Hitchins, Jane and Morawska, Lidia and Gilbert, Dale and Jamriska, Milan (2002) Dispersion of Particles from Vehicle Emissions Around High- and Low-Rise Buildings. *Indoor Air* 12(1):pp. 64-71.

# Dispersion of Particles from Vehicle Emissions Around High- and Low-Rise Buildings

J. Hitchins[1], L. Morawska[1*], D. Gilbert[2], and M. Jamriska[1]

[1]Centre for Medical and Health Physics, Queensland University of Technology, GPO Box 2434, Brisbane QLD, 4001, Australia.

[2]Built Environment Research Unit, Queensland Department of Housing, GPO Box 2457, Brisbane, QLD 4001, Australia

[*]Corresponding author **after** 20/8/99

Fax Number for correspondence: +61-7-38641521

## *Abstract*

Understanding the distribution of outdoor pollutants around a building envelope, generated by sources located in its vicinity, is important for choosing the location of building ventilation system intakes, as well as for quantifying the exposure of people living or working in the building. A systematic experimental characterisation of the number concentration of submicrometre particles was undertaken around the envelope of six buildings (both low- and high-rise) at different distances from a road, (the main pollution source). The concentrations were measured using two TSI Scanning Mobility Particle Sizers. $PM_{2.5}$ concentrations were also monitored around the low-rise buildings using two TSI DustTraks.

For the three high rise buildings the concentration of fine and ultra-fine particles decreased in most cases to about 50 - 60% from the approximate ground level readings (between heights of 0 to 6 m), to full building height (from 24 to 33 m above the ground).

Measurements of submicrometre particle number concentrations as well as $PM_{2.5}$ fraction in the envelope around low-rise isolated buildings did not show any significant trends from the front to the rear of the building. The sensitivity of $PM_{2.5}$ measurements to a small number of larger particles, possibly from sources other than vehicle emissions, was observed.

## *Keywords*

Submicrometre particles, high-rise buildings, low-rise buildings, vehicle emissions, $PM_{2.5}$, ventilation systems.

## *Practical Implications*

The best position for the intake of a high-rise building ventilation system would appear to be towards the top. However, when other buildings are located close to the building of interest, concentration measurements must be made on a case to case basis to assess the distribution of pollutants around the building envelope due to the complexity of the situation. For low-rise buildings, the outdoor concentration of submicrometre particles measured at any point around the building are representative for the whole building. For buildings located in the vicinity of a busy road, the main factor governing levels of particle concentrations around the building envelope is the distance of the building from the road.

## *Introduction*

Flow patterns around buildings have been modelled quite extensively particularly for application to building design. The dispersion of gaseous pollutants has been studied by a number of investigators, however the dispersion of particulate matter has rarely been investigated in this context. There is a growing body of scientific evidence that exposure to fine, (according to most definitions, smaller then 2.5 μm), and ultra-fine particles (smaller than 0.1 μm), can result in significant health implications. This has important consequences for buildings in a city location where understanding the behaviour of fine and ultra-fine particles from vehicle emissions is important for the positioning of ventilation system intakes. Most of the investigations into flow patterns reported focused only on the theoretical modelling of pollutant dispersion, with a smaller number including experimental investigations and model validation.

Flow patterns and pressure fields around a building have been measured and mathematically modelled in a full scale situation by Hoxey, 1993. The study showed regions of higher pressure gradients at the corners of the building as well as the influences on the static pressure horizontally away from the sides up to 4 or 5 times the height of the building. These could mean an entrainment of pollutants at building corners, and increased concentrations in the area surrounding the building. Flow patterns were observed using smoke which indicated a significant dependence of dispersion on localised building structure – in particular, smoke flowing over curved eaves remained attached to the roof whereas sharp eaves produced a separated flow region allowing greater dissipation to occur. The smoke however, was only used as a tool for visualisation, and concentrations were not quantified.

Modelling of flow and dispersion of gas concentrations around a building in wind tunnel and towing tank simulations have been done by a number of researchers (Huber 1989, Arya 1995, and Zhang, et al. 1996). Among the considerations in these studies were building width and orientation, wind strength and the stability of the stratified airflow. The point source of the pollutant in these studies was at the centre of the lee side of the building, which means that wake dispersion was the main focus and the concentrations around the building itself have not been well studied.

Other investigators (Tominaga, et al. 1997, Li and Stathopoulos 1997, and Selvam 1997) also modelled wake dispersion of pollutants but used numerical simulations and compared results with data from wind tunnel experiments. These studies did not investigate the concentration distribution for sources upwind of buildings.

A Lagrangian Stochastic model was used by Lee and Naslund (1998), to predict concentrations around buildings under turbulent conditions. Point source emissions were simulated at the top of one building, in the wake of one building, and upwind of the building. The results for a source located upwind show only the horizontal dispersion, and do not indicate how the pollution travels in the vertical plane.

Leuzzi and Monti (1998) simulated the trajectory of particles as they are dispersed around a building. Using a three dimensional Lagrangian Stochastic model, they predicted the dispersion of pollution released from the top of a building, and from a line source at ground level upwind and downwind of a high-rise building. The line sources were studied to model the impact of motor vehicle emissions on ventilation intake position. For an upwind source, results showed a decrease in concentration with height at the front of the building, with high concentrations in a horseshoe pattern around the base of the building. No experimental data were used for validation of this upwind model. Figure 1 a) and b) show the velocity vector field used in the modelling as an example of the flow patterns around a building.

In summary, existing dispersion models for high-rise buildings (eg. Leuzzi & Monti 1998), suggest that concentrations are lower at the tops of buildings, however these models have not been validated for submicrometre particles. Location of the air intake for building ventilation systems at a point of lower pollutant concentration, can significantly improve the indoor air quality of the building. Models of the outdoor to indoor penetration of particle pollution under natural ventilation conditions for residential houses have not included information on where the outdoor parameter must be measured. Concentrations of particles may not be similar in all regions in the envelope around a house, so it is important to determine where regions of higher concentrations may occur so that these values can be used in exposure models.

The focus of the present study was to experimentally determine the distribution of the total number concentration of submicrometre particles around building envelopes of both high- and low-rise buildings located in the proximity of a road.

In a pilot study conducted by Morawska, et al. (1999), the variation of number concentrations with height at three high-rise buildings was examined. No significant correlation between height and concentration was detected for the reported wind direction from the road. However, a central weather monitoring station located at the top of a building, approximately 400 m away, was used, which may have been misrepresentative of the local wind conditions at the sampling site due to turbulence around the buildings. This uncertainty means that, while there was no correlation in this case, the actual wind direction may not have been from the road. The study presented here was an extension of the pilot investigations to include more comprehensive tests for high rise buildings and also tests for low rise buildings. Two of the buildings investigated previously were included in the present study.

## *Experimental Procedures*

The experiments included measurements of the number concentration of submicrometre particles around the envelope of three isolated low-rise buildings, and around three partially isolated high-rise buildings. The buildings were located in proximity to a major road, considered as the main pollution sources in the area, however at slightly different distances from the road. The particle number concentration was measured using two TSI Scanning Mobility Particle Sizers (SMPS’). Approximate $PM_{2.5}$ concentrations (mass concentration of particles with aerodynamic diameter smaller than 2.5 μm) were monitored for the low-rise buildings using two TSI DustTraks.

### *Instrumentation*

The instruments used for measuring the submicrometre size particles were two Scanning Mobility Particle Sizers, TSI Model 3934. Each of these consists of an electrostatic classifier, which classifies particles by their electrical mobility, and a condensation particle counter (CPC), which condenses butan-1-ol liquid onto the particles increasing their size to enable detection by laser light scattering. Two CPC types were used, the Model 3010, and the Model 3025A. The two types differ in their measurable size range, and also in their total measurable concentration limits, however, operating parameters of the instruments as well as conditions for the experiments were chosen such that the data from both instruments was directly comparable. The measured size range was 0.015 – 0.697 μm with a sample duration of 90 s. The SMPSs were calibrated using a known size aerosol produced from a TSI Condensation Monodisperse Aerosol Generator (Model 3475).

$PM_{2.5}$ was measured with a TSI DustTrak (Model 8520), which is a real time device for the determination of aerosol mass concentrations in the range 0.001 to 100 $mg.m^{-3}$, for particles ranging in size from 0.1 μm to 10 μm. Different impactors are available for the inlet of the DustTrak allowing measurements of $PM_{10}$, $PM_{2.5}$, and $PM_1$. The measurements are performed using a light scattering technique where the amount of scattered light is proportional to the volume concentration of the aerosol. The $PM_{2.5}$ values obtained in this study using the DustTrak, are not actual gravimetric values, as the instrument was calibrated for Arizona dust particles by the manufacturer, and would need to be re-calibrated for the vehicle emission aerosol at the road site. It was used in this study to provide relative readings.

*Low-rise buildings*

Three isolated low-rise buildings at distances of approximately 11, 35 and 75 m from a major road were chosen for these measurements. The buildings were a small hall, a small sports clubhouse, and a large church, respectively. They were all located on relatively flat ground with unrestricted access to all four sides. Sampling was performed for wind blowing towards the buildings from the road in order to provide maximum concentrations around the buildings.

Two SMPS systems were used, one set up to monitor continuously close to the road (a reference site), and the other to measure at different points around the outside of the building itself. Concentrations of submicrometre particles were measured at each side of the building. The sampling points were approximately 1 m from the building walls, with the inlet port facing away from the building. An approximation of $PM_{2.5}$ was also measured using two DustTraks around these buildings. The measurement procedure was as follows:

1. Continuous measurements near the road with the first SMPS and first DustTrak.
2. The second SMPS and DustTrak measured at the front of the building, at the back of the building, and then at each side, with five samples taken at each point.
3. Step 2 was then immediately repeated twice under the same conditions to provide three tests in total, as an indication of repeatability.

Monitoring of the wind speed and direction was conducted at a point between the building and the road. The weather station was a portable unit and logged averaged data at 6 minute intervals.

Figure 2 shows the schematic diagrams of the building and sampling points locations for these measurements.

*High-rise buildings*

Three high rise buildings were chosen for the vertical profile measurements in this study. Two were office buildings and were located at distances of 15 and 80 m from a major road, and the third was a multi-storey car park located at a distance of 5 m from a major road. There were no obstructions between each building and the road, however, both office buildings had high-rises to one side, and to their rear.

Sampling for the office buildings was performed for wind conditions blowing towards the buildings from the road in order to provide maximum concentrations. The wind conditions during sampling of the car park were on average 34 ° to the direction of the road, and the car park formed one side of a street 'canyon'.

Figure 3 shows the schematic diagrams of the building and sampling points locations for these measurements.

It was assumed that the atmosphere within the measured heights of up to 33 m was stable during sampling. Local wind conditions were monitored during all measurements and were found to be reasonably stable, with standard deviations of no more than 2.5 $km.h^{-1}$.

Two SMPS systems were used with one being set up near the road or at a particular building level close to the ground (reference site), and the other was measuring air from outside the building while being located inside the building at different heights. For the office buildings, a 1 m sampling tube was used to extend the inlet on the instrument to a point beyond the windows of the building. For the car park, a 2 m tube was used to extend the inlet. The measurement procedures for each of the three high-rise buildings were as follows.

**Office building 15 m from road**

1. One SMPS located on Level 2 at a height of 6 m above the ground (road level) taking continuous measurements.
2. The second SMPS taking five samples at each of heights ~9, 15 and 33 m (Levels 3, 5 and 11) at the front of the building.
3. Step 2 was repeated once to give two tests in total.

**Office building 80 m from road**

1. One SMPS located 40 m from the road taking continuous measurements.

2. The second SMPS taking five samples at each of heights 0, 9, and 24 m (Levels 1, 4 and 9) at the front of the building, at one side of the building, and at the rear of the building.

**Car park 5 m from road**

1. One SMPS 2 m horizontally away from the road and at a height of 4 m above the road, taking continuous measurements.
2. The second SMPS taking five samples at each of heights ~5, 6, 7, 9.5, 12, 14, 16, 19, and 21 m at the front of the building.

Measurements were not done at the rear and side of the 15 m office building or the car park due to restricted access to these positions.

## *Results and discussion*

### *Low-rise buildings*

The results of the isolated building measurements are presented in Figures 4 to 7. The relative concentrations around the building were calculated as a percentage of the concentration measured at the closest point to the road. This point was restricted by the physical location of the building. The points shown are averages of the three tests done at each building, and the error bars represent the standard error from the fifteen (five samples, three tests) samples taken at each point. Figure 4 presents the submicrometre particle concentrations for the low-rise building 11 m from the road. There appears to be a slight decreasing trend in the data from front to rear of the building, however, when the errors are considered, the decrease is not statistically significant and thus the conclusion is that there is no change in particle concentration. Figures 5 and 6 also show submicrometre particle number concentrations for low-rise buildings 35 and 75 m from the road, respectively. Again, there is no significant trend around the buildings and thus there does not appear to be any appreciable effect on the concentrations due to the building structure. However, the variation between measurements, represented by the standard error bars, is thought to be due to turbulence, which is a building related factor.

Figure 7 shows the $PM_{2.5}$ concentrations around all three low-rise buildings. There is no significant variation between the concentrations in the front and the rear of the buildings, however there does appear to be an increase of about 50% in the concentrations from the road to the rear for two of the buildings (35 and 75 m from the road). Concentration levels measured for these two buildings however, were low and were close to city ambient levels measured from the Environmental Aerosol Laboratory (EAL) in the city of Brisbane. This indicated low emission levels from roads which are in the vicinity of these buildings. The standard errors for these measurements are also much larger than for those from the third building (11 m from the road), where the concentration levels measured near the road were up to four times greater than the city ambient levels. This indicates that a small number of larger particles from sources other than vehicle emissions may be dominating the $PM_{2.5}$ readings for the two buildings which show an increase. Other sources could include dust from the gravel car park at one side of the 75 m building, or dust from the synthetic surface of the netball court to one side of the 35 m building. The concentration levels from vehicle emissions around the 11 m building are large enough for interference from other sources to be negligible, and the standard errors in this data are consequently much smaller. Mass concentration data from the DustTrak can thus be misinterpreted as vehicle emissions, particularly for cases where the concentrations are low and particles from other sources can dominate the readings.

In conclusion, number concentrations of submicrometre particles from a line source of vehicle emissions do not vary significantly around the envelope of a low-rise building. $PM_{2.5}$ from vehicle emissions is also constant around the building, although other sources such as dust redispersion must be considered, particularly when vehicle emission concentrations are low.

*High-rise buildings*

Figures 8 to 10 show the vertical concentration profiles for the three high rise buildings at distances of 5, 15, and 80 m respectively, from a major road. The relative concentrations at each height were calculated as a percentage of the concentration measured at the lowest height. The lowest height measured was restricted by the physical characteristics of the location. All show a clear decrease in concentration with height for measurements taken at the front (facing the road) of the buildings to about 50 - 60% from the approximate ground level readings (between heights of 0 to 6 m), to full building height (from 24 to 33 m above the ground). These data support the simulated results from a model presented by Leuzzi & Monti (1998), which show a decrease in concentration with height at the front of the building under source conditions similar to those in the present study. For the 80 m building (Figure 10), however, concentrations were also measured at the rear and at the side of the building, and these show an increase with height to about 140 % of the ground level reading. This could be due to the presence of buildings behind the investigated building, which would affect the vertical dispersion of pollutants by creating a back flow or other flow disruption patterns (see Figure 1).

The pilot study of the vertical number concentration profile of submicrometre particles by Morawska, et al. (1999) showed no significant correlation between height and concentration for the reported wind direction from the road. As discussed previously, turbulence around the buildings may have affected the accuracy of the wind direction readings. For this case then, there is uncertainty as to whether or not there would be a correlation for wind blowing directly from the road, as measured close to the sampling site under non-turbulent conditions.

A practical conclusion which can be drawn from these findings is, that locating the intake of a ventilation system at the top of a high-rise building, facing the source (road), is an optimal solution for a building which is unobstructed from the pollution source. Any other location of the ventilation system in relation to the source, particularly for more complex situations involving more buildings, would need to be studied individually, unless more advanced models for such cases became available.

## *Conclusions*

A study on concentrations of submicrometre particles measured around low-rise and high-rise buildings was undertaken. This included measurements of the distribution around three low-rise buildings, and the vertical distribution of particles from three high-rise buildings at three different distances from a major road.

Measurements of submicrometre particle number concentration in the envelope around low-rise buildings show no significant change from the front to the rear of the building. $PM_{2.5}$ measurements also show no change in concentration from the front to the rear of the building. Thus there seems to be no effect on concentrations due to the building itself, except to produce turbulence which creates some variations in the measurements.

There is a clear decrease in concentration with height when measurements are conducted from the front of the building for all three buildings situated 5, 15, and 80 m from a major road. The concentration of submicrometre particles decreases by about 50 - 60% between the ground level reading and full building height. Measurements taken from the side and rear of one of the buildings show an increase in concentration with height of about 140%. Further investigation into the side and rear measurements are recommended to confirm this result, as it is suspected that buildings behind this one have influenced the behaviour of the particles. Modelling and measurement of the dispersion of particles around two or more buildings, and the interaction between the buildings, needs to be performed.

In summary, the best position for the intake of a high-rise building ventilation system would appear to be towards the top and facing the source for a building if it is exposed directly to a source of vehicle emissions, such as a busy road, with no obstructions from other buildings. When other buildings are located close to the building of interest, concentration measurements must be made on a case to case basis to assess the distribution of pollutants around the building envelope, until more advanced models for complex situations become available. In the case of mechanically ventilated high rise buildings, the exposure inside the building would thus depend on the location of the inlet of the ventilation system as well as filter performance for the size of particles emitted by the source.

For low-rise buildings, the outdoor concentration of submicrometre particles measured at any point around the building are representative for the whole building. This is also the case with measurements of $PM_{2.5}$, however local conditions which are likely to include sources of $PM_{2.5}$, such as the surrounding ground type, must be taken into consideration. This conclusion is important when measurements are to be undertaken to assess outdoor particle concentration around a particular building, as well as for modelling of exposure of the building occupants when both outdoor and indoor particle sources are to be considered. If investigations of this nature are undertaken for buildings located in the vicinity of a busy road, the main factor governing levels of particle concentrations around the building envelope will thus be distance from the road, as reported by Hitchins et al, (2000).


### *Acknowledgments*

This project was funded by an Australian Research Council SPIRT grant and by the Built Environment Research Unit, Qld Department of Housing, and thanks go to Chris Greenaway, Keith Eigeland and Brian Stockwell. Thanks also to all members of the QUT EAL for assistance with field work and for discussions.


### *References*


Arya S.P. (1995) Modeling And Parameterization Of Near-Source Diffusion In Weak Winds. Journal of Applied Meteorology. 34(5), May, 1112-1122

Hitchins J, Morawska L, Wolff R, and Gilbert D (2000) Concentrations of Submicrometre Particles form Vehicle Emissions near a Major Road. Atmospheric Environment 34:51-59

Hoxey R, Richards (1993) Flow patterns and pressure field around a full-scale building. Journal of Wind Engineering and Industrial Aerodynamics 50:203-212

Huber A.H (1989) The influence of building width and orientation on plume dispersion in the wake of a building. Atmospheric Environment 23(108):2109-16

Lee R and Naslund E (1998) Lagrangian Stochastic Particle Model Simulations Of Turbulent Dispersion Around Buildings. Atmospheric Environment. 32(4), Feb., 665-672

Leuzzi G and Monti P (1998) Particle Trajectory Simulation Of Dispersion Around A Building. Atmospheric Environment. 32(2), Jan, 203-214

Li Y and Stathopoulos T (1997) Numerical Evaluation Of Wind-Induced Dispersion Of Pollutants Around A Building. Journal of Wind Engineering & Industrial Aerodynamics. 67-8, Apr-Jun, 757-766

Morawska L, Thomas S, Gilbert D, Greenaway C, and Rijinders E (1999) A study of the horizontal and vertical profile of submicrometer particles in relation to a busy road. Atmospheric Environment 33:1261-1274

Selvam R (1997) Numerical Simulation Of Pollutant Dispersion Around A Building Using Fem. Journal of Wind Engineering & Industrial Aerodynamics. 67-8, Apr-Jun., 805-814

Tominaga Y, Murakami S, and Mochida A (1997) CFD prediction of gaseous diffusion around a cubic model using a dynamic mixed SGS model based on composite grid technique. Journal of Wind Engineering and Industrial Aerodynamics 67-8:827-841

Zhang Y, Arya S, and Snyder W (1996) A comparison of numerical and physical modelling of stable atmospheric flow and dispersion around a cubical building. Atmospheric Environment 30(8)

Figure 1 Velocity vector field: a) in the horizontal plane; b) in the vertical plane (Leuzzi & Monti 1998).

Figure 2. Schematic diagrams of the low-rise building and sampling point locations for these measurements. Dimensions are in metres, the SMPS was placed at position “X”, and the weather station at position “Y”.

Figure 3. Schematic diagrams of the high-rise building and sampling point locations (marked as horizontal bars on the building front) for these measurements. One SMPS measured continuously from the reference point. Dimensions are in metres.

Figure 4. Low-rise building 11 m from road, concentration profile of submicrometre particles (Wind: 1.9 – 3.1 $km.h^{-1}$ from the road). The “Road” point is a distance of 5 m from the road.

Figure 5. Low-rise building 35 m from road, concentration profile of submicrometre particles (Wind: 8.3 – 12.1 $km.h^{-1}$ from the road). The “Road” point is a distance of 15 m from the road.

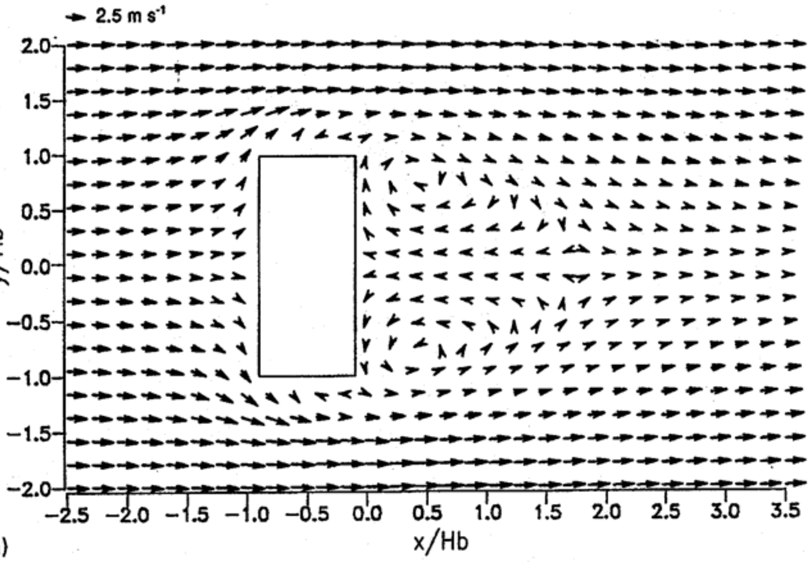
Figure 6. Low-rise building 75 m from road, concentration profile of submicrometre particles (Wind: 1.2 – 2.3 $km.h^{-1}$ from the road). The “Road” point is a distance of 55 m from the road.

Figure 7. $PM_{2.5}$ concentration profile for all three low-rise isolated buildings.

Figure 8. High-rise building (car park) 5 m from road, vertical concentration profile of submicrometre particles (normalised to height 4 m).

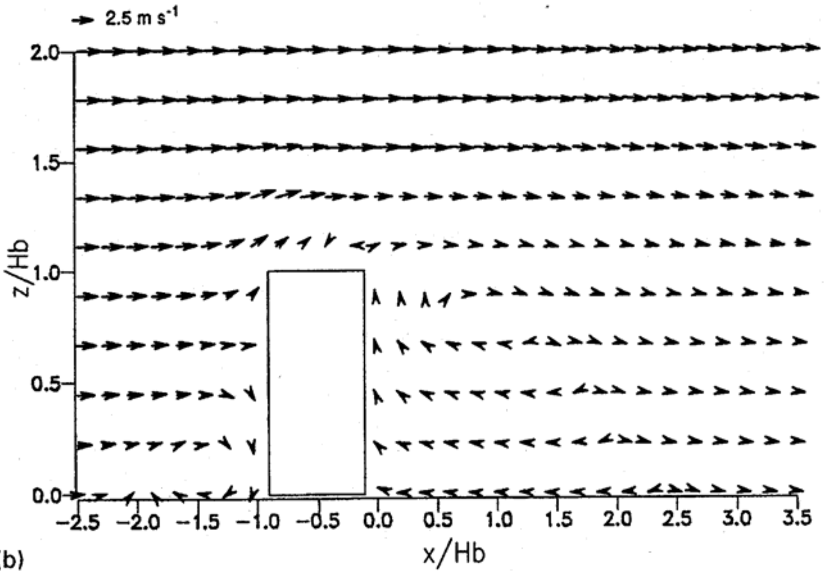
Figure 9. High-rise building 15 m from road, vertical concentration profile of submicrometre particles (normalised to height 6 m – level with road). Wind: 13.7 $km.h^{-1}$ (SD 2.5 $km.h^{-1}$) from the road.

Figure 10. High-rise building 80 m from road, vertical concentration profile of submicrometre particles (normalised to height 0 m), for the front, side, and rear of the building. Wind: 5.5 $km.h^{-1}$ (SD 1.1 $km.h^{-1}$) from the road.



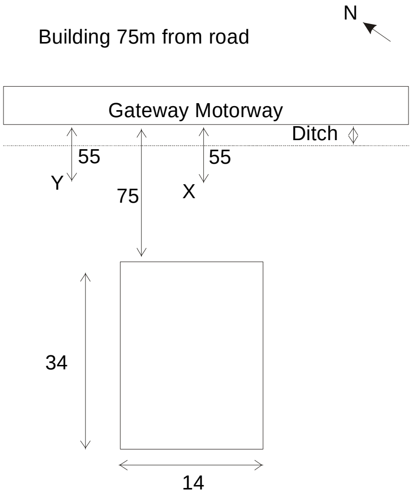
2.5 m s-1
y/Hb
x/Hb
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
3.0
3.5


(a)

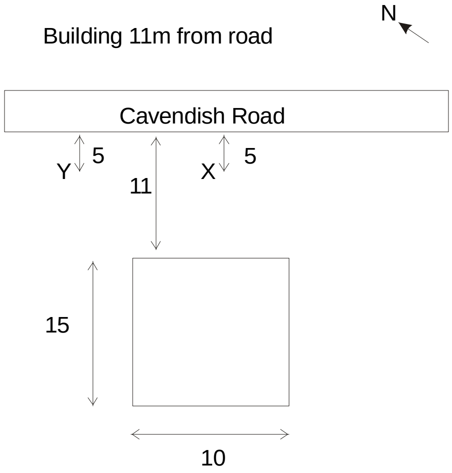


2.5 m s-1
z/Hb
x/Hb
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
2.5
3.0
3.5

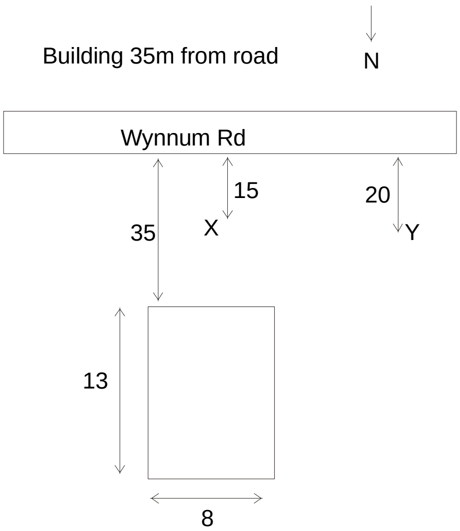

(b)




Dimensions in metres
SMPS at position “X”
Weather station at position “Y”

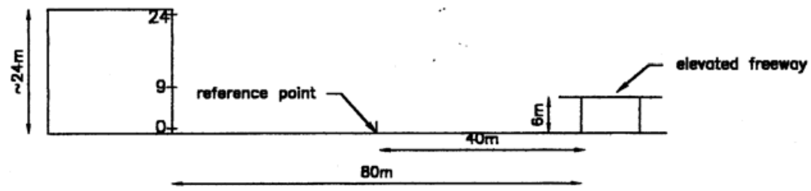



Dimensions in metres
SMPS at position “X”
Weather station at position “Y”

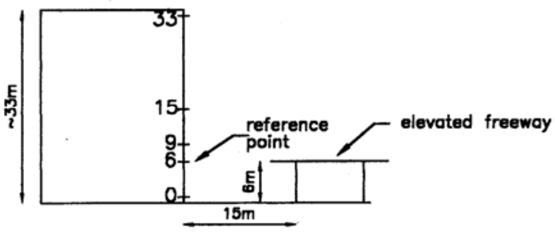



Dimensions in metres
SMPS at position “X”
Weather station at position “Y”

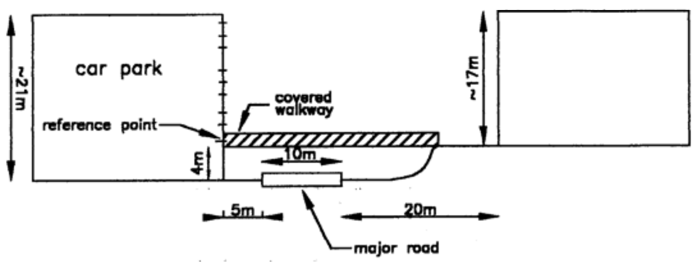
Building 80m from Road

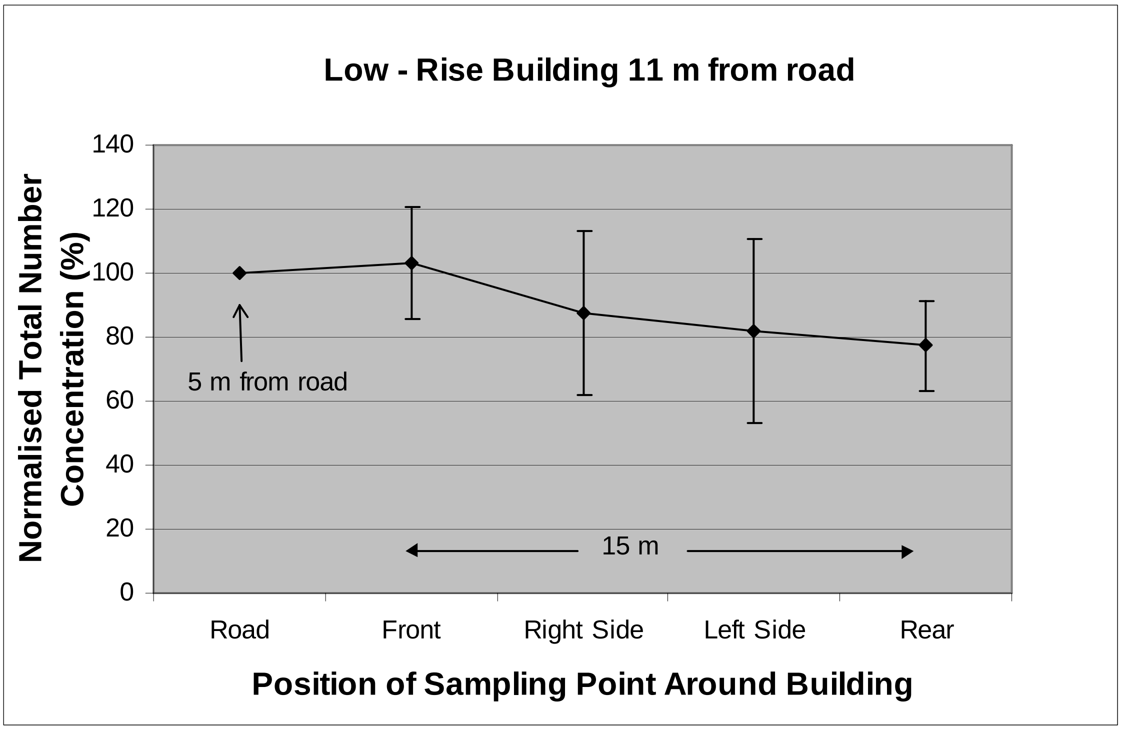


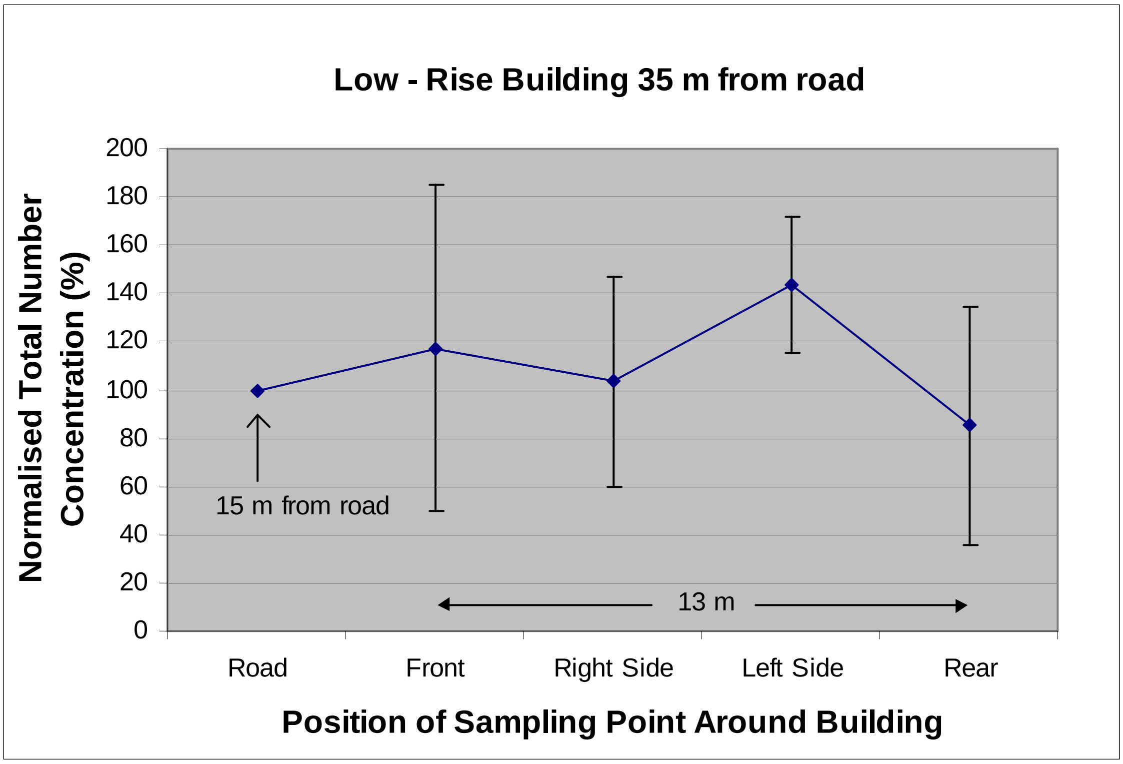

Building 15m from Road

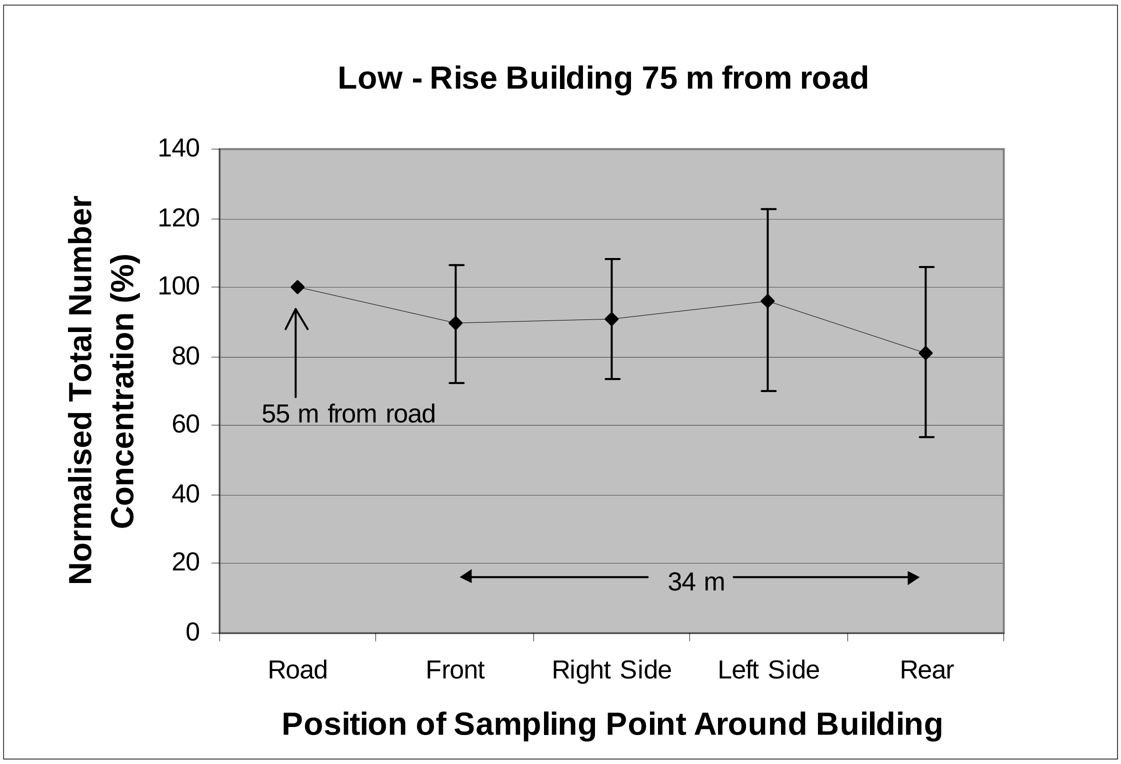


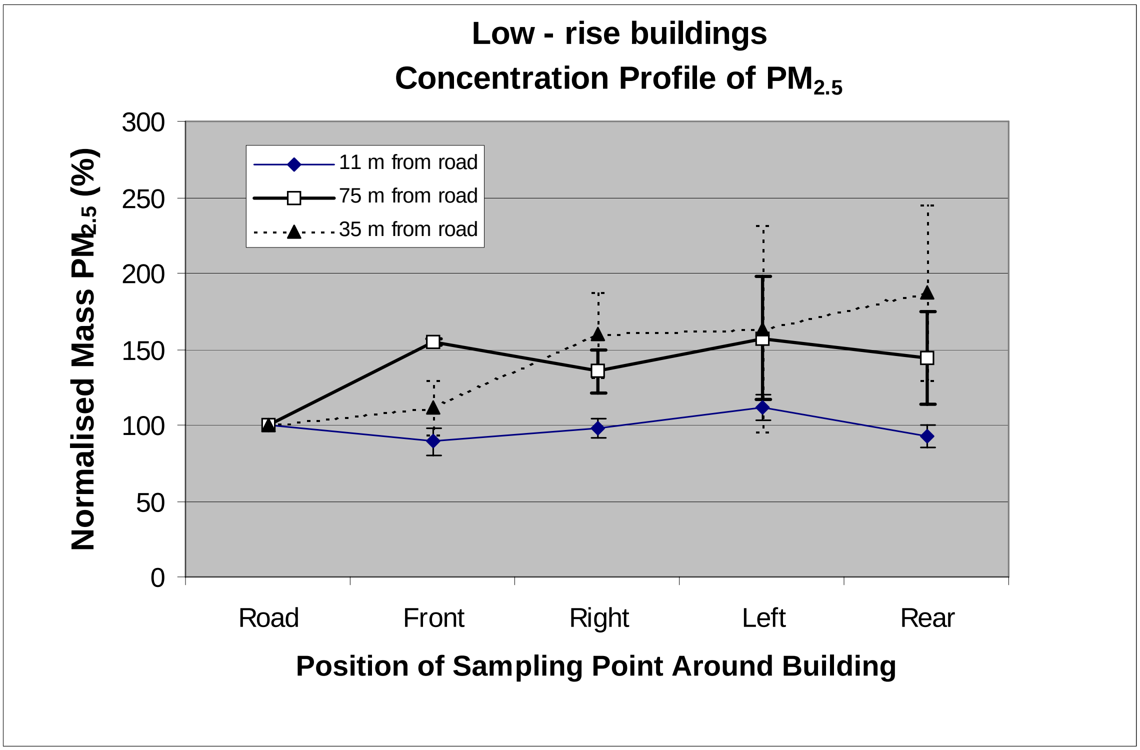

Building 5m from Road

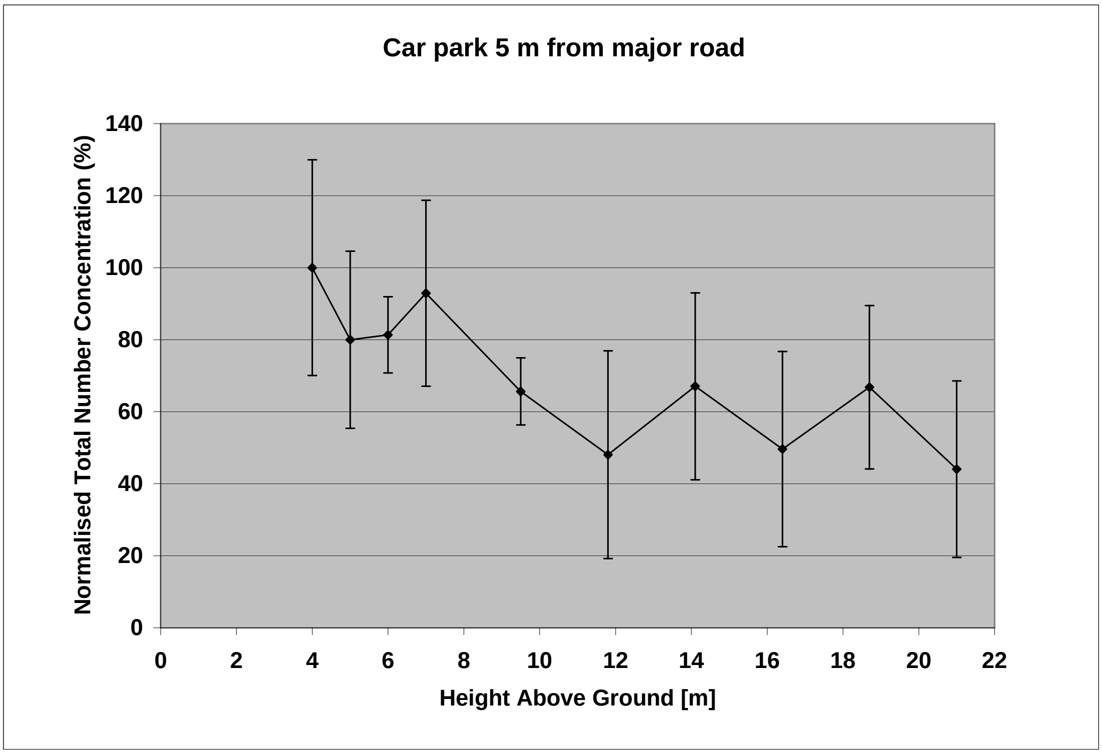


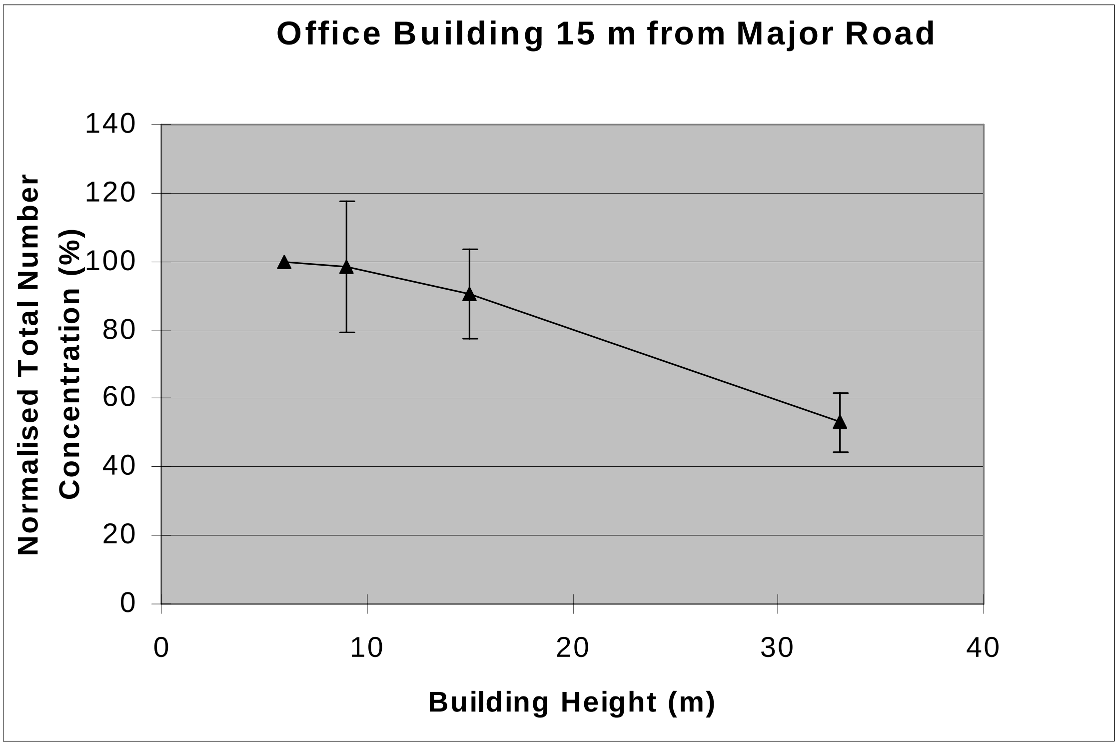

Low - Rise Building 11 m from road
Normalised Total Number Concentration (%)
140
120
100
80
60
40
20
0
5 m from road
15 m
Road
Front
Right Side
Left Side
Rear
Position of Sampling Point Around Building

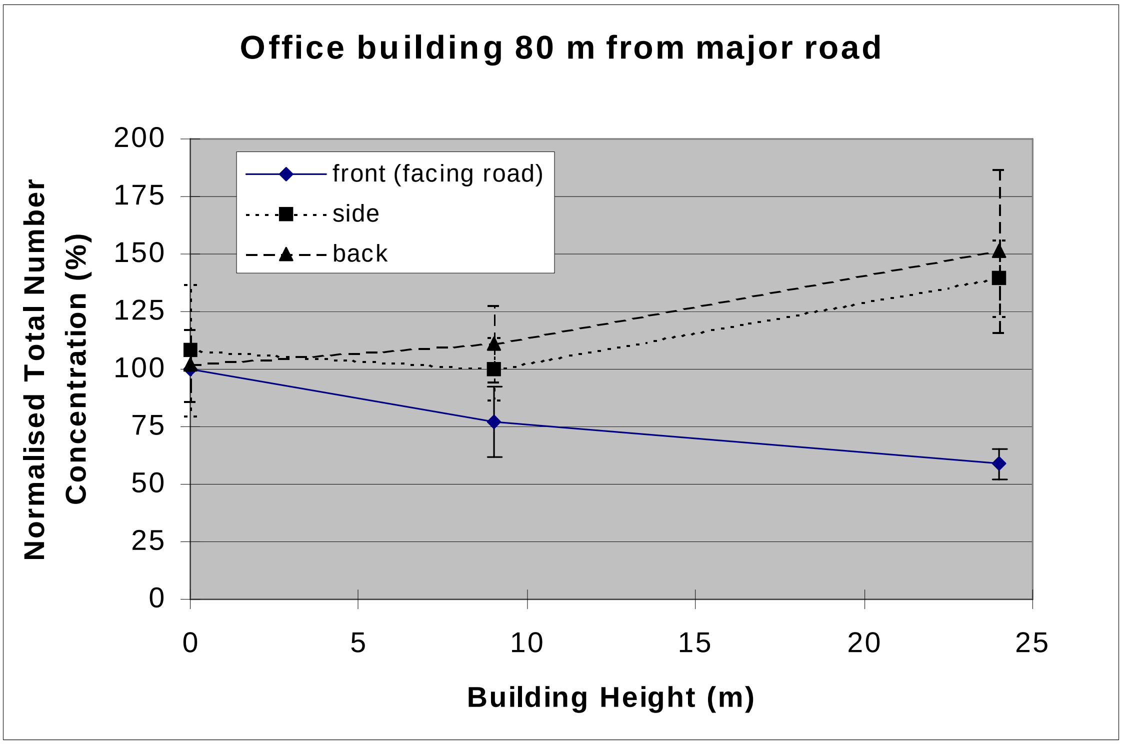

Low - Rise Building 35 m from road
Normalised Total Number Concentration (%)
200
180
160
140
120
100
80
60
40
20
0
15 m from road
13 m
Road
Front
Right Side
Left Side
Rear
Position of Sampling Point Around Building


Low - Rise Building 75 m from road
Normalised Total Number Concentration (%)
140
120
100
80
60
40
20
0
55 m from road
34 m
Road
Front
Right Side
Left Side
Rear
Position of Sampling Point Around Building


Low - rise buildings
Concentration Profile of PM2.5
11 m from road
75 m from road
35 m from road
Normalised Mass PM2.5 (%)
300
250
200
150
100
50
0
Road
Front
Right
Left
Rear
Position of Sampling Point Around Building


Car park 5 m from major road
Normalised Total Number Concentration (%)
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
Height Above Ground [m]


Office Building 15 m from Major Road
Normalised Total Number Concentration (%)
140
120
100
80
60
40
20
0
0
10
20
30
40
Building Height (m)


Office building 80 m from major road
Normalised Total Number Concentration (%)
200
175
150
125
100
75
50
25
0
0
5
10
15
20
25
Building Height (m)
front (facing road)
side
back