# VENTILATION TECHNOLOGIES IN URBAN AREAS

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# A WIND TUNNEL STUDY INTO THE LOCATION OF NATURAL VENTILATION AIR INTAKES IN URBAN AREAS


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**A wind tunnel study into the location of natural ventilation air intakes in urban areas.**

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**Synopsis** Ventilation of buildings in urban areas may result in high internal concentrations of traffic pollutants if air intakes are positioned where external concentrations are highest. This paper presents the results of a wind tunnel study into different wind-driven natural ventilation strategies for a building situated close to a busy road. Measurements of the concentration of a simulated traffic pollutant inside and around the building illustrate that noticeable reductions in internal concentrations can be achieved if air intakes are placed at roof level or on the leeward face of the building.

## 1. Introduction

Traffic pollution is of increasing concern in many of the world's cities. Occupants in buildings situated close to busy roads can expect to be exposed to a range of pollutants emitted by the motor vehicle such as oxides of nitrogen ($NO_X$), volatile organic compounds (VOC) and carbon monoxide (CO). On an urban scale, eighty-nine percent of all the CO in the atmosphere is due to the motor vehicle[1] and the concentration of CO in the atmosphere has been shown to be a good indicator of the concentration of other traffic related contaminants[2]. Although the health effects of these pollutants are not yet fully understood, asthma, other respiratory diseases and some cancers have all been linked to traffic emissions[3, 4].

When considering the ventilation of a building in the urban environment, either by natural or mechanical methods, the position of openings/air inlets is of great importance. If openings are placed where the pollutant concentration is highest then indoor concentrations can reach considerably high levels[5, 6]. The concentrations of traffic pollutants have been observed to decay with height and distance away from the road, which suggests that placing air intakes higher up or on the opposite side of the building to the traffic source should minimise the ingress of contaminated air into the building[7, 8].

It is difficult to assess the benefits of different air intake positions from measurements in the field. There are the obvious problems associated with constructing a full size prototype system or implementing a system into an existing building, and more significantly, the problem of analysing the data collected. When concentration measurements are taken in the field there is no control of parameters such as wind speed and direction, which strongly influence the dispersion of vehicle pollutants around buildings and therefore make the interpretation of data difficult.

Testing ventilation designs at model scale in a boundary layer wind tunnel enables some of the difficulties inherent in full-scale testing to be overcome. If the appropriate scaling conditions are satisfied then measurements made on the scale model will be representative of those that could be expected at full-scale. Several studies have illustrated the similarity between concentrations measured in the field and on scale models in a wind tunnel[9, 10], however at present little attention has been placed on testing ventilation air-intake positions.

This paper presents the results of a wind tunnel study of different natural ventilation air-intake positions for a building on the University of Nottingham campus situated close to a busy road. In a previous study by the authors the dispersion of a simulated traffic pollutant around this building had been investigated using a 1:100 scale model. Significantly lower concentrations of the pollutant were measured at the rooftop and at the non-roadside face and in general showed good agreement with field observations[11]. The present study goes further in that a model is also used to determine the ventilation rate and internal concentration.

## 2. Wind Tunnel Testing

The wind tunnel used in the tests was a small open-jet wind tunnel capable of delivering a maximum flow rate of 4.5 m/s. The working section has a width of 1 m, height 0.75 m and length 2.25 m[12]. The wind tunnel is relatively simple, and its use may be criticised on the grounds that is does not allow appropriate simulation of the turbulence structure. The mean velocity can be reasonably well simulated, but there is no real control over the generation of turbulence. However, the present concern is with time-averaged concentrations (rather than instantaneous values) and furthermore the pollutant is emitted from a line source (rather than a point source). Both of these factors will tend to reduce the importance of precise modelling of the upstream turbulence. Also the tunnel is an inexpensive facility in terms of capital and running costs. This can be an important factor when dealing with the design of buildings for which the development budgets are often likely to be small.

## 3. Scale Model Construction

A 1:50 scale model was constructed of the area shown in figure 1. The Institute of Building Technology (IBT) is housed in a naturally ventilated building in close proximity to a busy urban ring road (A52). Traffic flow figures supplied by Nottinghamshire City Council for this section of the A52 show that rush hour flows are typically in the region of 2500 vehicles in either direction and vehicles can be stationary for short periods during this time.

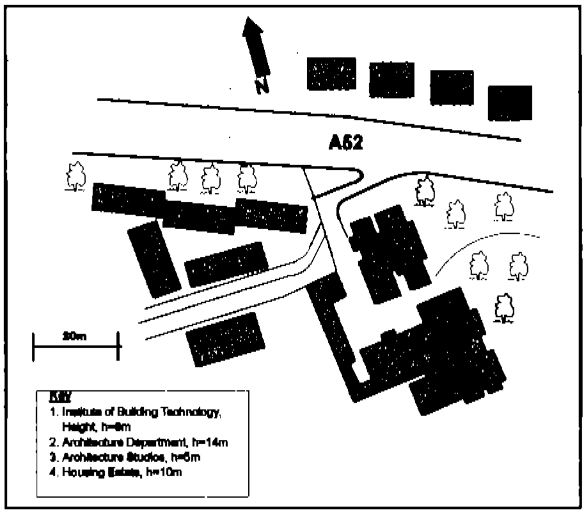


**Figure 1** Plan of area modelled in wind tunnel.

A hollow model IBT building was constructed from 6 mm Perspex and the surrounding buildings and features constructed from medium density fibreboard. The detail on the building was kept deliberately simple and no attempt was made to model any surface roughness. On the roadside face of the IBT a circular, sharp-edged opening of 10 mm diameter was added at a height of 85 mm and on the opposite face an opening of the same dimension was placed at a height of 65 mm. On the roof openings of 25 mm diameter were added.

To simulate the exhaust emitted from a queue of stationary traffic 20 x 2 mm diameter holes were drilled in a length of plastic tubing (internal diameter = 18mm). The holes were separated by 40 mm to represent an average spacing of 2 m full-scale between

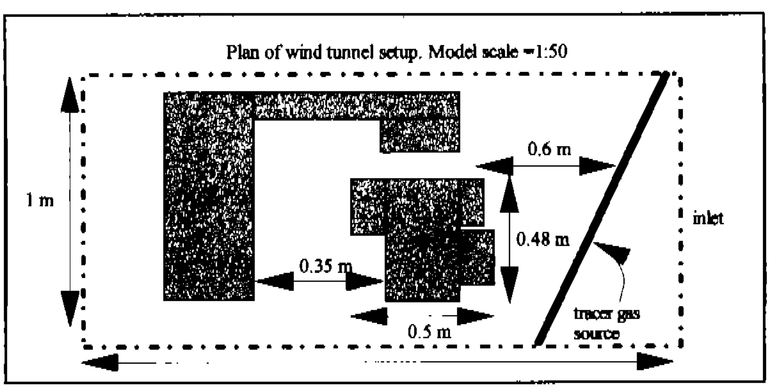


**Figure 2** Wind tunnel arrangement of model building and tracer gas source.

successive vehicle exhausts in congested traffic. A tracer gas nitrous oxide ($N_2O$) was delivered to the tube at a controlled rate of 5 l/min and the tube aligned on the model to represent the actual position of the A52 with respect to the IBT (figure 2). Air was sampled from the interior of the modelled building and at the intake positions and the concentration of tracer analysed using a Binos 1000 analyser.

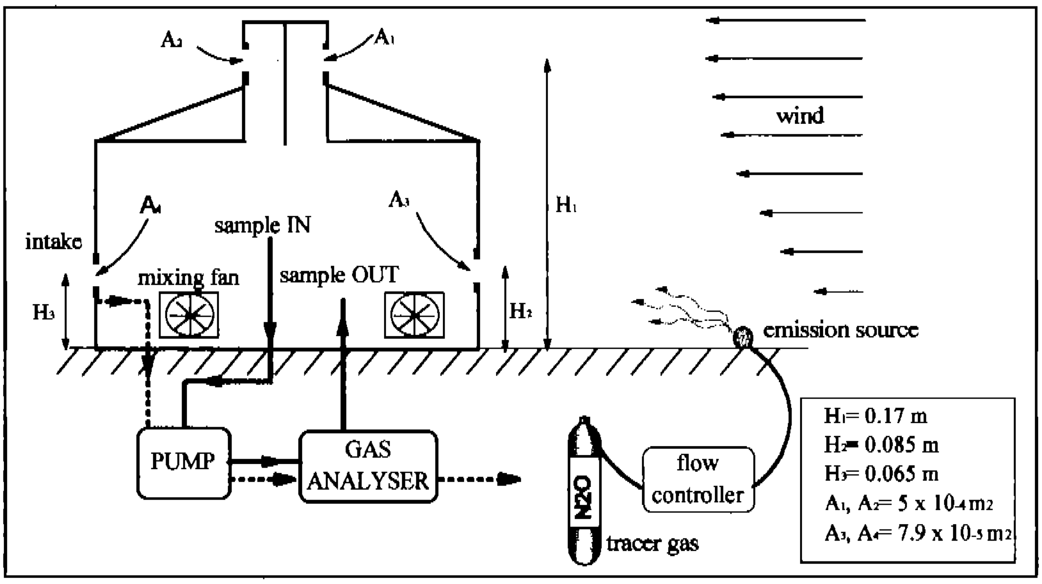


**Figure 3** Schematic of model and tracer gas delivery and analysis system.

### 3. Scaling considerations.

In principle, dynamic similarity of the external flow fields in the model and full-scale requires equality of Reynolds number (*Re*). In practice it is not possible to achieve this equality in a normal wind tunnel using air as the working fluid and therefore at the range of wind speeds available *Re* is much smaller than the full-scale value. For sharp-edged (bluff-body) buildings, the influence of *Re* will be small if *Re* is greater than a critical value (typically quoted as 11,000).

The flow through openings (and hence ventilation rate) however has been shown to be strongly dependent on *Re*[13], in particular the discharge coefficient is a strong function of *Re* for low values of *Re*. For sharp-edged openings such as air vents, the concept of a critical *Re* can be applied, so the problem can be overcome by operating the wind tunnel at a velocity at which the ventilation rate, when expressed as a nondimensional coefficient, becomes independent of *Re*. Figure 4 is a plot of the nondimensional ventilation rate (determined using the tracer decay technique) against wind tunnel speed for each of the models tested (see §4).

From the plots it can be seen that independence of *Re* is obtained for tunnel speeds of 2.5 m/s and greater. A tunnel speed of 2.5 m/s was therefore selected for the experiments, giving $Re = 3.3 \times 10^4$ (for a characteristic model height of 0.16 m).

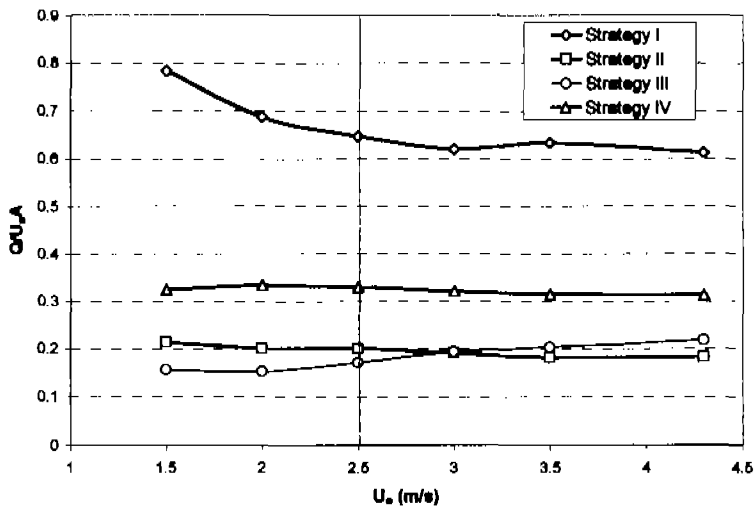


**Figure 4.** Non-dimensional ventilation rate against wind tunnel speed.

## 4. Experimental Procedure

Four different ventilation strategies were tested as illustrated in figure 5:

I) Air inlet on the roadside face, air outlet on the leeward face;

II) Air inlet on the leeward face, air outlet on the roof;

III) Air inlet on the roof, air outlet on the leeward face;

IV) Air inlet and outlet on the roof.

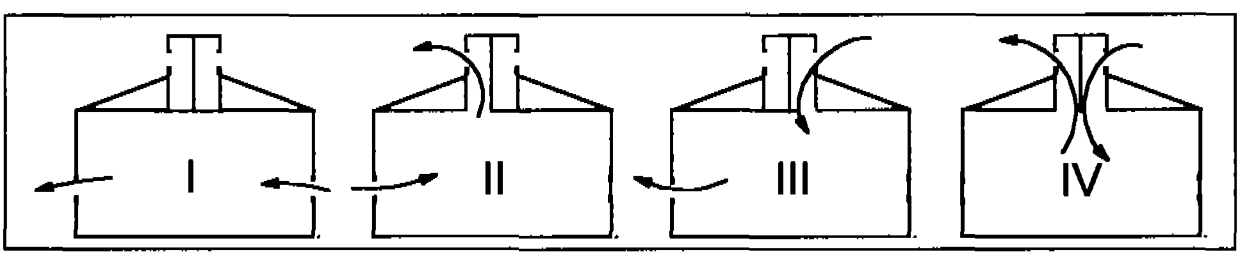


**Figure 5** Four ventilation strategies tested in wind tunnel with constant wind speed of 2.5 m/s and constant wind direction (wind direction from right to left).

In each experiment the wind direction was held constant so that the roadside face of the IBT was always perpendicular to the direction of the wind and downwind of the pollutant source. The $N_2O$ tracer gas was released and concentrations were recorded at the openings (inlet and outlet) and inside the model for each ventilation strategy once a steady state condition had occurred. The steady state was judged to have occurred at the time when the internal concentration would theoretically reach ninety-five percent of the concentration at the inlet ($T_{95}$) and was calculated from the air change rate. Steady state (or equilibrium) concentrations were logged as 2-minute averages on the gas analyser.

## 5. Results

Table 1 summarises the results obtained for the four strategies. The values of Q/UA range from about 0.2 to 0.65 with the largest value obtained with the low-level crossflow strategy. Q/UA is directly related to the coefficient of pressure difference $\Delta C_p$ across the two faces, which itself is dependent on wind direction. One would therefore expect strategy I to have a relatively large value and strategy II to have a small value and this is apparent in the results. The observation of similar values for strategies II and III is somewhat surprising but may be specific to the particular wind direction and roof geometry.

In principle the value of Q/UA has no influence on the equilibrium concentration inside the model, it will simply determine the time taken to reach that concentration. For the case of a single inlet and outlet the internal equilibrium concentration should also in principle be equal to the inlet and outlet concentrations. It is evident from table 1 that this is not precisely the case. The internal equilibrium is dependent on the average concentration at the opening and since the concentration at the intake was sampled at one point only, the difference between equilibrium concentrations is likely to be due to this point being unrepresentative of the average concentration. Another possible cause is some correlation between the instantaneous flow rate and concentration at the inlet.

The variation of the internal concentrations between the different strategies is due to the different location of the inlets. Strategy I has the highest concentration with a low-level intake close to the road. Strategy II, with the intake furthest away from the road, has a concentration about one-third lower. The two strategies with high level intakes give reductions of about twenty percent.

| Strategy | Q/UA | Position | Concentration (ppm) |
|---|---|---|---|
| I | 0.65 | Inlet | 285 |
| | | Outlet | 189 |
| | | **Inside** | **240** |
| II | ≅0.2 | Inlet | 127 |
| | | Outlet | 167 |
| | | **Inside** | **159** |
| III | ≅0.2 | Inlet | 212 |
| | | Outlet | 143 |
| | | **Inside** | **194** |
| IV | 0.32 | Inlet | 196 |
| | | Outlet | 189 |
| | | **Inside** | **193** |

**Table 1** Wind tunnel results (U=2.5 m/s).

### 6. Conclusions

Wind tunnel tests indicate that small but significant reductions in internal pollution concentrations arising from road traffic can be achieved by judicious siting of air inlets.

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