AIR POLLUTION DISPERSION AROUND URBAN BUILDINGS: A WIND TUNNEL STUDY

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ABSTRACT

Contamination of indoor air from outdoor pollution is dependent on the pollutant concentration levels around a building. The concentration distributions generated on the building surface are strongly influenced by the position of the pollutant source and the subsequent wind flow and dispersion processes from the source. The effects of the pollutant source position on the magnitude and spatial variation in concentrations likely to be generated on urban buildings have been investigated in a boundary layer wind tunnel. The aim was to determine the region around a building from which the pollutant plumes from sources were likely to interact with the building (region of influence of sources) and generate concentration patterns on its surface. The tests were carried out at a nominal model scale of 1:100 and used continuous releases of a tracer gas at different locations within generic arrays of rectangular building models representative of urban areas. This paper reports the results of these experiments. This work is intended for use in developing guidance on effective ventilation strategies for minimising contamination of indoor air from outdoor pollution.

INTRODUCTION

Minimising the transfer of outdoor pollution into buildings is an important part of providing good indoor air quality for occupants particularly in urban areas where outdoor pollution levels can be high. Areas on the building where there is a combination of high-pressure differential across the surface, and high pollutant concentrations are high risk areas for ingress of outdoor pollution. These areas therefore need to be avoided when siting ventilation inlets. At present, it is not easy to predict where these high risk areas occur because there are limited measurements from which a direct correlation of pressure and concentration data can be made [1]. To understand where these high risk areas are likely to occur and before pressure and concentration measurements are made, it is important to first determine the region around the building from which the pollutant plumes from sources are likely to interact with the building (the region of influence of sources). Within the region of influence there are two sub-regions:

1. There is a region from which pollution sources generate relatively uniform concentrations on the building (in which case the ingress of outdoor pollution is independent of the concentration distribution and hence the siting of ventilation inlets);
2. There is also a region from which pollution sources generate non-uniform concentration distributions on the building (in which case the concentration distribution influences the ingress of external pollution and it is possible to site ventilation inlets to minimise this) [1].

The present study aims to provide this information and takes into consideration the effects of the area density of the array (the proportion of the surface covered by buildings) and the incident wind direction. The results of this work will provide a basis from which guidance on effective ventilation for buildings in urban areas can be produced. This research is being carried out at the Building Research Establishment Ltd (BRE) as part of a PhD thesis in partnership with the University of Manchester Institute of Science and Technology (UMIST).

EXPERIMENTAL DETAIL

2.1 The Dispersion Modelling Wind Tunnel

The experiments were carried out under neutral atmospheric conditions in BRE's Dispersion Modelling Wind Tunnel. The wind tunnel has a working section that is 22 m long, 1.5 m high and 4.3 m wide and is specially designed and equipped for dispersion modelling using tracer gases. The atmospheric boundary layer model was simulated using Counihan's [3] system of crenellated fence and vorticity generators followed by a long fetch of suitably roughened surface. Details of the atmospheric boundary layer model used in the present study can be found in [2].

2.2 Concentration measurements

A neutrally buoyant gas mixture consisting of 47% by volume of methane (tracer gas) in argon was used to represent the air pollution source. This was discharged at negligible momentum (volume flux of the order of 10^{-5} m^3s^{-1}) at different locations within the building arrays. Only ground level source positions were studied and for each individual source position the concentrations generated on the surface of an instrumented test building model (Figure 1) were measured using Flame Ionisation Detectors. Details of the concentration sampling procedure can be found in [2].

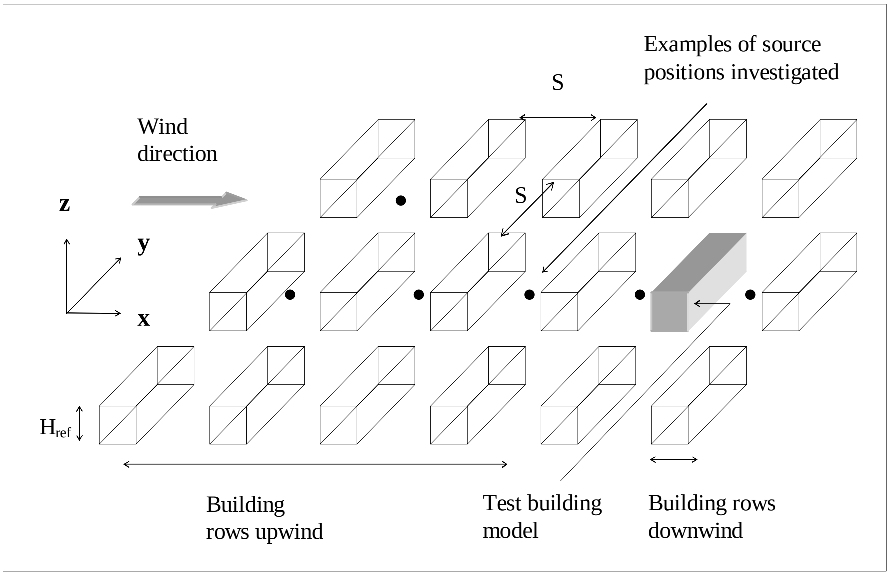

Figure 1. Basic experimental arrangement. S is the distance between individual buildings and H_{ref} is the reference height of the building models (0.1 m).

Individual measurements were sampled over two minutes, which was sufficient to obtain a stable average of the fluctuating concentration [2]. The measured concentrations were expressed as a dimensionless concentration, K, as given by,

$$K = \frac{c u_H H^2}{Q} \qquad (1)$$

where, c is the tracer gas concentration measured on the building, u_H is the wind speed at the reference height H (taken as the height of the building model) and Q is the volumetric rate of discharge of the tracer gas. For a given measured value of K, full-scale concentrations can then be obtained by substituting the appropriate full-scale values of u_H, H and Q.

2.3 Range of experiments

The experiments used rectangular buildings models is two area densities (A_d): 16% and 44% which approximate suburban areas and city centres respectively. These generic configurations were studied in a range of wind directions as detailed in Table 1 where the distance between individual buildings, S, is normalised with respect to the reference height of the building models, H_{ref}.

Building shape	Area density (%)	Spacing between building faces (S/H_{ref})	Number of building rows upwind	Wind directions (º)
(4x1x1)	16	2.75	6	0º, 15º, 30º, 60º, 90º
	44	0.9	9	0º, 15º, 30º, 45º, 90º

Table 1. Range of experiments

RESULTS AND DISCUSSION

Figure 2 shows concentration contours plotted over the 16% and 44% A_d arrays of building models, with variation in the incident wind directions. The values on the contours show the spatially averaged concentrations, K_{av}, over all faces of the test building from sources within the contoured regions. The outer-most contour represents an effective zero beyond which sources generate K_{av} values of the order of 10^{-5} or less. For the present study, this was taken as the boundary of the region of influence of sources. In each configuration, the region of influence was truncated at a fairly short distance downwind of the test building but always extended upwind of the test building to distances beyond the leading edges of the arrays studied in the wind tunnel. In Figure 2 (a), the extent of the region of influence across the wind in each configuration shows that the long building forms encouraged lateral spread of the plumes from upwind sources. This was particularly so in the 16% A_d array where the absolute distance across the region of influence, at its widest point, was up to 1.5 times higher than that in the 44% A_d array. The region of influence across the wind in the 16% A_d array did however cover the same number of streets as that in the 44% A_d array. When the incident wind direction was progressively increased from 0º through to 90º (Figure 2 (a to e)), the region of influence became increasingly skewed in the direction of the approaching wind.

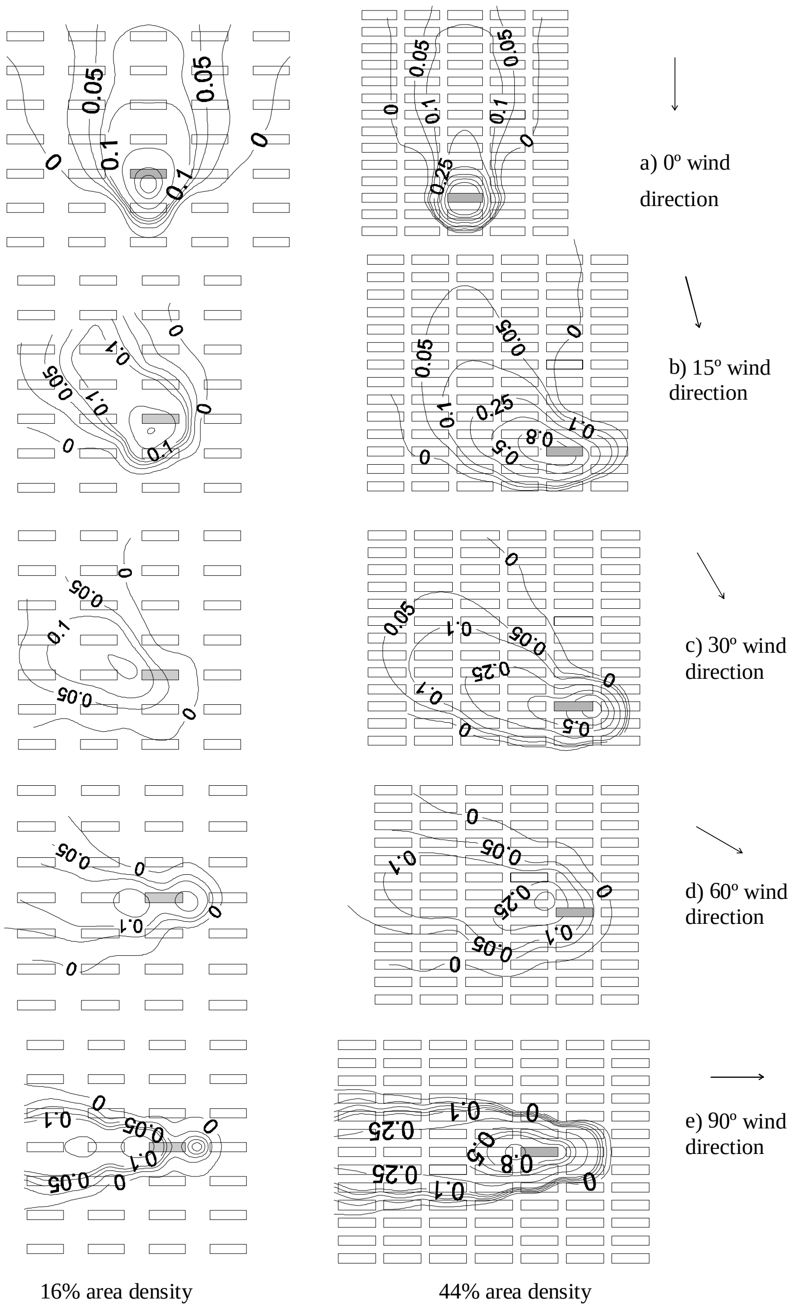

Figure 2. Spatially averaged concentrations, K_{av}, on the test building (shaded grey) from sources within the contoured regions.

Generally, the highest concentrations on the test building were generated by sources closest to it. The concentrations decreased with increasing source distance from the test building as plume diffusion increased in the wakes of successive buildings.

The contour maps in Figure 3 show the distribution in concentrations across the faces of the test building (spatial variation) for the same experiments as in Figure 2. In the contour maps, the spatial variation in concentrations is shown by the parameter, K_{diff}, which is the largest normalised difference in concentrations across any two faces on the test building (Equation

2). K_{diff} has a scale of 0 to 2 with the lower limit, zero, representing perfectly uniform concentrations on the test building and the upper limit, two, representing high spatial variation in concentrations on the building, due to one face having zero concentration.

$$K_{diff} = \frac{(K_{\max} - K_{\min})}{(K_{\max} + K_{\min})/2} \qquad (2)$$

In Equation 2, K_{max} *and* K_{min} are the maximum and minimum non-dimensional concentrations on the test building respectively.

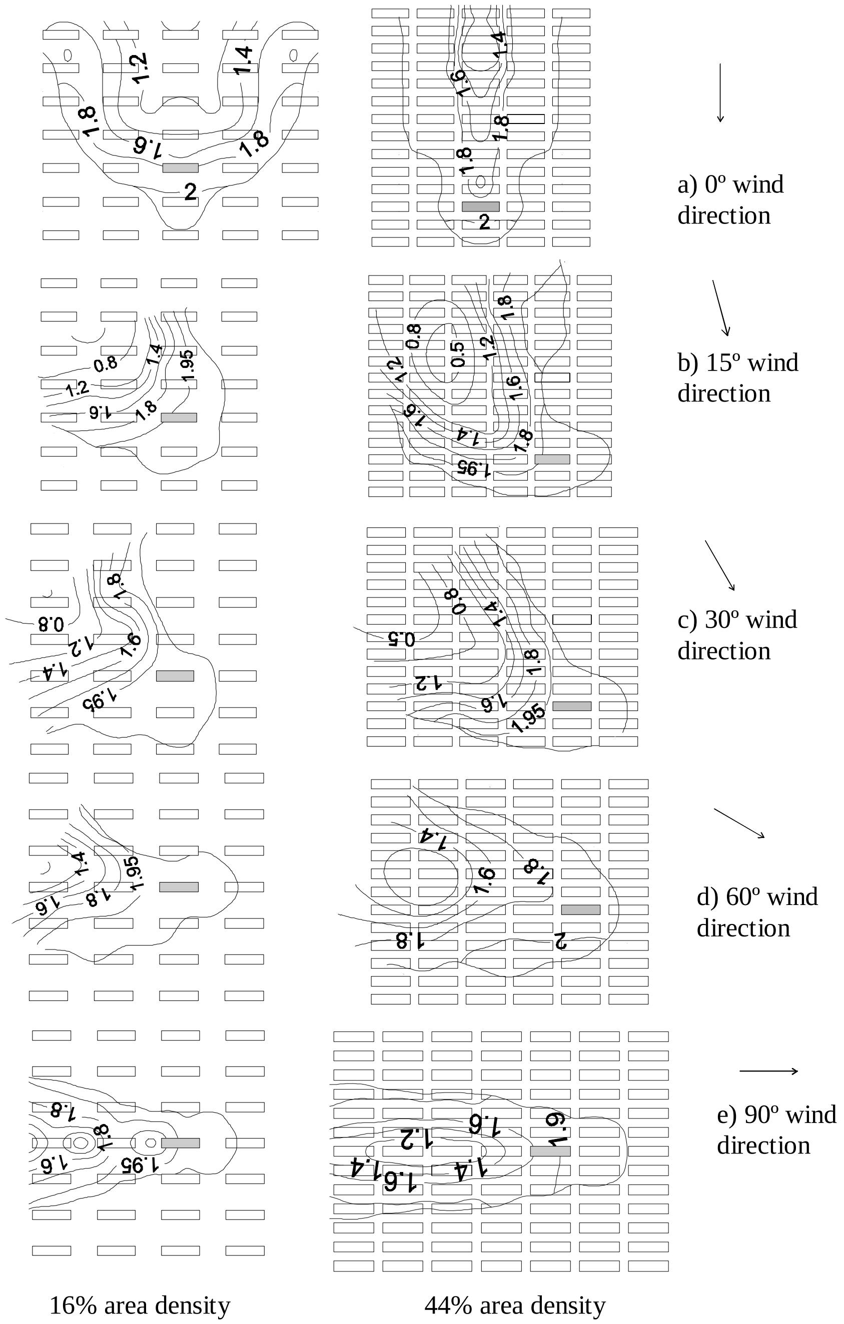

Figure 3. Spatial variation in concentrations, K_{diff}, on the test building (shaded grey) from sources within the contoured regions.

Sources close to the test building generated high K_{diff} values across its faces. Generally, the K_{diff} values decreased with increasing source distance from the test building as concentrations across the building faces became more uniform. The K_{diff} values decreased more quickly with upwind source distance in the 16% A_d array than in the 44% A_d array because the relatively widely spaced 16% A_d array facilitated plume diffusion more than the more densely packed 44% A_d.

CONCLUSIONS

The effects of the position of a pollution source on urban building exposure have been investigated in a boundary layer wind tunnel. The aim was to determine the region around a building within which the plumes from pollution sources were likely to interact with its surface and also the concentration levels that these sources generated. The variation in concentration patterns on the building depend strongly on the source position. The region of influence was found to extend a short distance downwind of the test building but upwind of the test building, always extended to distances beyond the arrays used in the wind tunnel. The incident wind direction had a strong effect on the region of influence. When the incident wind direction was progressively increased from 0º through a 90º arc, the region of influence became increasingly skewed in the direction of the approaching wind. Within the region, sources closest to the test building generated the highest concentrations, which decreased with increasing source distance from the building. Sources close to the test building also generated the greatest spatial variation in concentrations across the faces of the building. The results presented briefly in this paper show that it is should be possible to develop a strategy for predicting pollutant concentration levels on buildings taking into consideration the multiplicity of potential sources in urban areas. This work will play an important part in the development of guidance on effective ventilation strategies for minimising contamination of indoor air from outdoor pollution.

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