BUILDING VENTILATION AND URBAN AIR POLLUTION

Vina Kukadia, David Hall, Steven Walker

Building Research Establishment Ltd, Garston, Watford, WD2 7JR

At present, there is no formal guidance on strategies to minimise the ingress of pollutants into buildings. Adequate guidance requires an understanding of the following:

- Typical pollutants, their sources, how they disperse in urban areas and the concentration patterns produced on building surfaces.
- Surface pressures on buildings, ventilation and infiltration processes as experienced by buildings in urban layouts.
- The relationship between the indoor and outdoor pollutant levels.

This paper reviews current work at the Building Research Establishment Ltd (BRE) aimed at producing guidelines on effectively ventilating buildings in urban areas using low-energy technology and gives results of a recent review carried out together with preliminary results from wind tunnel studies.

1. INTRODUCTION

Fresh air for the ventilation of buildings is essential in order to provide an acceptable indoor environment in terms of both indoor air quality and thermal comfort for the inhabitants and in preventing a variety of problems such as condensation within the structure. The term 'fresh' in this context implies an air supply largely free from the internally generated contaminants that are traditionally of most concern; for example, water vapour, odour, VOCs from furnishings, ozone from printers and photocopiers and Environmental Tobacco Smoke (ETS). Carbon dioxide, although also mainly internally generated, is not regarded as a contaminant but an indicator of the indoor air quality.

In many cases the external air supply may carry a variety of contaminants of its own whose introduction to the internal atmosphere by ventilation is undesirable. These include the conventional air pollutants, for example nitrogen and sulphur oxides, ozone and inhalable particles, as well as nuisance contaminants such as, dust and odour. The ingress of such contaminants from urban pollution sources is therefore increasingly becoming a major issue in the ventilation of urban buildings.

At present, the use of mechanical ventilation and air-conditioning systems is primarily favoured to 'clean' the incoming air even though there is evidence that such systems do not always provide clean fresh air (1,2). However, there are significant advantages to the use of natural ventilation in urban areas if this can be achieved without the ingestion of excessive levels of external pollutants. In comparison to natural ventilation, mechanical ventilation has high operating costs and energy consumption, leading to higher CO_2 emissions. The contribution of building-related energy use to overall CO_2 emissions is considerable, estimated at 2,900 PJ (about 50% of the total). This has thus led to building designers being encouraged to design and construct energy efficient buildings suitable for natural ventilation and sustainable development.

There is therefore, a growing interest in the use of natural ventilation in buildings on polluted urban sites, for example the work by Philips et al (3), Yocum (4), Ekberg (5), Trepte (6) and Kukadia et al (1,7). However, there is still a lack of information on, and fundamental understanding of, the complex external flow regimes and pollutant sources together with the interaction of these with ventilation processes and indoor air quality in buildings. As a result, there is limited formal design guidance on effectively ventilating these buildings using low-energy technology, especially with the use of natural ventilation, while at the same time minimising the ingress of external pollution.

In order to be able to develop effective low-energy ventilation guidelines, an understanding of the following is required:

- Typical pollutants, their sources, how they disperse in the urban environment and the concentration levels produced on building surfaces in urban areas.
- Pressures on building surfaces, ventilation and infiltration processes as experienced by a building in an urban area.
- The occurrence of common areas of high pollutant concentrations and surface pressures on buildings.
- The relationship between indoor and outdoor pollutant levels.

In this paper, a brief account is given of some of the parameters that are important in understanding this subject, together with the findings of a recent review that has been carried out at the Building Research Establishment Ltd (BRE) as part of a major programme investigating these problems. A brief description of the field monitoring of internal and external pollutant levels of buildings and wind tunnel studies of pollutant concentrations on buildings is also given.

2. TYPE OF EXTERNAL POLLUTANTS

External airborne pollutants which cause building contamination problems can be classified in a number of ways. In terms of their effects the two most important for building contamination problems are:

- adverse health effects, and
- nuisance.

The most common external pollutants affecting health are acid gases (such as sulphur dioxide), nitrogen oxides, carbon monoxide, ozone and inhaled particles. The most common sources of 'nuisance' pollutants likely to enter a building are odour and airborne particles depositing on surfaces.

In recent years, a broad-based spectrum of contaminants and contaminant sources have been recognised as being of concern in building ventilation problems. Their sources range from the conventional polluting discharges (such as those from combustion and stationary generating plants) to:

- vehicle emissions (currently considered to be a major source of urban pollution),
- process discharges (including for example, fume cupboard discharges and incinerators),
- nuisance discharges (especially odours) and
- building ventilation exhaust discharges.

Vehicle emissions are distinguished by mobility and therefore by a strong variation in their siting and periods of emission. All the other sources are static. Although road traffic is currently identified as probably the major local pollution source in urban areas (8), it must be appreciated that in many localities other sources may often be the principle component of the overall pollution level. Of the pollutant discharges from different sources, only those from combustion plant running on conventional fuels are relatively closely classified. The other sources are usually only known approximately; this applies especially to odours, which are not easy to quantify. However, nearly all process discharges are now highly regulated and are authorised to operate under the Environmental Protection Act (1990) on the basis of defined limits to their polluting discharges.

The other important distinction between different sources for the present purpose is the height of release. Discharges from road traffic are mostly (but not always) at the ground, while those from combustion and process discharges are (with a few exceptions) elevated above the local building heights. In the latter cases there is normally a regulatory requirement for minimum discharge stack heights to ensure that pollution levels at the ground from these sources are within acceptable guideline levels. Only some types of pre-diluted gas fired combustion plant exhausts are permitted to discharge below roof height. Ventilation exhaust discharges are under no specific regulation and the heights and positions of these and fugitive emissions are largely arbitrary. This area has been covered in greater detail elsewhere (9).

3. CONTRIBUTIONS OF DIFFERENT POLLUTANT SOURCES

When developing a ventilation strategy for a building, it is important to understand the relative contributions of pollutant sources from both short and long range and to distinguish between the sources that can be avoided and those which cannot. In an urban area, an individual building will be exposed simultaneously to a large number of individual pollution sources from varying distances, heights and also timescales. It is the relationship between these various pollution sources from these different distances and varying timescales and their proportionate combination under different circumstances which govern the overall pollutant concentration patterns on the building and hence building contamination problems. Hall et al (10) have reviewed this subject and describe the way in which contributions from different pollution sources at different distances disperse in the atmosphere to contribute to the resultant overall exposure experienced by buildings in urban areas.

Figure 1, taken from Hall et al shows a hypothetical example of how the contribution from the sources at different distances overlay to produce an overall level of concentration at some point in an urban area. It shows that in general, pollutant sources from short distances (microscale, ~100 m, neighbourhood, <1 km and urban scale, 1-10 km (as defined by Munn (11)) govern the variation in concentration over a building. Pollutants from sources at greater distances than these, defined by Munn as 'regional' and 'continental' scales, diffuse through the whole area and produce relatively uniform concentration levels on buildings which vary only slowly with time. When these latter components dominate the overall pollution level, it is not possible to develop a ventilation strategy to avoid the ingestion of the pollutants. Therefore, it is primarily the contribution from 'local' sources that need to be taken into account in any ventilation strategy.

4. BUILDING CONTAMINATION PROCESSES

For naturally-ventilated buildings, it is the combination of pressure forces and contaminant levels around the building that is important in generating the internal contamination level. Regions of high external pressures combined with high external pollutant concentrations will give regions of high probable ingress of contaminants and hence lead to greater internal pollutant concentrations. In building design, it is therefore desirable to avoid siting inlets where there is likely to be ingestion of high concentrations of pollutants.

The processes that generate both pressure and contaminant concentration patterns on buildings are complex and affected by the surrounding structures, as well as by the size, shape and the orientation of the building itself to the wind, and finally by the type, position and distance of the contaminant sources.

The arrangement of the urban area and the distribution of contaminant sources within it are therefore important factors in the building contamination process.

5. PREVIOUS STUDIES ON BUILDING CONTAMINATION AND INTERNAL/EXTERNAL POLLUTION LEVELS

The literature on this subject has recently been reviewed (9), and the information available considered from the fields of building ventilation, wind pressures on buildings, pollutant dispersion and air pollution monitoring that may be used to assist in the design of building ventilation systems in polluted urban areas. Their overall conclusions were:

- There is currently no formal guidance on low energy ventilation design that accounts for external pollutants and the guidance that exists is tentative and usually conflicting.

- There are few measurements of internal/external pollution levels in buildings which could indicate the severity of the problem or offer any information on the effects of different ventilation systems. No measurements have been made over sufficiently long periods to typify the performance of particular buildings. Periods of measurements have in general been too short (typically 10-20 days) to reveal the longer term variation in contamination patterns. Apart from the effects of different types of weather patterns which will normally only persist for limited periods, the characteristic long term cycle of the weather and air pollution patterns and of ventilation usage is one year.

- There are no published measurements of both pressure and contaminant concentration distributions on building surfaces in parallel experiments, which are required to predict the ingress of pollutants. Existing measurements of pressures and contaminant concentrations alone are limited in extent and have few common features. In particular, there have been few measurements of the effects of surrounding buildings (which are an important feature of urban wind patterns) on either pressure or pollutant concentration distributions.

The present programme and other activities at BRE are investigating these issues with a view to providing detailed information and guidance.

6. CURRENT STUDIES ON BUILDING CONTAMINATION

Currently, research at BRE is investigating how the fundamental parameters detailed above affect the indoor air quality in naturally ventilated buildings located in urban areas. This is being done through both full scale building monitoring studies to investigate the pollution levels inside and outside buildings in urban areas and through small scale experimental studies. Full scale studies are being carried out in Manchester, in collaboration with the Environmental Technology Centre at UMIST. Internal and external levels of a number of pollutants (carbon monoxide, nitrogen and sulphur oxides, ozone and particles) in a number of different buildings are being measured over long monitoring periods. In addition, ventilation rates, temperatures and humidity levels are also being monitored. To give an idea of the types of buildings being studied, Figure 2 shows the site where the building monitoring studies are being carried out. Data from these studies are currently being collected and analysed and therefore are not available at present.

Small scale wind tunnel studies are currently measuring the contaminant levels and also the pressures on the surfaces of buildings, both in isolation and within arrays of urban structures. This is the first investigation known to the authors that is investigating these two parameters simultaneously. The data obtained will be coupled with assessments of the effects of various pollution sources at different distances to the total exposure experienced by buildings from the field monitoring work.

7. PRELIMINARY RESULTS FROM WIND TUNNEL INVESTIGATIONS

Figures 3(a) and 3(b) show preliminary results of concentration contours on a rectangular building from the wind tunnel measurements. The building faces are shown 'unfolded' in plan, so that concentration patterns on all the faces can be seen. The data are for a unit contaminant source on the ground directly upwind of the building. Figure 3(a) shows concentration contours for a single building in isolation and in the direct line of the pollutant source which is five Building Heights (5H) from the building under investigation. In Figure 3(b), the building is within a regular array of similar structures occupying about 16% of the surface area. The pollutant source is at the same distance as in Figure 3(a) but there is now another building in the array interposed.

Comparison of the two results shows that when within the array the variation of pollutant concentration over the building is much diminished. The ratio of the highest to the lowest concentrations over the building is reduced from a factor of about 5:1 (Figure 3a) to about 1.6:1 (Figure 3b). When the building is in direct line with the pollutant source (Figure 3a), the concentrations are generally higher at corresponding points than when it is sheltered by the interposed building (Figure 3b). Furthermore, concentrations on the upwind face (front) of the building in the array are reduced by a factor of up to 5 in comparison with the upwind face of the isolated building. Concentrations on the downwind face (back) are reduced by up to a factor of 3. This is partly related to the enhanced rates of pollutant dispersion that occur within urban building arrays.

Concentrations in both cases are higher on the upwind face of the building than on the downwind face. This implies that it would be beneficial to locate air inlets on the face of the building away from the pollutant source. Building monitoring studies reported previously (7) also draw similar conclusions.

It can also be seen that when the building is in the array, the concentrations increase with height even though the pollutant source is at the ground. The highest pollutant concentrations appear to occur on the roof of the building. This could have important implications given the common practice of siting ventilation inlets on the roof. For pollutant sources at short ranges, modifications to local dispersion patterns within the urban building array can produce results of this sort. Dispersing plumes can be displaced upwards within the array, while air from outside is advected inwards laterally at the ground, reducing concentration levels close to the ground.

Contrary to this, results obtained by Booth et al (12) and Ajiboye et al (13) show that pollutant concentrations decrease with height. Furthermore, results from the isolated building case (Figure 3a) also show that concentrations decrease with height. These results imply that it would be safe to locate ventilation inlets on the roof of buildings although, in reality buildings are generally not isolated in urban areas. These opposing findings indicate the complexity of this subject and the need for further research.

Finally, it must be noted that the above are only preliminary results and as such no firm conclusions can at present be made from them. However, they do indicate the variability and complexity of pollutant gradients in urban areas. The work at BRE is continuing on this subject both in the wind tunnel and on long term monitoring of buildings, which will expose more fully the mechanisms that govern the ingress of external pollutants into buildings and provide the information required to produce guidelines on effective ventilation strategies.

8. CONCLUSIONS

The effect of natural ventilation strategies on external pollution levels found indoors and the variation of these with space and time are presently being investigated at BRE. We will be using the results of these and our other studies to develop appropriate guidance for effectively ventilating buildings located in urban areas where external air pollution may be a problem.

This paper has shown that, at present, it is not easy to predict the level of ingress of external pollutants into buildings since the mechanisms which govern the ingress are complex. A review of the available information has indicated that the scale of the issue is not well understood due to a lack of both field measurements and an understanding of the mechanisms of pollutant ingress into buildings. This latter requires basic data on combined pressure and concentration contours on buildings within urban layouts.

To enable effective guidelines on low-energy ventilation strategies to be produced which take account of external pollution levels, a multi-disciplinary approach needs to be taken. It is important to understand the broad-based character of air pollution in urban areas, the more detailed aspects of contaminant dispersion at short ranges around buildings, the airflows and pressure distributions on building surfaces, the nature of building ventilation and its current practice and, finally, the relationship between internal and external pollutants and pollution levels. Currently there is little overlap between these disciplines and a general lack of detailed information sufficient for generating reliable guidance on ventilation design in urban areas.

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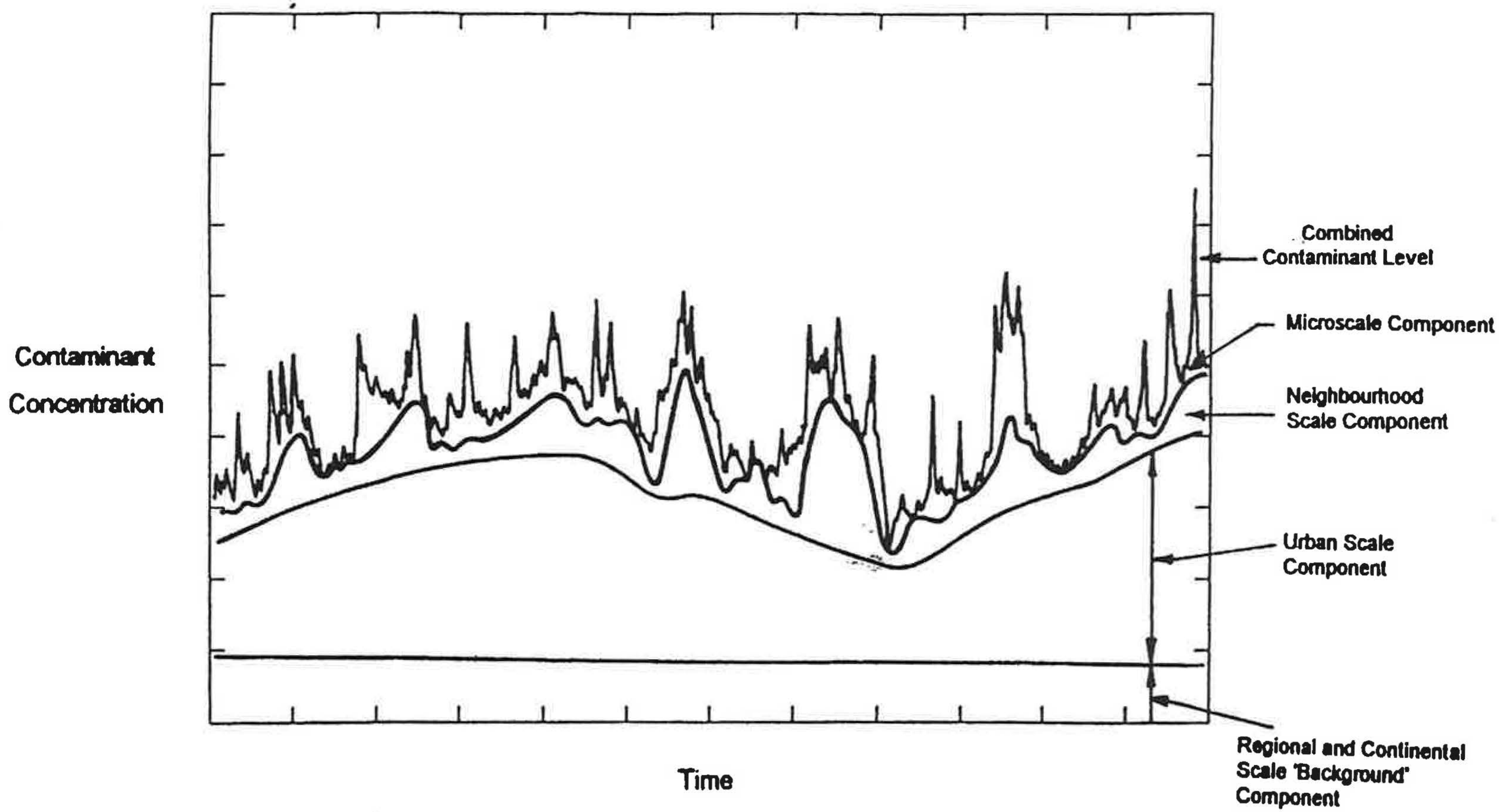


Figure 1. Hypothetical example of the contributions of contaminants from different sources regimes (from Hall et al 1996)

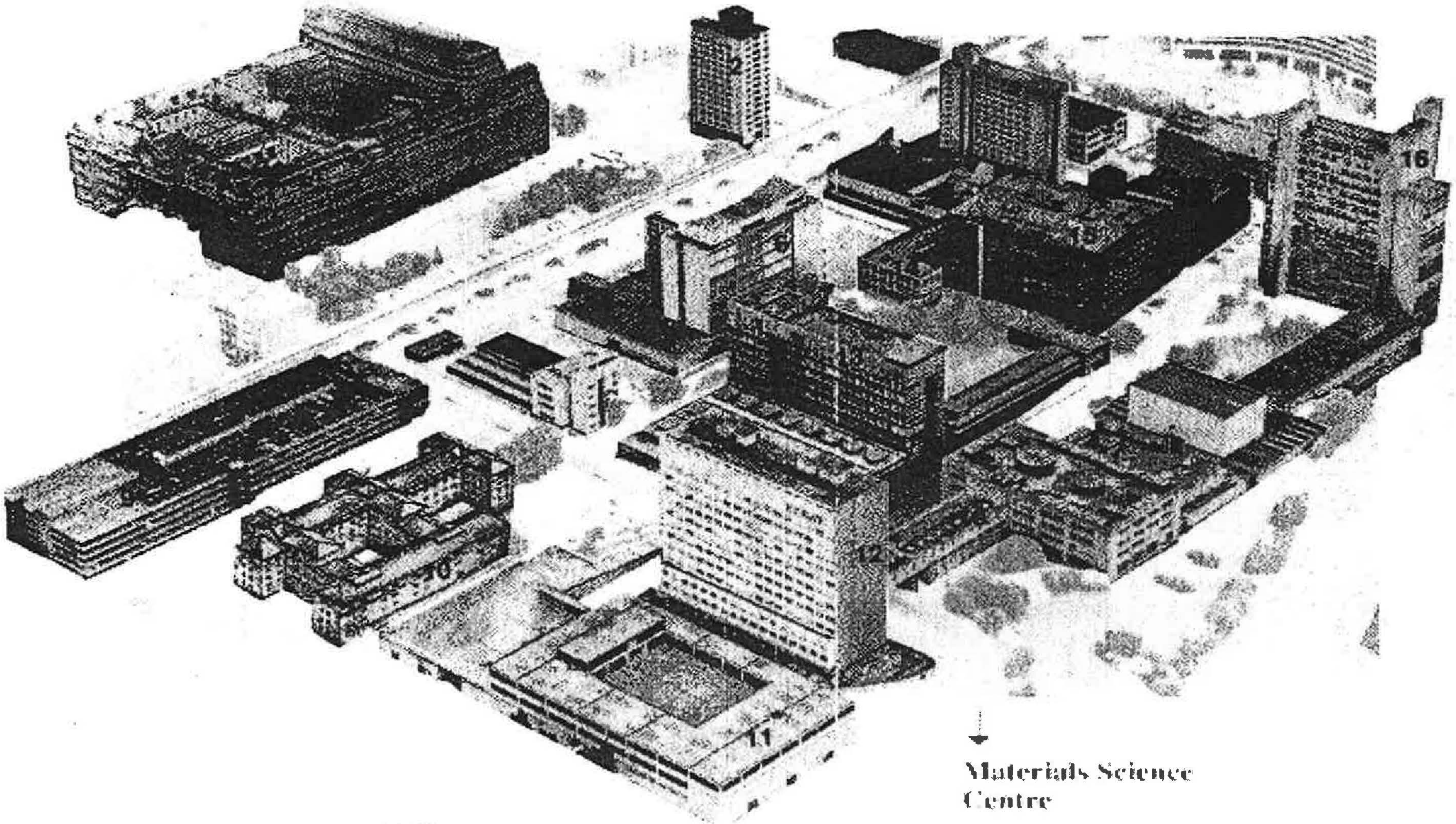
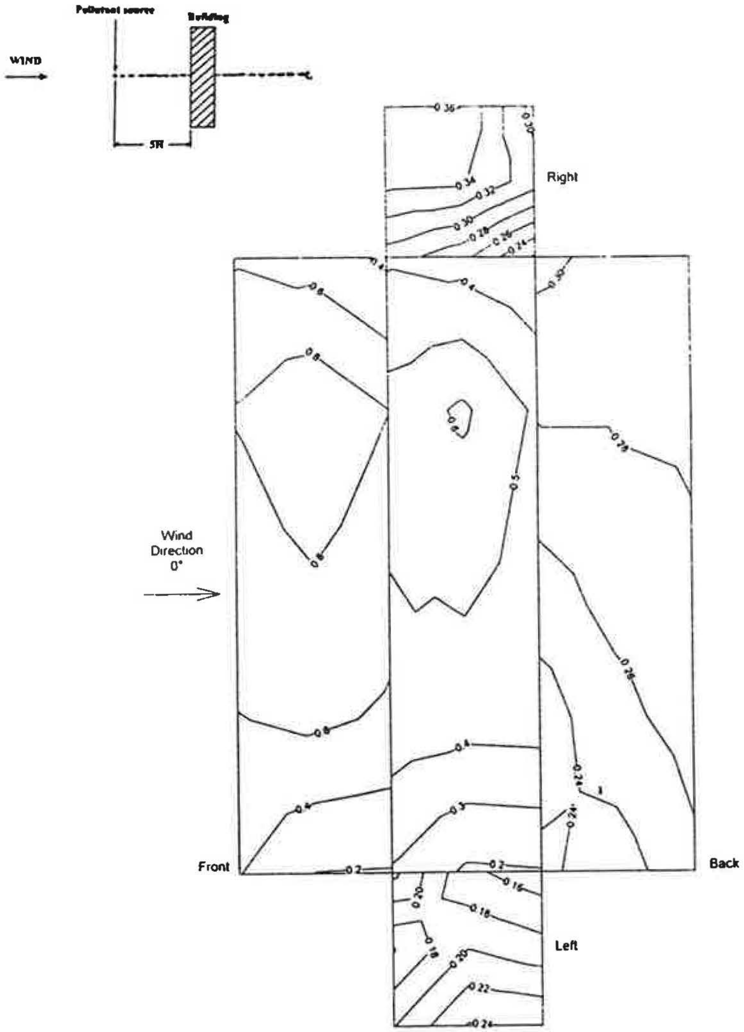
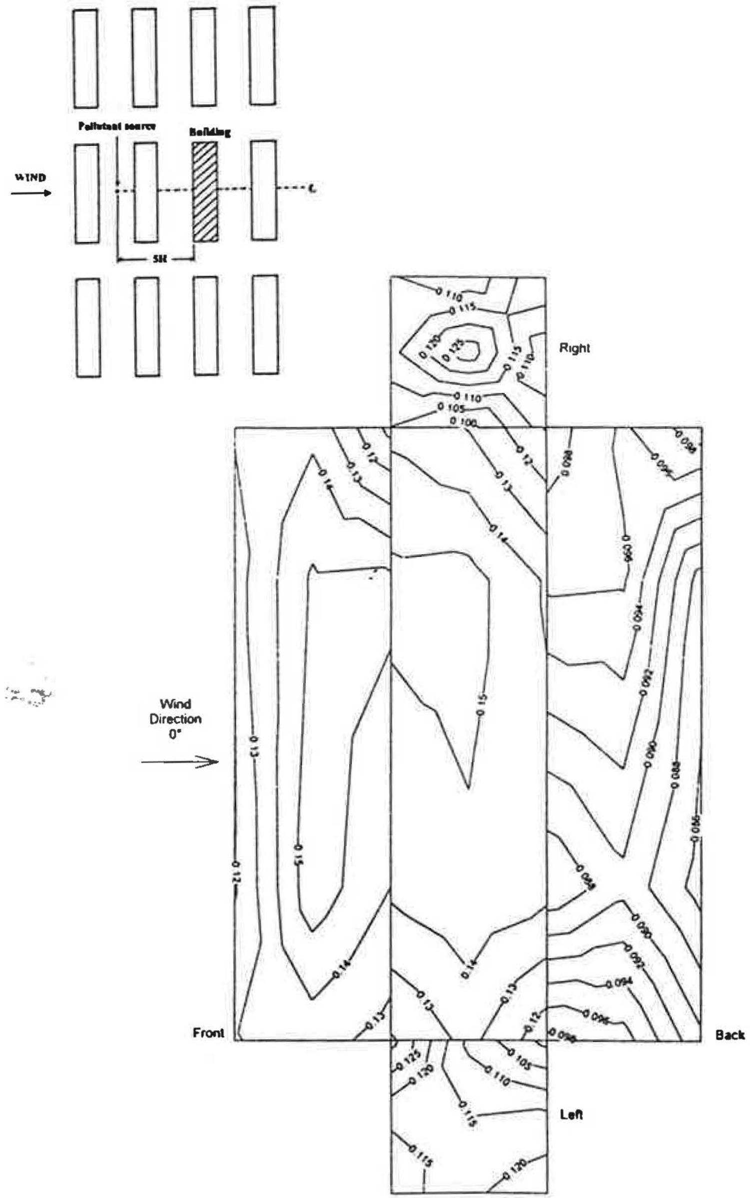


Figure 2. The University of Manchester Institute of Science and Technology Site where Building Monitoring Activities are being carried out.

Figure 3. Pollutant Concentration Contours on
a) an isolated building and b) a building in an array



(a)



(b)