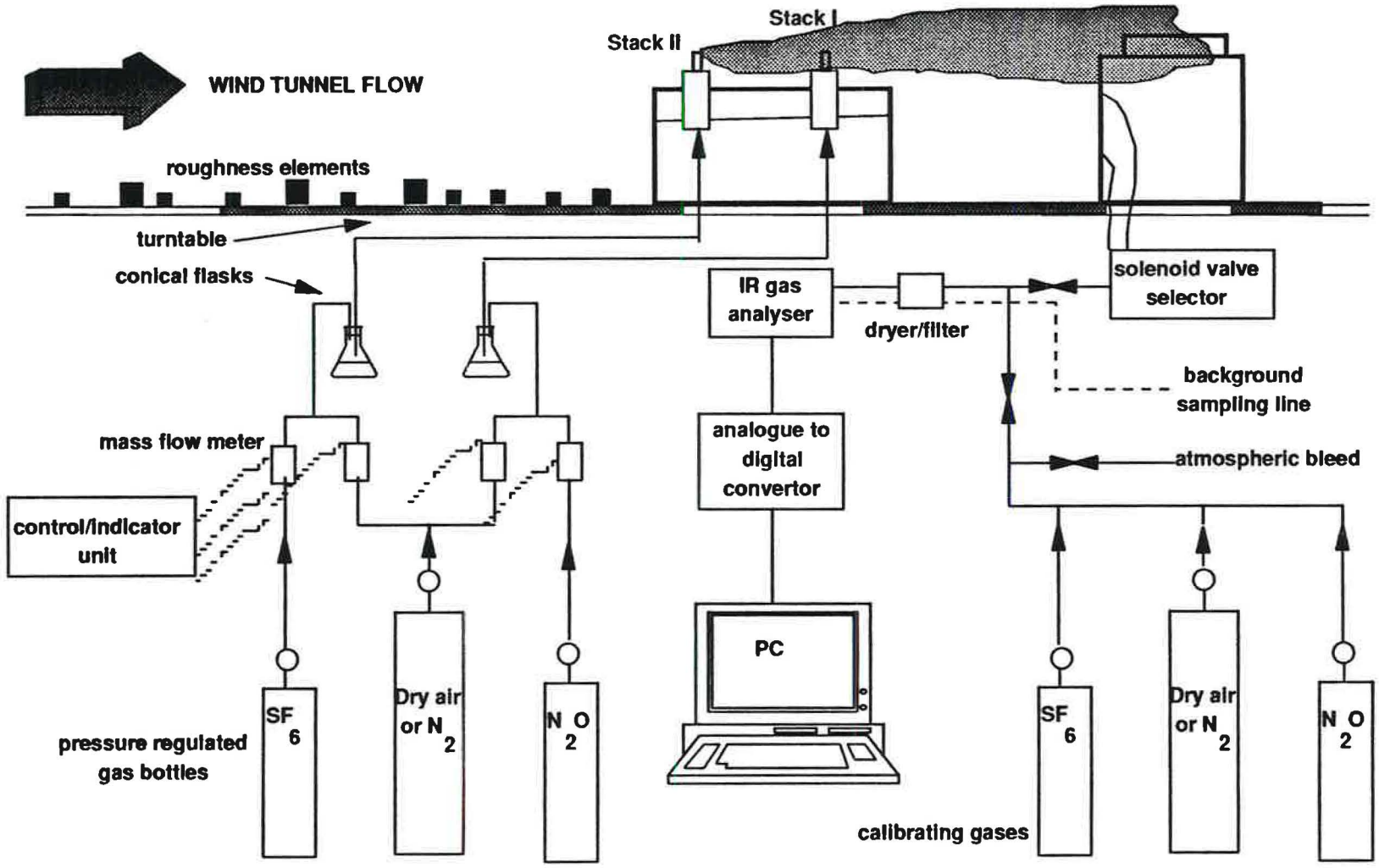

FIGURE 2 - SCHEMATIC OF GAS SUPPLY AND SAMPLING SYSTEM

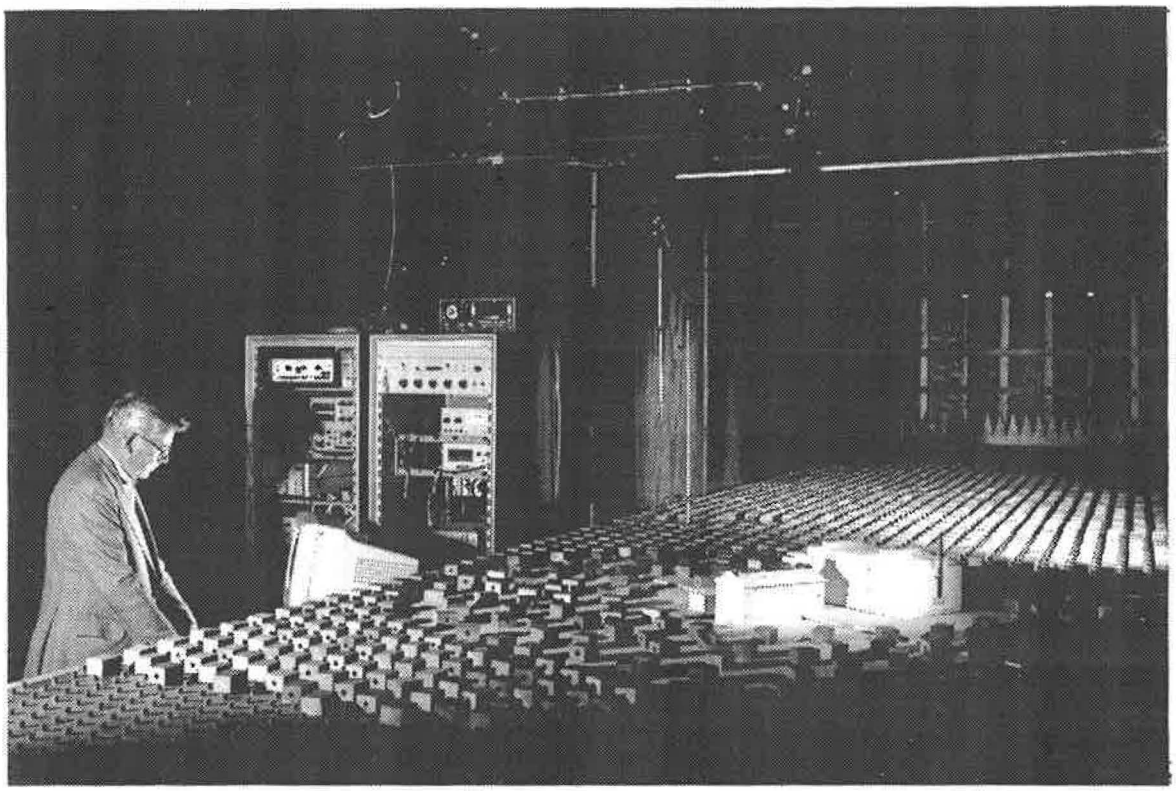

FIGURE 3 - MODEL BUILDINGS IN WIND TUNNEL

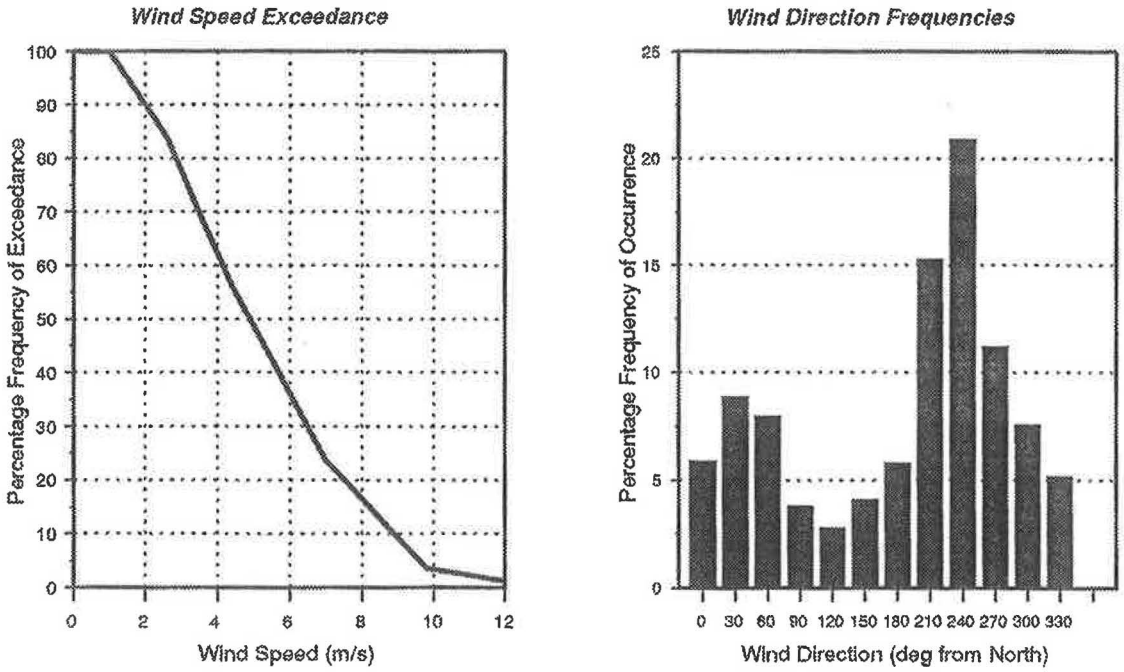

FIGURE 4 - WIND CONDITIONS AT MET. SITE

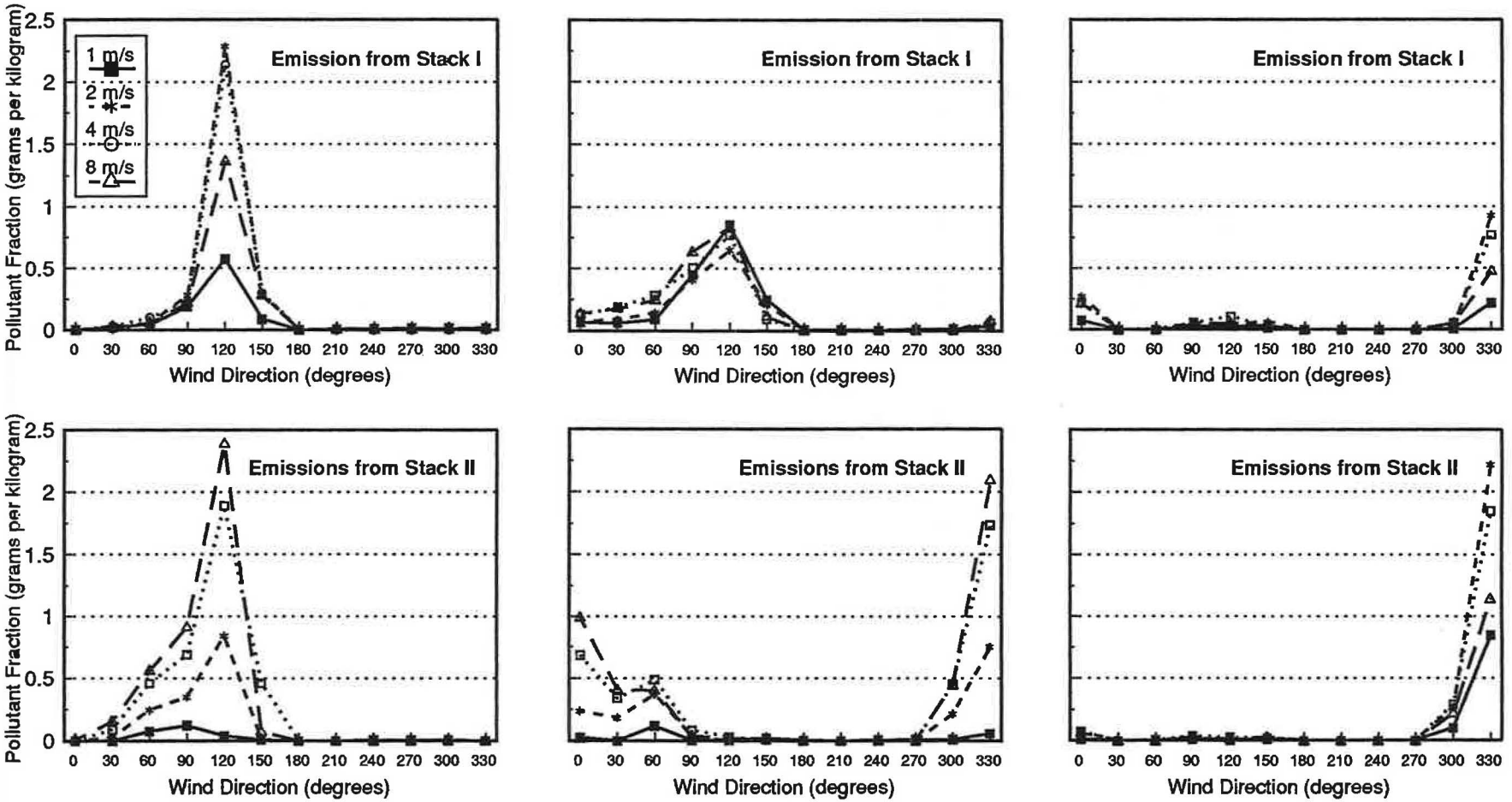

FIGURE 5 - POLLUTION FRACTIONS AT INTAKE LOCATIONS

Building Research Establishment PD 213/91

WIND TUNNEL METHOD TO ASSESS INTAKE CONTAMINATION FROM BUILDING EXHAUST

by M D A E S Perera and R G Tull

SUMMARY

The possibility of unacceptable internal air pollution levels can cause concern at the design stage given the potential for cross contamination between building exhausts and ventilation intakes. The complexity of airflows around buildings, however, makes it extremely difficult to predict the contamination levels at the intake locations. This paper reports a wind tunnel technique using a model of a proposed building to determine the pollutant levels expected at various inlet locations due to the reingestion of noxious emissions from its two stacks.

This paper is to be published in Building Services - The CIBSE Journal - as a Research Report.

December 1991
Project: GW551
BRE/66/7/6

Building Research Establishment
Garston, Watford, WD2 7JR
Telephone: 0923 894040
FAX: 0923 664010

WIND TUNNEL METHOD TO ASSESS INTAKE CONTAMINATION FROM BUILDING EXHAUST

by Earle Perera and Roger Tull

The possibility of unacceptable internal air pollution levels can cause concern at the design stage if there is a potential for cross contamination between building exhausts and ventilation intakes. There is general guidance [1] on the expected levels of contamination but this guidance addresses 'isolated' buildings, i.e. where there is no strong and direct airflow interaction with neighbouring buildings. On occasions when interactions are expected, e.g. a building of similar height nearby, the complexity of airflows around buildings makes it extremely difficult to predict the levels of contamination. In such instances, wind tunnel studies can provide the nearest approximation to that expected at full scale.

Recently, BRE carried out a wind tunnel study [2] to determine distribution of fume cupboard effluent from two 4m-high stacks on the roof of a 30m-high proposed laboratory building. As part of the study, the resulting levels of contamination expected at outside air intakes and windows were measured in both the proposed and an existing adjacent building.

A 1:200 scale model of the proposed building, the nearby existing building of approximately the same height and some surrounding low-rise buildings were mounted on the 1.75m-diameter turntable of the BRE environmental wind tunnel. Each of the two stacks was modelled by brass tubing through which a mixture of air and tracer gas was supplied.

At each sampling location, short lengths of brass tubes were fitted from the inside, one end flush with the external building surface and connected internally to lengths of small bore plastic tubing. These, in turn, were brought together to a multiway valve connected to a gas sampling system.

Tests were carried out in the wind tunnel (Fig. 1) with a simulation for the approaching wind corresponding to that over a suburban terrain. To simulate the atmospheric dispersion of building exhausts, it was necessary to match (equal in model and full-scale) the ratio of the exhaust velocity to the mean undisturbed upwind speed at a reference height; in this case at the height of the proposed building. Tests were conducted at various wind speeds to cover a sufficient range of these velocity ratios.

The tests involved injecting separately two tracer gases, sulphur hexafluoride and nitrous oxide, at known concentrations from each of the two stacks. The resulting concentrations at each sampling location were measured using infrared gas analysers. The pollutant fractions, i.e. the ratios of sample concentration to emitted concentration, were then calculated and expressed as grams sampled per kilogram emitted. Figure 2 shows a typical result obtained at one measuring location.

A feature of interest, shown in this example, is the low contamination with a 1 m/s wind, rising to high contamination at the intermediate winds of 2 and 4 m/s and then decreasing to medium

contamination at the highest 8 m/s wind. This is because at low wind speeds, the exhaust jet rises well above the building (and the wind region influenced by it) so that concentrations at the building intakes are low. At higher wind speeds, a given amount of exhaust plume is proportionately stretched out by the wind which again results in low concentrations. Between these two extremes, there is a critical wind speed at which the highest concentration occurs.

The pollutant levels expected at various other inlet locations on the two buildings were also similarly measured. This allowed us to identify maximum contaminant levels expected at these locations with the corresponding wind conditions.

In conclusion, there is increasing public awareness over health and environmental issues related to air quality in buildings. In response to this awareness, and in parallel to it, there is also growing concern among CIBSE members about the interaction between building exhaust and the internal air environment. This study shows how these concerns can be addressed at the preconstruction stage by a wind tunnel test and the power of such an environmental assessment.

REFERENCES

1. ASHRAE, Chapter 14: Airflow around buildings, 1989 Fundamentals Handbook (SI), ASHRAE, Atlanta, USA, (1989).

2. Perera, M D A E S, Tull, R G, White, M K and Walker, R R, Assessing intake contamination from atmospheric dispersion of building exhaust, Proceedings of the 12th AIVC Conference on Air Movement and Ventilation Control within Buildings, (September 1991).

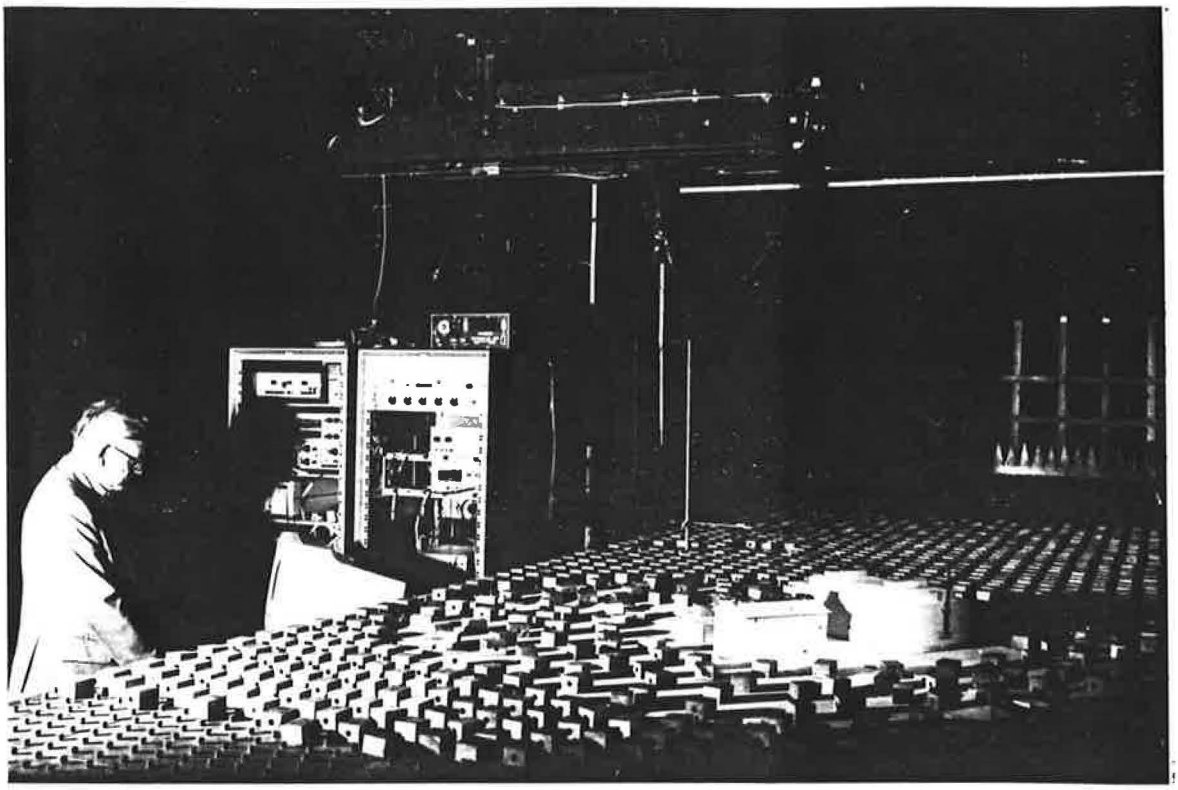

FIGURE 1 - MODEL BUILDINGS IN WIND TUNNEL

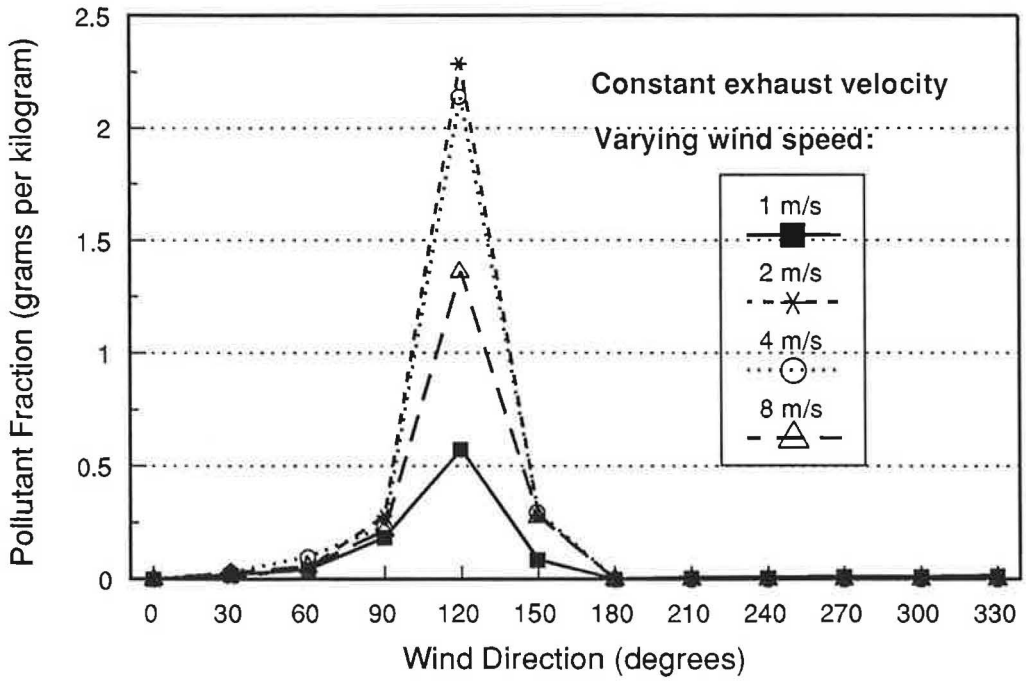

FIGURE 2 - POLLUTANT FRACTION AT INTAKE LOCATION