The Effects of Particles from Construction Activity: Analysis of Data from a Construction Site in Cardiff

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Prepared for:
DETR

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Final approval on behalf of BRE:

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SUMMARY

Airborne particulate matter is an important form of pollution, which has generated increasing concern in recent years. As well as contributing to poor visibility and surface soiling, airborne particulate matter can have adverse effects on human health. Construction and other civil engineering sites have been perennial sources of nuisance dust (that is, dust deposited on surfaces and generating complaint). However, there is currently no formal advice or Code of Practice for regulating the emission of particles from construction activity. One of the main reasons for this is that there is no published data from detailed particle monitoring of a construction process on which to base the Codes. However, one dataset of PM_{10} measurements from the UK Automatic Monitoring Network has been identified which relates to construction process on a site in Cardiff during 1994. This has been analysed here in relation to the various phases of the construction process and the weather pattern (especially wind speed and direction).

The study has found sufficient correlation between the high particle concentrations from the site and the phases of the construction to indicate that the construction process was, on the balance of probabilities, the source of these. However, the evidence is not unequivocal.

It appears that the highest particle concentrations were associated with stronger winds, the working day and the phase of the construction, especially the wall construction and internal/ external finishing phases.

The report is part of a project whose longer term aim is to provide technical advice to and develop Codes of Practice for the DETR and industry on reducing particle emissions from construction activity.

CONTENTS

1. INTRODUCTION

Airborne particulate matter is an important form of pollution which has generated increasing concern in recent years. As well as contributing to poor visibility and surface soiling, airborne particulate matter can have adverse effects on human health. These effects, especially on respiratory diseases, have been of concern for the last century and beyond; some of the first measurements of air pollution being those of airborne particles at the turn of the century. The initial interest, mainly from the 1950's, was in 'black smoke', especially in combination with sulphur dioxide, and human exposure limits for particles on this basis, were laid down by the EC (mainly on the basis of the UK experience) in the 1970's. The interest in the broader range of particles and their effects on respiratory disease is more recent. Work in the US in the 1970's and 1980's led to the definition of the PM_{10} fraction of the particle size distribution (the thoracic fraction of particles below about 10μm diameter, which passes the larynx and enters the upper airways and deep lung) which is significant in respiratory disease. Monitoring studies of ambient PM_{10} concentrations began in the US during the 1980's.

In the UK, the first long running measurements of PM_{10} were made in 1992 and reported in the first QUARG (Quality of Urban Air Review Group) report on urban air quality in 1993. From 1993 the UK National Automatic Urban Monitoring Network began recording concentrations of PM_{10} at a number of sites. By this time there was a rapidly growing interest in the significance of this particle fraction (and its smaller sub fractions) and positive evidence of its adverse effect on human health. The second QUARG report in 1993 reviewed the contribution of diesel vehicles to urban pollution (stressing the importance of particle emissions) and the third QUARG report in 1996 was concerned solely with airborne particulate matter. In 1995, the Expert Panel on Air Quality Standards (EPAQS) laid down the first UK advisory limit of $50\mu gm^{-3}$, for ambient concentrations of PM_{10} (as a running 24-hour mean), which is currently set as a standard to be achieved by 2005 as part of the UK National Air Quality Strategy.

The implication of construction sites on the total burden of the urban PM_{10} fraction in the UK arises mainly from some of the first National Network measurements of PM_{10} in Cardiff in 1994. The monitoring instrument was near a construction site and recorded significantly higher concentrations than occurred in other urban areas or at the same site before construction was begun and after it was completed. The levels also frequently exceeded the EPAQS advisory limit of PM_{10} concentration of $50\mu gm^{-3}$. This was remarked upon at the time and reported in the third QUARG Report in 1996, which noted the impact of dust from construction sites on local levels of PM_{10}. In addition, the National Atmospheric Emissions Inventory has noted that construction sites represent an important non-combustion source of PM_{10} emissions and has estimated this to be about 2% of total emissions in the UK.

Construction sites are therefore increasingly likely to become the subject of environmental attention locally. As part of the UK National Air Quality Strategy, Local Authority Environmental Health Officers are now required to assess the local air quality and then prepare and execute action plans to reduce locally excessive levels of pollution, including particles. Having been identified as a source of particle pollution of current major concern, construction sites can expect to have to demonstrate that their fine particle emissions are controlled and are within acceptable limits. However, any control strategy for minimising airborne particulate matter must be based upon a firm understanding of the origins of those particles and the factors which influence their concentrations in the atmosphere.

There is currently no formal advice or Code of Practice for regulating the emission of particles from construction activity. One of the main reasons for this is that there is no published data from particle monitoring on which to base such Codes. At present, data from systematic monitoring of particles generated during construction processes does not exist in the literature. Nor is there currently any detailed evidence of how substantial this contribution may be to the PM_{10} burden either locally or on a larger scale. However, one dataset of PM_{10} measurements from the National Monitoring Network was identified (as mentioned earlier) which relates to a construction site operating nearby. The data is from a construction process on a site in Cardiff during 1994.

In this report, the particle concentrations from this dataset, the Cardiff site, have been analysed in detail in relation to the phases of the construction process and the weather pattern (especially wind speed and wind direction). This has been carried out in order to assess contributions from the various phases of the construction process to the generation of particles and the additional contribution to local background levels. The results are also compared with data obtained from the years 1993 and 1995 when there was no major local construction activity in progress.

2. DESCRIPTION OF THE BUILDING AND ITS SURROUNDINGS

Figure 1 shows a photograph of the building. It is a three-storey retail unit located in the main shopping precinct on the corner of a pedestrianised street (Frederick Street) which runs South from a major pedestrian thoroughfare, Queen Street to a large covered Shopping Centre. Figure 1 also shows the AUN monitoring station which is located close-by in Frederick Street, about 5m away from the building. The station houses the instrumentation for monitoring a number of pollutants including the PM_{10} particle size fraction. Figure 2 shows a view of the AUN monitoring station looking at it from Frederick Street towards Queen Street with the building on the right.

Figures 3 and 4 show photographs of two views (taken from Queen Street) of the local surroundings. The area around the site is pedestrianised and therefore there is little contribution from vehicular traffic to local particle concentrations. The nearest major traffic carrying road is Castle Street, about 200m to the west of the building (Figure 5). Figure 6 shows a detailed plan of the site in relation to the immediate surroundings. The heights of the surrounding buildings range between 5m and 21m, the majority being about 10m in height. Besides the buildings themselves, there are no special features of the local topography that are likely to have had any particular effect on the dispersion of particles around the site.

3. THE CONSTRUCTION PROCESS

Table 1 gives an approximate breakdown of construction activities for the retail unit together with their dates. Ground preparation and excavations on the site began in December 1993 and lasted through to the end of February 1994. This consisted of site clearance and removal of the top layer of ground in preparation for the foundations. It is not clear whether or not an existing building had been demolished prior to the construction of the present building. During February and March 1994, trenches were dug and concrete poured for the main foundations. During March, April and May 1994, the steel frame for the building was erected and the concrete for the first and second floors poured. The walls for the building were constructed during May, June and July 1994. These were of concrete blocks faced with bath stone. The roof of the building was of timber with a slate covering constructed during July 1994. The final internal and external finishes were applied from August to December. Final inspection after completion of the building was towards the end of December 1994.

Table 1: Phases of the construction process, with dates

Activity	Date
Ground works and excavation	- December 1993 - January 1994 - February 1994
Concrete for foundations	- February 1994 - March 1994
Steelwork (frame) and concrete for floor slabs	- March 1994 - April 1994 - May 1994
Wall construction	- May 1994 - June 1994 - July 1994
Roof construction	- July 1994
Internal and external finishes	- August 1994 - September 1994 - October 1994 - November 1994 - December 1995

4. PARTICLE MONITORING

4.1 The National Automatic Urban Monitoring Network

Over the last decade, the DETR has funded the operation of the UK national air quality monitoring network known as the Automatic Urban Network (AUN). This is a network of sites located in cities throughout the UK where a comprehensive range of pollutants, including airborne particles, are continuously monitored. A total of 107 sites throughout the UK monitor concentration levels of various pollutants. Of these 50 sites, including the Cardiff site, monitor particles.

The pollutant concentration data for all the pollutants measured at these sites is now available on the World-wide Web. The data from the AUN site in Cardiff used for this study has been obtained from this source.

4.2 Definition of PM_{10} Particles

There are many definitions of airborne particle size fractions. Some are linked to specific sampling devices, whilst others are connected with human respiratory exposure. PM_{10} is a USEPA definition, representing the fraction of ambient airborne particles that penetrates the larynx of the human respiratory system and deposits in the upper airways and lungs (Mark et al, 1997). It was specified in 1986 as the particle size fraction that would most effectively correlate with health effects suspected of being caused by inhalation of airborne particles in the ambient atmosphere. Figure 7 shows the definition of the PM_{10} fraction, which has 100% penetration of small particles, 50% penetration of 10μm particles and zero penetration of particles larger than 16μm.

In Europe, sampling of the PM_{10} particle size fraction has been increasingly adopted during the past few years after reports by Wagner et al (1988) confirmed that the 'thoracic fraction' (similar to the PM_{10} fraction) was likely to be the most important for health effects. In recognition of this, the UK DETR is now monitoring the PM_{10} particle size fraction at a number of sites throughout the UK as detailed above.

4.3 Measurement of PM_{10} Particles

The AUN monitoring sites use the Tapered Element Oscillating Microbalance (TEOM) (Patashnick and Rupprecht (1991)) to measure the PM_{10} particle size fraction (Figure 8). A standard 16.7 l/min PM_{10} inlet selects the PM_{10} particle fraction which passes through a flow splitter and is deposited on a 16mm diameter filter connected to the top of the narrow end of a hollow tapered glass tube. As the particles collect on the filter, the tube's natural frequency of oscillation decreases. The change in this frequency is directly proportional to the added mass. The inlet including the sensing system is kept at a steady temperature of 50°C to drive off any sampled water droplets. The instrument is microprocessor controlled providing continuous average readings of mass concentration every hour. Since short-term measurements are taken, it allows any extreme values of particle concentration to be identified and correlated with any short-term activities that may be going on. The TEOM does have some idiosyncrasies that affect the measurements. For example, volatile organic particles depositing on the surface can evaporate over time, providing an apparent reduction in the collected mass.

5. RESULTS AND DISCUSSION

5.1 PM_{10} Data for the Cardiff Site for 1993, 1994 and 1995

Concentrations of the PM_{10} particle size fraction data collected by the AUN monitoring station in Cardiff have been studied here for three years, 1993, 1994 and 1995. The major part of the construction process took place during 1994 and comparison of the data with the other two years enabled a comparison to be made between the periods when construction was in progress and those periods, before and after, when no such activity was taking place.

It is useful to study the characteristics of hourly PM_{10} concentrations as well as exceedences of the 24-hour running average EPAQS limit value, since this allows short-term high concentrations to be correlated with any short-term activities that may be significant. Figure 9 shows hourly PM_{10} concentrations for the three years. It can be seen that during 1994, there were many large, short-term excursions of particle concentration compared with the other two years. Hourly concentrations occasionally reached values as high as 600 μgm^{-3}.

Table 2. Statistics of PM_{10} Concentrations During the Years 1993, 1994 and 1995.

	Year		
	1993	**1994**	**1995**
Annual mean	31	34	25
EPAQS Limit Exceedances >50μgm^{-3} (Number of running 24-hour periods)*	-	1319 on 91 days	293 on 24 days
Individual hours exceeding:			
50μgm^{-3}	698	1262	505
100μgm^{-3}	35	342	29
200μgm^{-3}	2	90	11
Standard deviation of hourly values	35	37	18
95% ile of hourly values	1.0	0.8	0.4
99% ile of hourly values	1.3	1.0	0.5

* AEA (1995)

Table 2 gives the statistics of the PM_{10} concentrations during the years 1993, 1994 and 1995. As expected, the annual mean concentration was higher in 1994 than in the other two years. The EPAQS Limit of 50 μgm^{-3} which is based on a running 24-hour mean was exceeded on a larger number of occasions during 1994 when construction was in progress) than during 1995 (1319 in comparison to 293). Data on exceedences of the EPAQS limit for 1993 do not exist as the limit was set at a later date.

Since we are dealing with short term concentrations, it is also useful to examine the hourly PM_{10} values exceeding some given level. We have taken here exceedences of 100 and 200 μgm^{-3}. A level of 100 μgm^{-3} was exceeded on 342 occasions in 1994, about ten times more than in the other two years. A level of 200 μgm^{-3} was exceeded only twice in 1993, eleven times in 1995 and on ninety occasions in 1994. Thus during 1994 there were many periods when short term concentration levels were far higher than those typical of the site.

5.2 PM_{10} Concentrations Associated with the Construction Process in Cardiff

The PM_{10} concentrations associated with the various activities of the construction process during 1994 are shown in Figure 10. During January when site clearance and excavation was undertaken, PM_{10} levels reached concentrations of 200μgm^{-3} and on one occasion in excess of 400μgm^{-3}. During February, when the foundations were being laid, hourly concentrations tended to remain around 100μgm^{-3}, rising again during March, April and May when the steel frame construction and concrete pouring for the upper two floors was being carried out. However, the highest concentrations, of about 600 μgm^{-3}, occurred during July when the wall and roof construction was in progress. There were also some relatively high PM_{10} concentrations during September and October during the finishing of the external walls and the internal fitting-out. After the work came to an end in December, particle levels mostly fell to below about 100 μgm^{-3}.

5.3 Comparison of PM_{10} with Local Nitrogen Dioxide (NO_2) concentrations

If the unusually high levels of PM_{10} in 1994 were associated with more general pollution, then levels of other pollutants should also have been high. We have taken NO_2 levels as an indication of the latter. Figure 11 shows a comparison of hourly PM_{10} concentrations with those of NO_2 for the years 1993, 1994 and 1995. This gives some indication of whether or not PM_{10} levels measured were associated with more general pollution levels around the site or with some other factor. High concentrations of both PM_{10} and NO_2 occurring during the same periods would seem to indicate that the PM_{10} levels were associated with more general pollution levels. However, Figure 11 shows that during 1994, there were many more large excursions of PM_{10} concentrations when compared with NO_2 levels. This indicates that in 1994 another local source of PM_{10} apart from that due to combustion was present. During 1993 and 1995 the PM_{10} concentrations showed few large excursions. In the absence of information of any other source of PM_{10} in the locality during 1994, this data indicates that the high particle levels that occurred in 1994 were probably due to the local construction activity.

5.4 Occurrences of High Concentrations of PM_{10}.

Figure 12 shows the occurrence of exceedences of hourly PM_{10} concentrations of 50, 100 and 200 μgm^{-3} broken down by hour of day and day of week. There is a cross on the plot for any measurement below the set level and a solid circle if the level was exceeded. As can be seen in the figure, the hourly limit of 50 μgm^{-3} was exceeded on a large number of occasions in all three years, and it is not possible to identify any relationship between the occurrence of exceedences and time of day or day of the week. Exceedences of 100 and 200 μgm^{-3} levels mainly occurred during the working day between about 8am to 5pm, mostly during the working week, Monday to Friday. There were also some exceedences out of these hours and during the weekend. Although no construction work was carried out during these periods, especially over the weekends, it is possible that high PM_{10} concentrations during these times were due to wind blown dust from the construction site.

Figure 13 shows the effect of wind speed and direction on the occurrences of exceedences for the three set concentration levels of 50, 100 and 200 μgm^{-3}, plotted in the same fashion as in Figure 12. Exceedences of the set levels occurred mainly in westerly and easterly winds. Exceedences of the higher limits of 100 and 200 μgm^{-3} predominated during 1994 (as the basic statistics of the data in Table 2 show), again over the whole range of wind speeds. Windroses (data taken from the nearest meteorological station at Rhoose Airport) for the three years are shown in Figure 14. They are similar for the three years and show a pronounced bias to high frequencies of easterly and westerly directions. There is also a predominance of stronger winds from these two directions. The higher frequency of exceedences generally in easterly and westerly winds is probably not significant as the higher frequency of these wind directions is alone sufficient to explain this. However, the larger number of exceedences at higher wind speeds indicates that at least some of the higher concentrations may be due to wind-raised particles. It is a feature of wind-raised particles that concentrations increase markedly with rising wind speed. If the particles were from other sources (such as combustion), their rate of production is not dependent on wind speed and in these cases it is a fundamental feature of pollutant dispersion that concentrations fall with increasing wind speed.

The sampling site was on the westerly side of the construction site, so that in principle, the predominant exposure of the sampling site to particles from the construction site would be in easterly winds. However, Figure 13 shows a predominance of the occurrences of high concentrations of PM_{10} in both easterly and westerly winds. The large number of buildings relatively closely packed around the site will modify both mean wind speed and direction locally. There will also be recirculating airflows within the narrow 'canyon' streets and this can have the effect of reversing the local wind speed at the ground. Without a quite detailed study of the local wind patterns it is not therefore possible to reliably correlate wind direction over the site (especially at the ground) with the monitored particle concentrations. However, it is possible to correlate wind speeds as, in general, all strong wind speeds around the site will be in proportion to the value from the meteorological data.

Figure 15 shows the hourly exceedences of 100μg m^{-3} against wind speed and direction for the different phases of the construction, plotted on the same basis as previously. It can be seen that the most frequent exceedences occurred during wall construction and internal/external finishing, the most infrequent during roof construction. The latter was, by definition, at the highest level on the site and it is possible that any particles produced during this phase were more readily carried away from the site by the wind.

6. CONCLUSIONS

The study has shown that the high particle concentrations recorded at the Cardiff AUN site during 1994, frequently exceeding the EPAQS running 24 hour limit and also producing very high, shorter term hourly concentrations, correlate closely with the construction period of the adjacent building. It also seems likely, from the failure to correlate with the NO_2 measurements, that the higher particle concentrations compared with the adjacent years are not associated with more general levels of pollution. The occurrence of very high concentrations over short periods, often during only a single hour's measurement, indicates a relatively local source within 1km distance. Additionally, there seem to be a preponderance of high particle concentrations associated with higher wind speeds, which is more consistent with wind-raised particles than with more general pollution levels, as in the latter case particle concentrations should fall with increasing wind speed. Further, the majority of occurrences of high particle concentration were during the working day. It was not practicable to attempt a correlation of high particle concentrations with wind direction and the alignment of the construction and monitoring sights due to the effects of local topography (the relatively closely packed buildings) modifying the local wind directions.

This does not amount to an unequivocal correlation of particles from the construction site being the major source of the monitored high particle concentrations. However, due to the close proximity of the two sites, the monitoring site is less than 5m away, half way across the adjacent street, the balance of probabilities is that it was. The relatively close packing of the buildings on the site would give rise to relatively low wind speeds at the ground, low rates of ventilation of contaminants and relatively high particle concentrations as a result.

Correlations of particle concentration with the different phases of the construction process showed the highest concentrations occurring during wall construction and internal/external finishing, though there were occasional high concentrations of PM_{10} during other phases of the construction.

7. RECOMMENDATIONS

Although this investigation has highlighted construction sites as probable sources of high concentrations of particles, it has not been possible to identify their sources with any specific construction activity such as materials handling, disc cutting and angle grinding, diesel generators etc. Information on these aspects is currently not available apart from the knowledge that they 'result in large quantities of dust resulting in increasing numbers of complaint'. Discussions with a number of Environmental Health Officers have indicated that there are many practical problems of this sort.

To enable identification of the major sources of particle production from the various construction processes (such as disc cutting) and materials, it is necessary to carry out detailed monitoring of particle generation from these processes on a daily basis and for the period of the whole process. It is also important to keep a daily log of activities being carried out on the site. Similarly, the attribution of high particle concentrations to specific activities needs correlation with meteorological data, mainly wind speed and direction, but also with precipitation.

8. ACKNOWLEDGEMENTS

The funding for the above work by the Construction Directorate of the Department of the Environment, Transport and the Regions is gratefully acknowledged. Thanks are due to Leighton O'Conner from Cardiff City Council who supplied the information regarding the activities carried out during the construction of the building studied here. Thanks are also due to James Pike and Michael Chandler of BRE with assistance with some of the figures.

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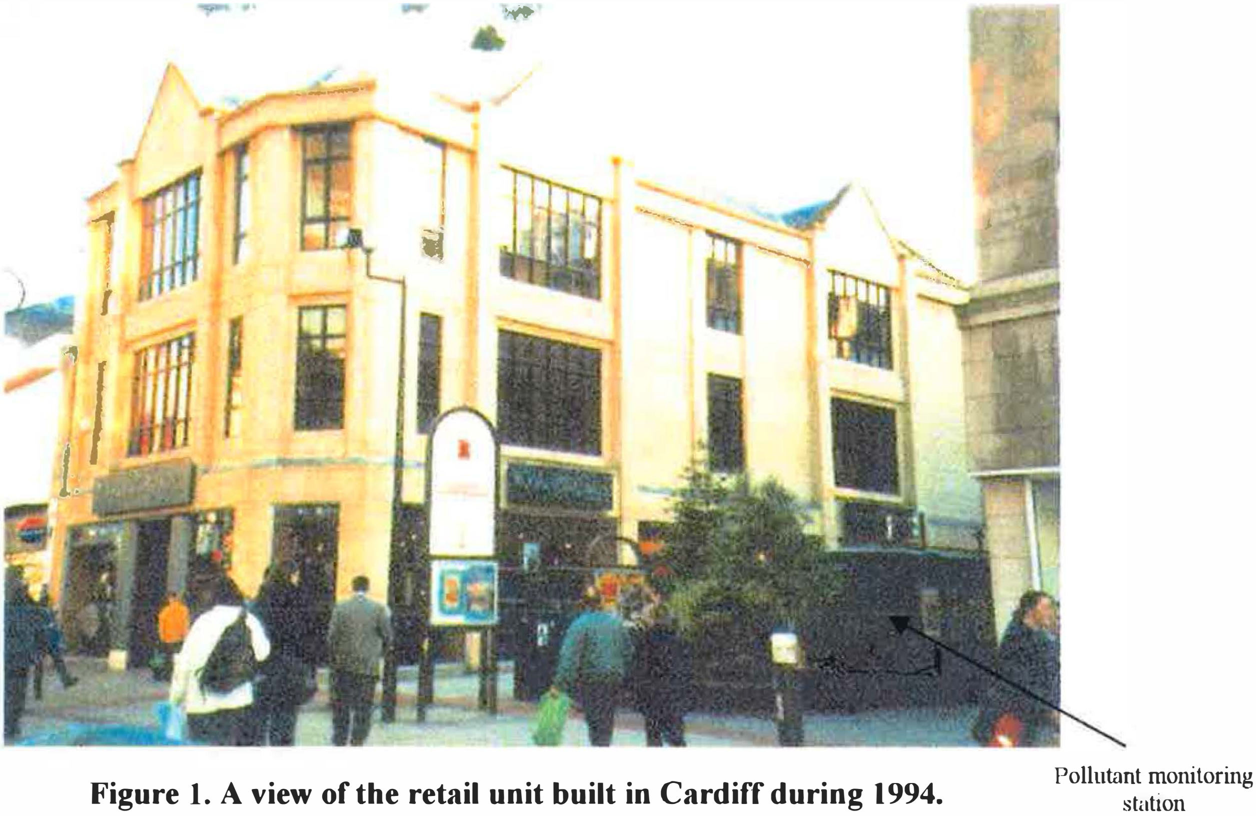


Figure 1. A view of the retail unit built in Cardiff during 1994. The AUN monitoring station can also be seen.

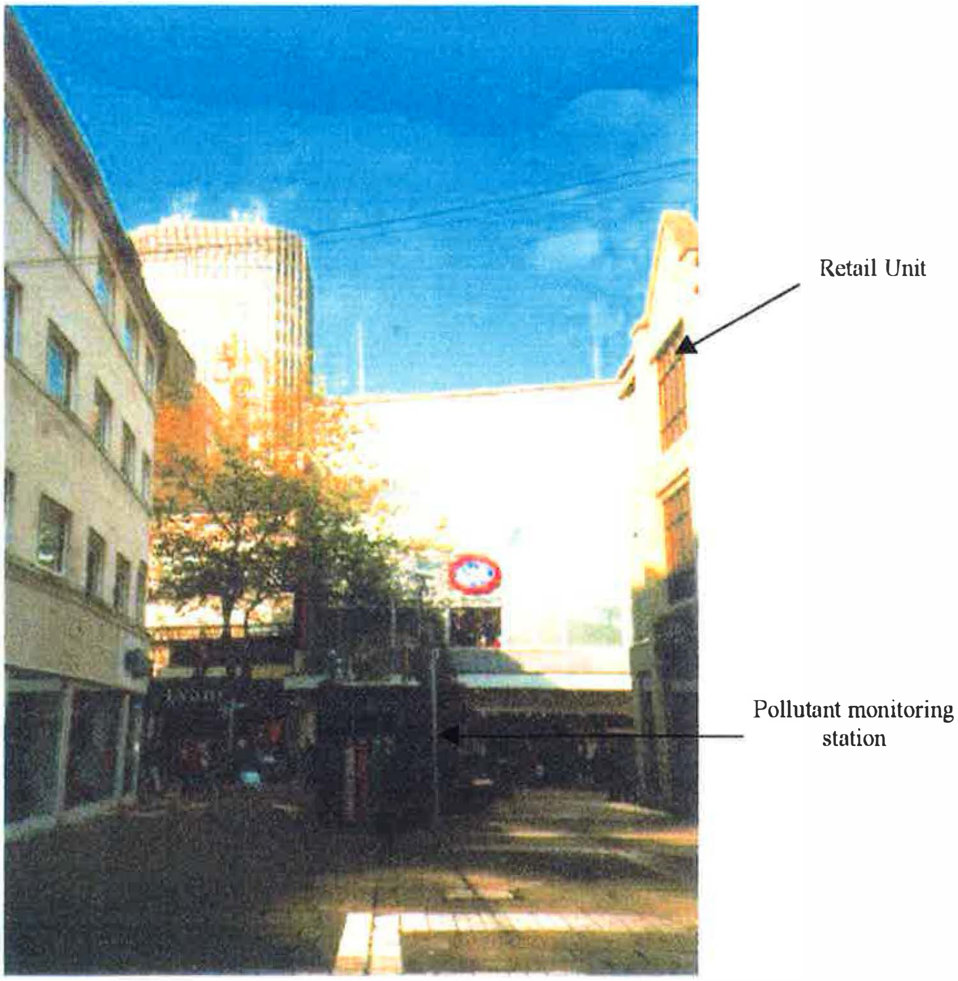


Figure 2. A view of the AUN monitoring station from down Frederick Street.

Figure 3. A view of the surroundings looking west, down Queen Street.

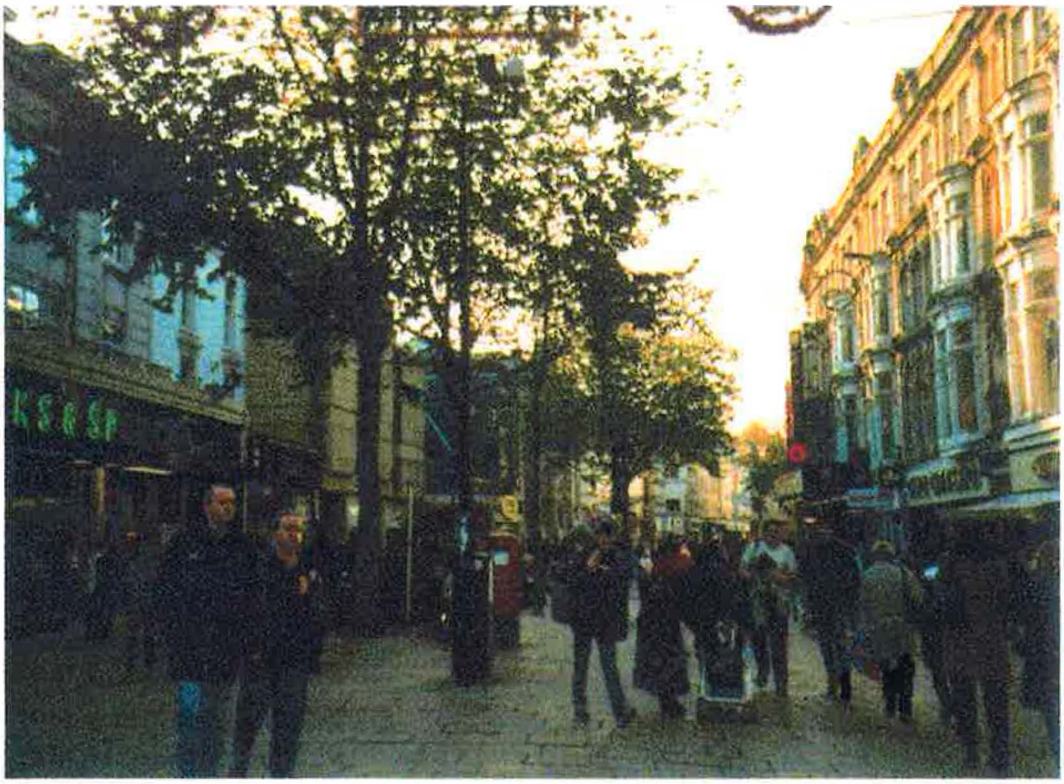


Figure 4. A view of the surroundings looking east, down Queen street.

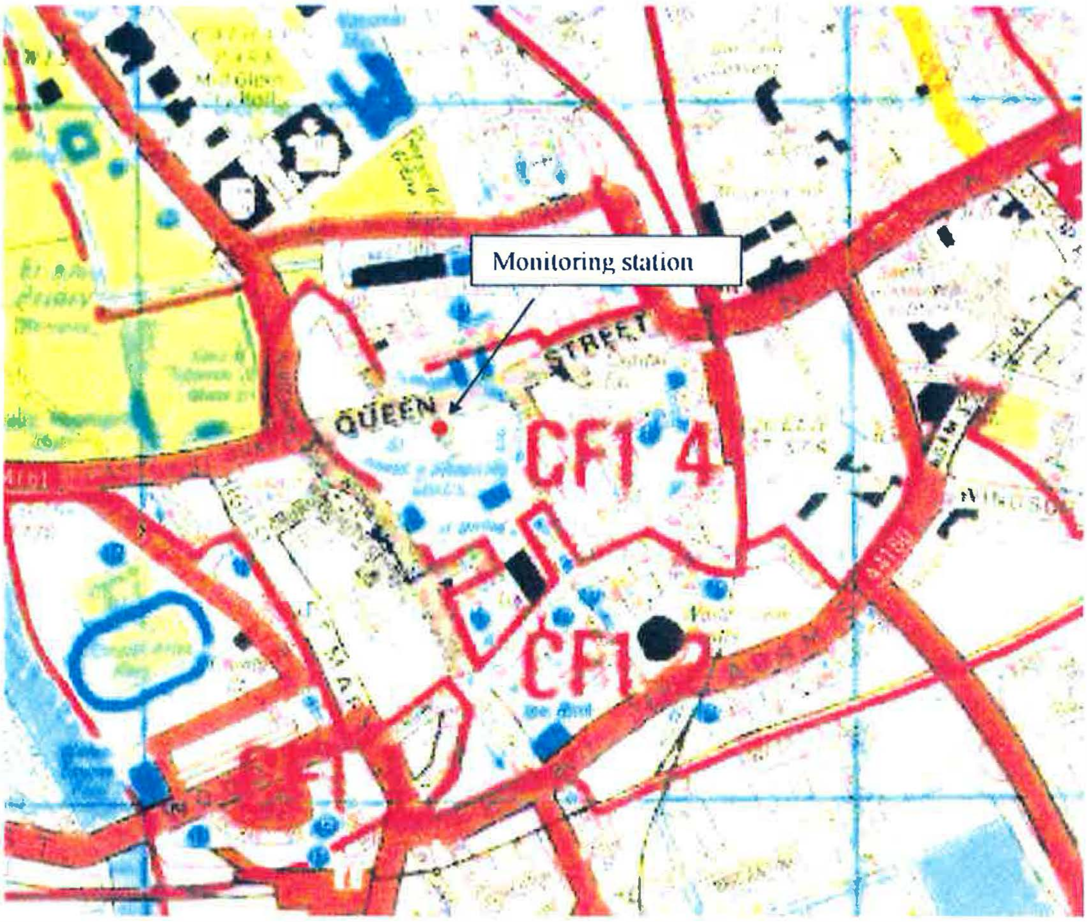


Figure 5. Detailed map of Cardiff City centre

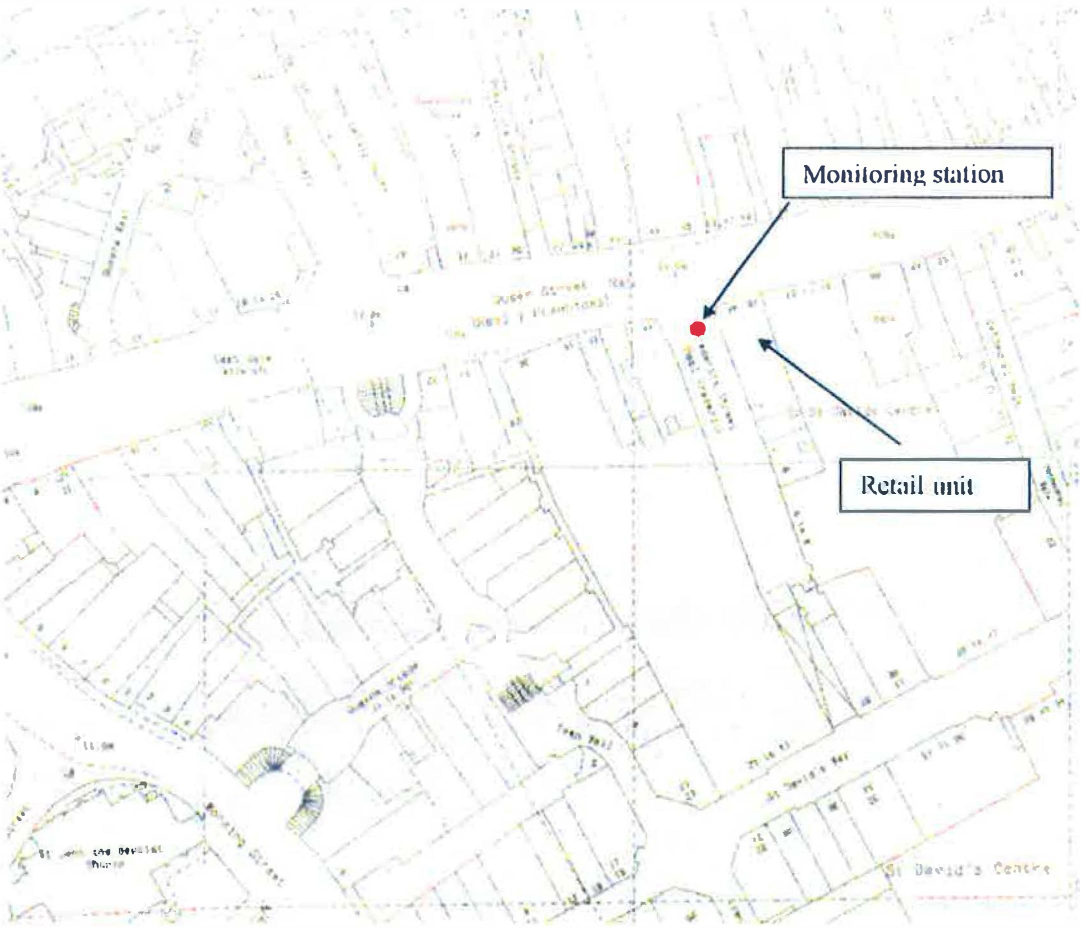


Figure 6. Detailed plan of the site

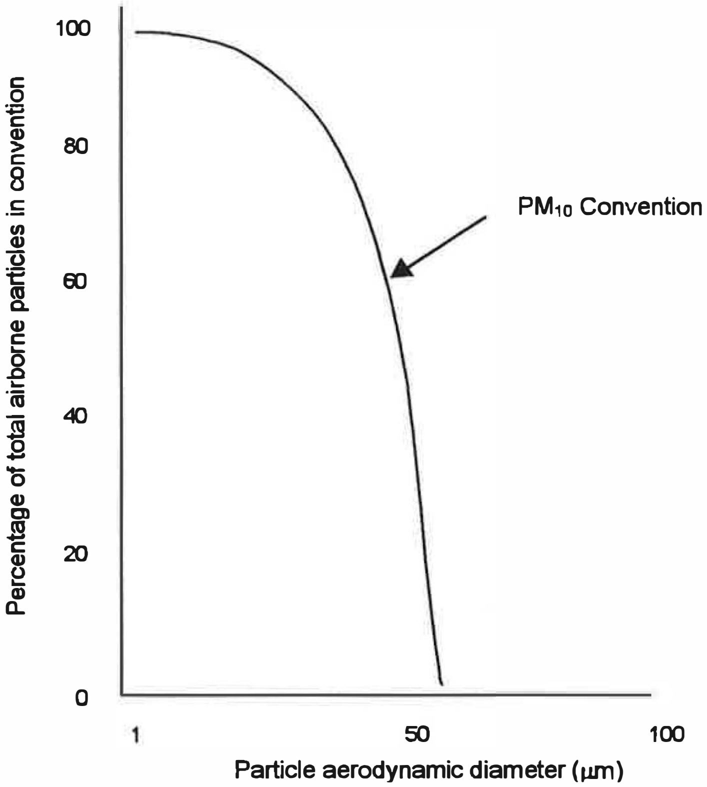


Figure 7. Definition of PM_{10}

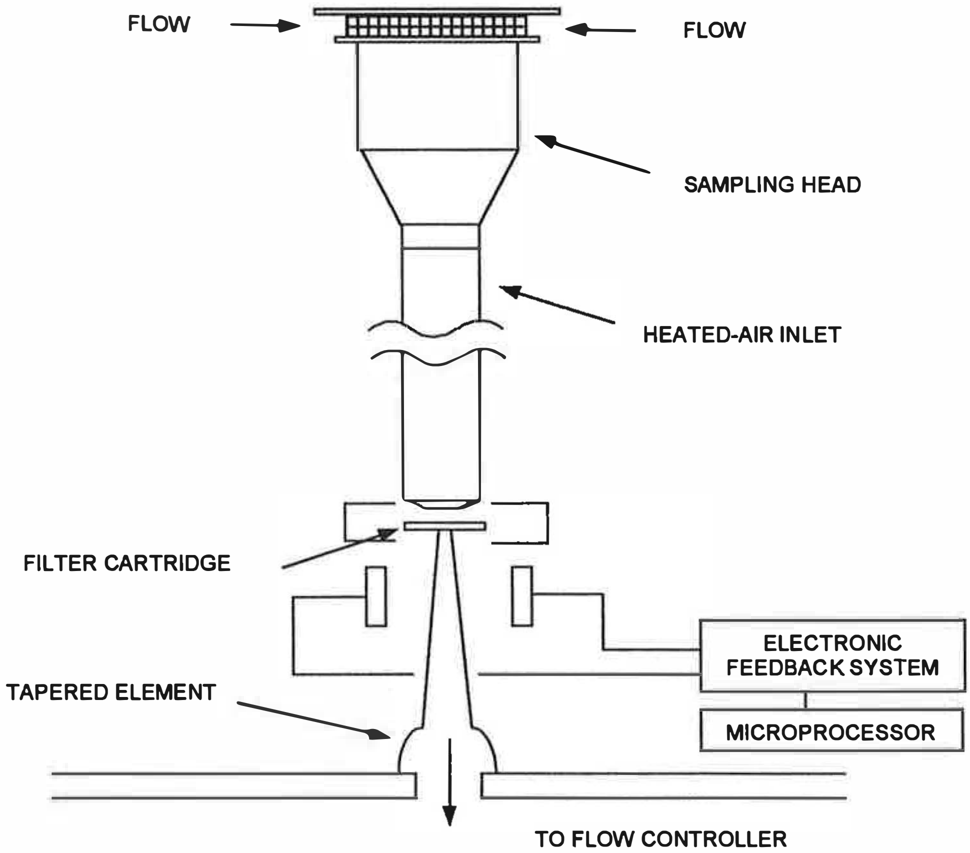


Figure 8. Schematic diagram of Rupprecht and Patashnick TEOM Ambient PM_{10} Monitor

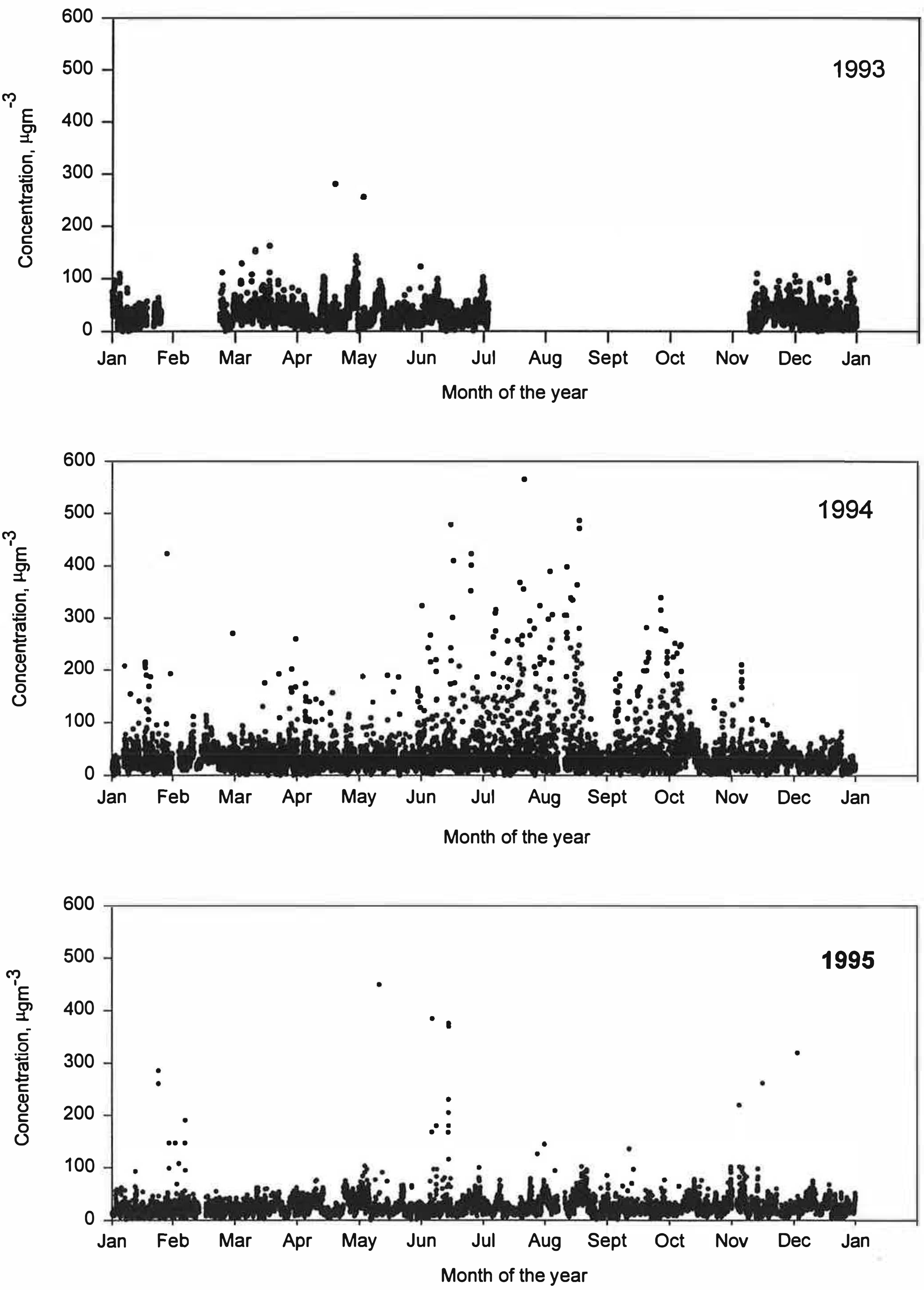
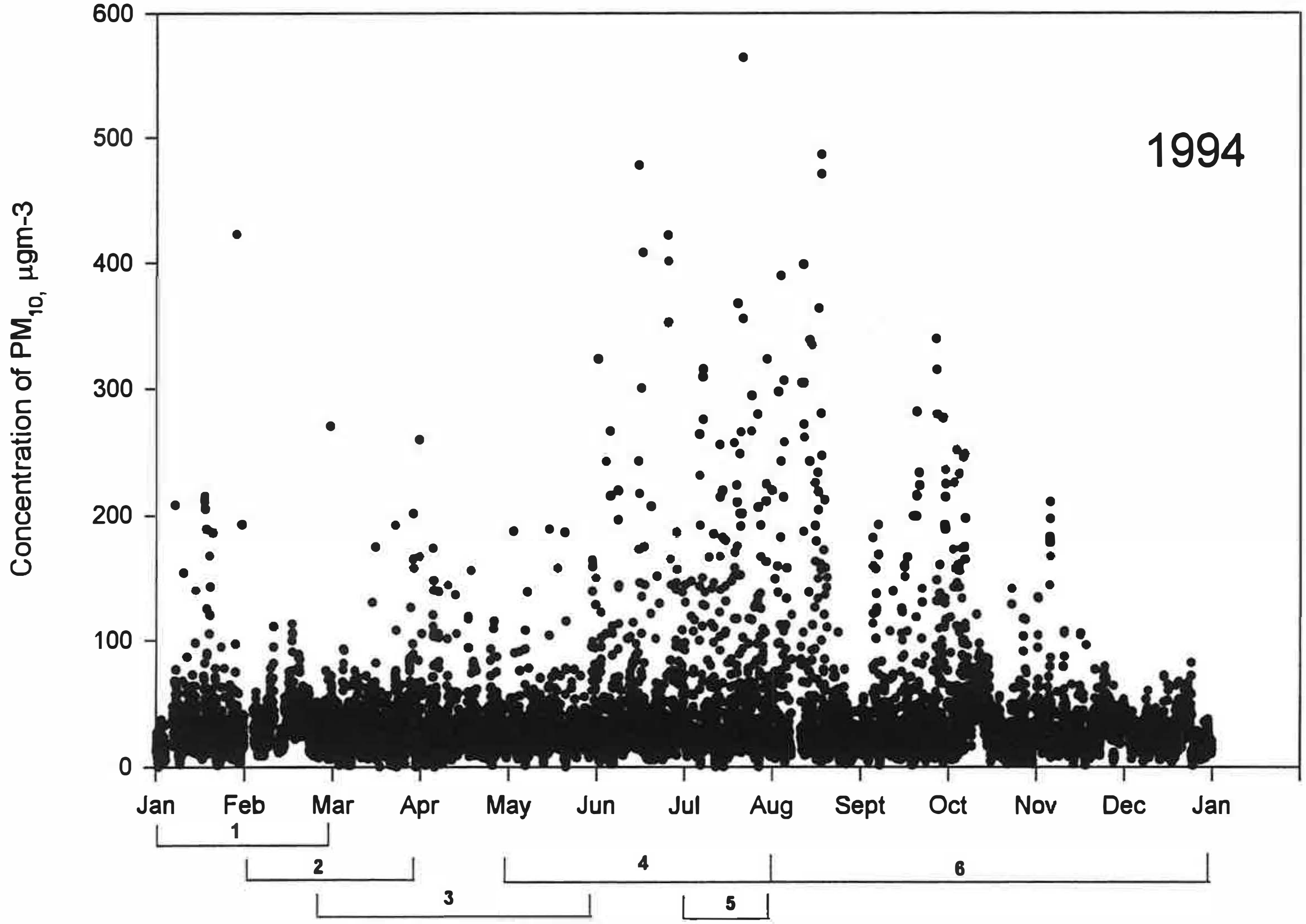


Figure 9. Hourly PM_{10} Particle concentrations for the years 1993, 1994, 1995



Key:

1. Ground works and excavation
2. Concrete for foundations
3. Steelwork (main steel frame) and concrete for floor slabs
4. Wall construction
5. Roof construction
6. Internal and external finishes

Figure 10. Concentration of PM_{10} as a function of construction activities

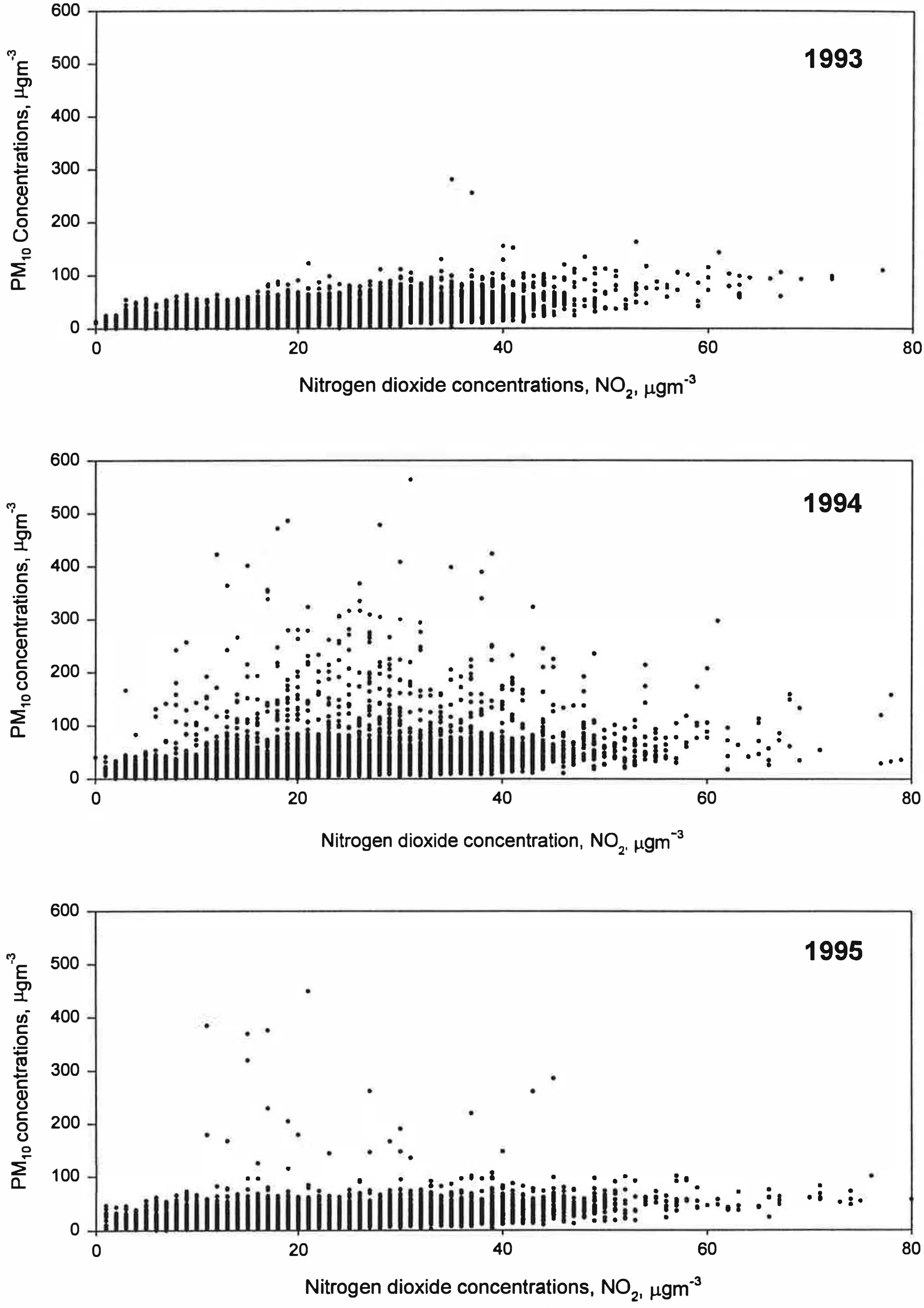


Figure 11. Comparison of PM_{10} with NO_2 concentrations for the 1993, 1994, 1995

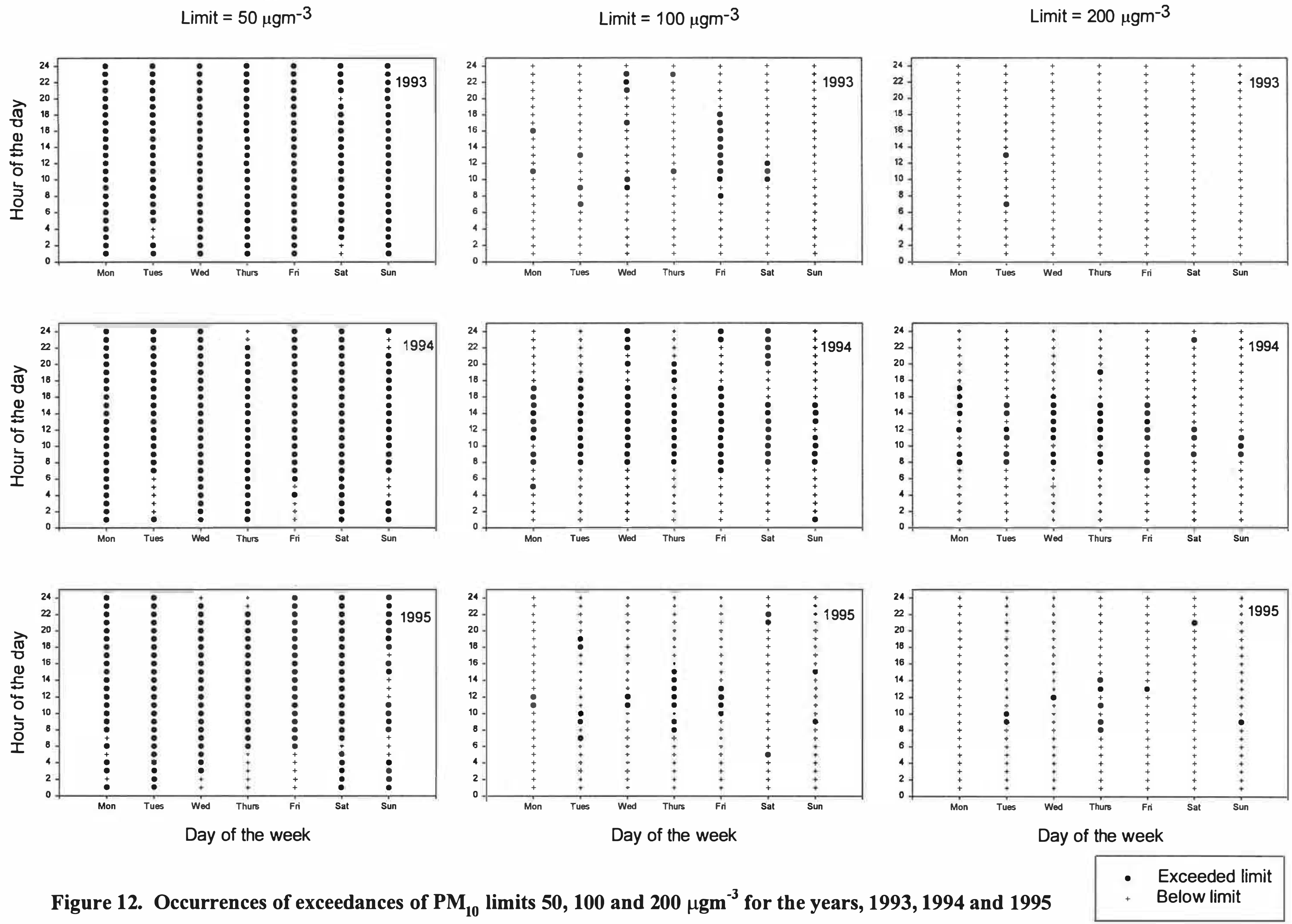


Figure 12. Occurrences of exceedances of PM_{10} limits 50, 100 and 200 μgm^{-3} for the years, 1993, 1994 and 1995

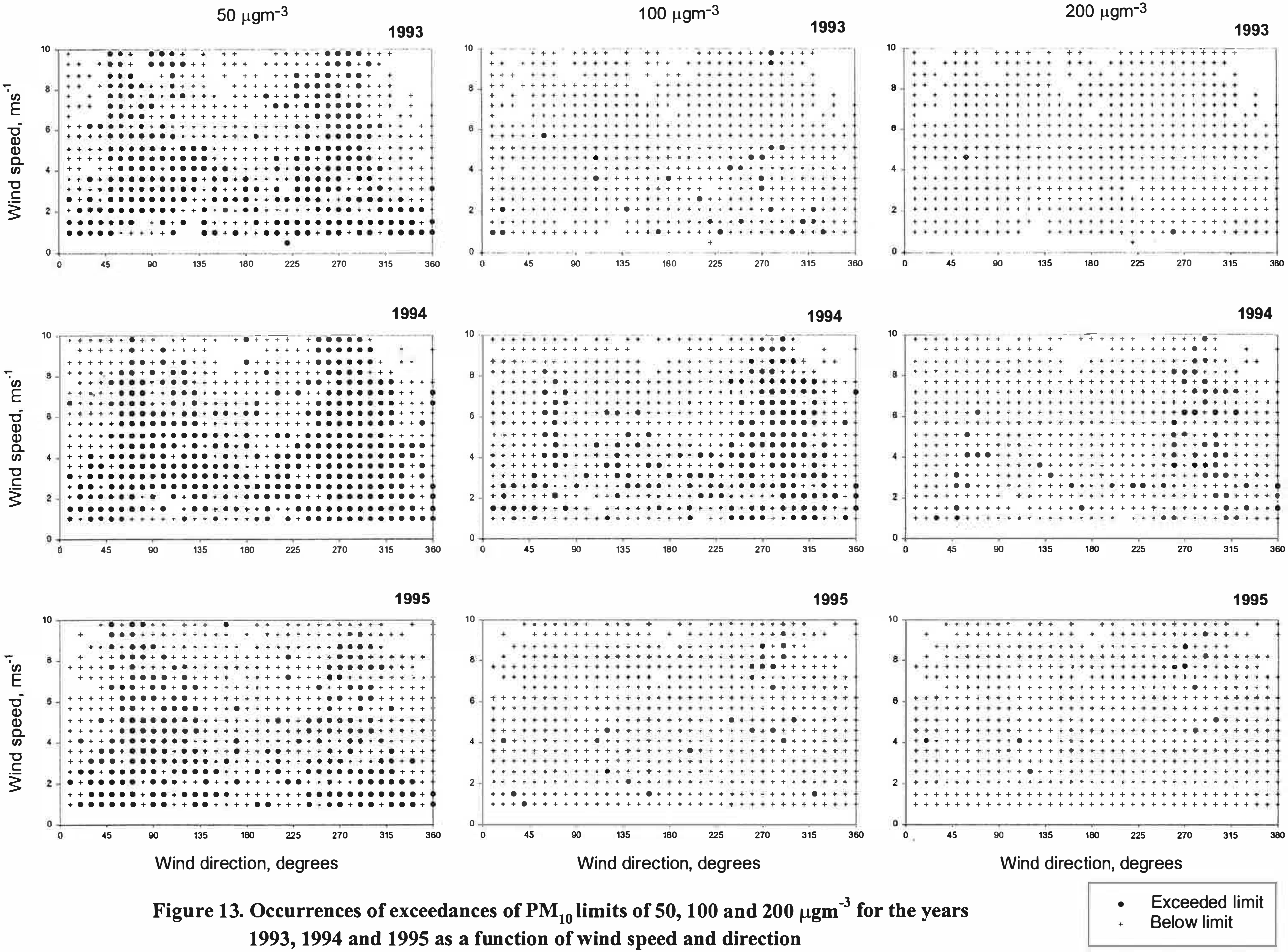
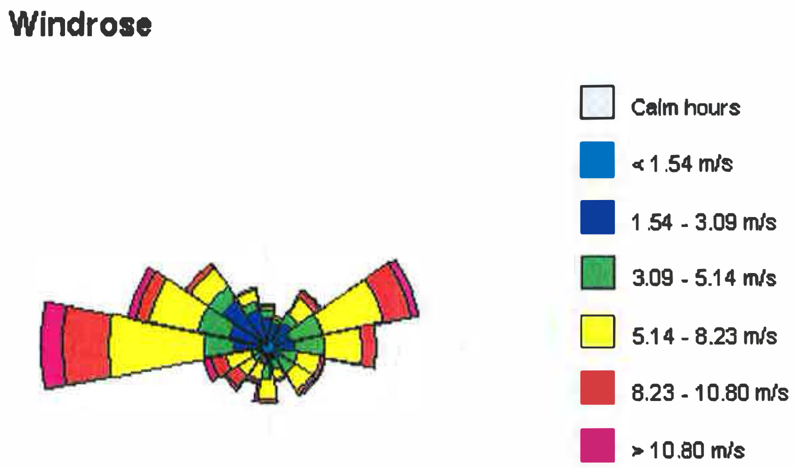
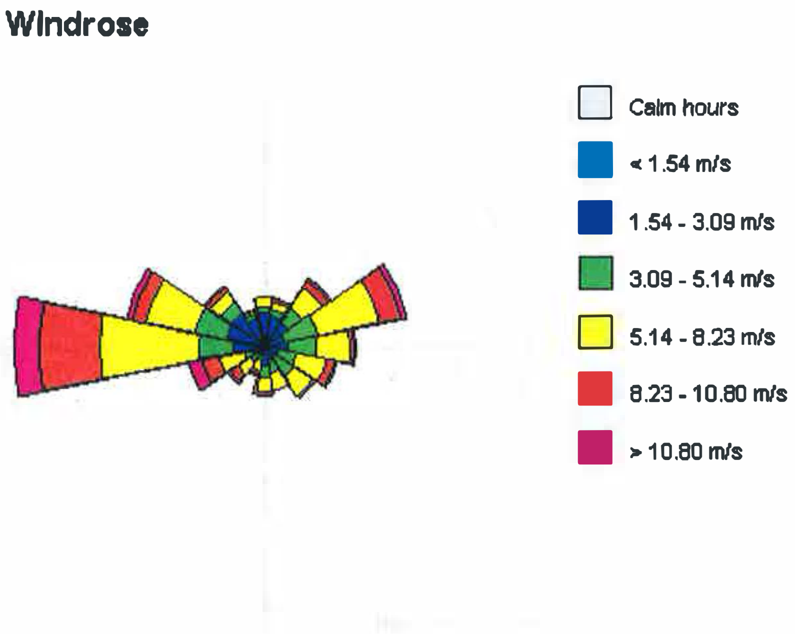


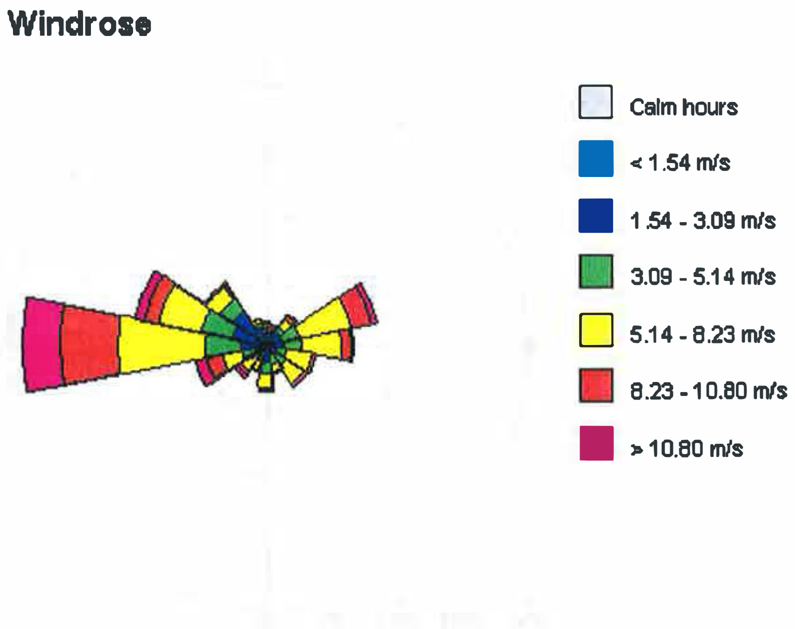
Figure 13. Occurrences of exceedances of PM_{10} limits of 50, 100 and 200 µgm^{-3} for the years 1993, 1994 and 1995 as a function of wind speed and direction


Windrose
Calm hours
< 1.54 m/s
1.54 - 3.09 m/s
3.09 - 5.14 m/s
5.14 - 8.23 m/s
8.23 - 10.80 m/s
> 10.80 m/s

(c)



(a)



(b)

Figure 14. Windrose for: a) 1993, b) 1994 and c) 1995

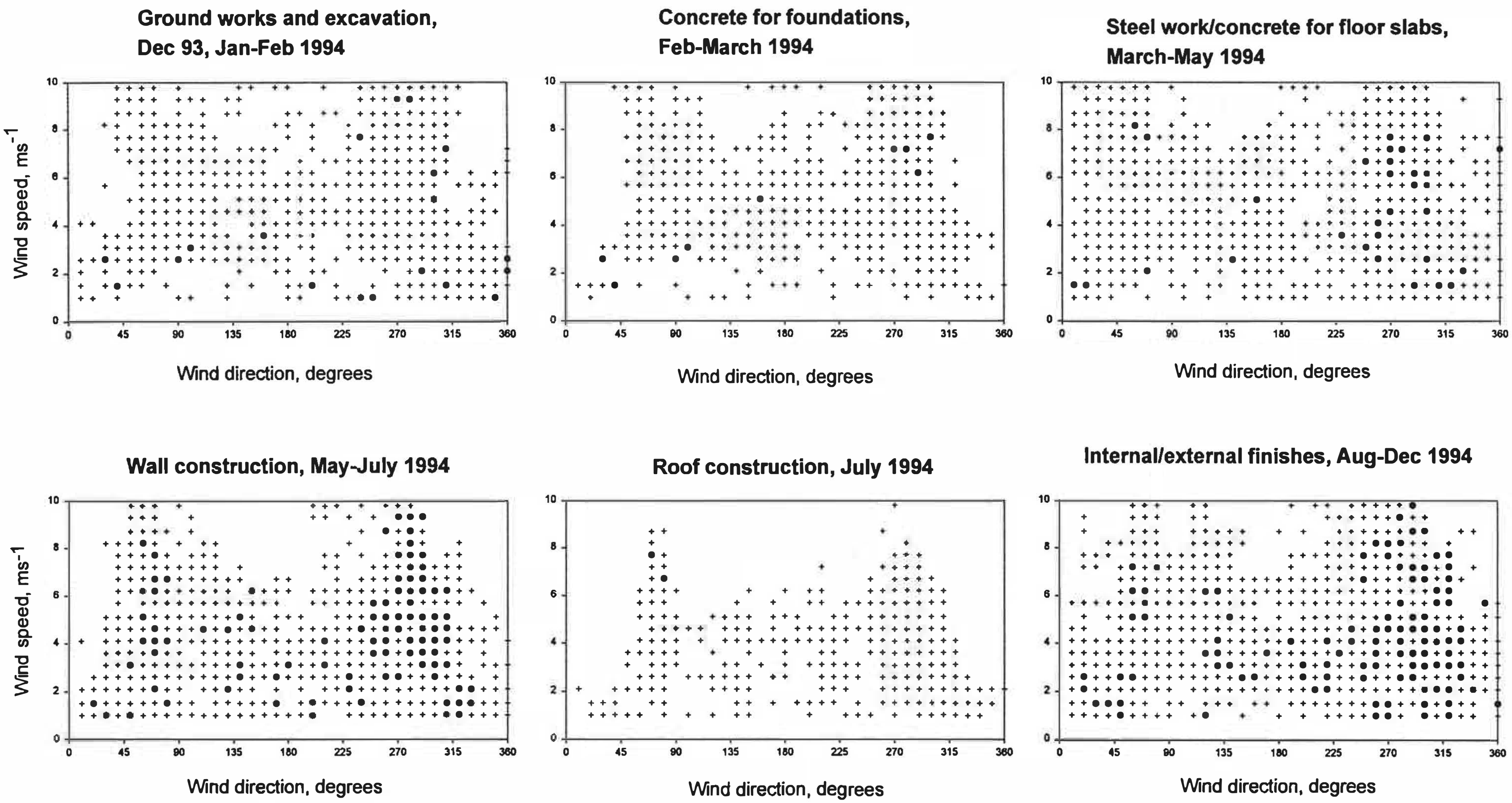


Figure 15. Occurrences of exceedances of a PM_{10} limit of 100 μgm^{-3} for the various construction phases