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AIRBORNE PARTICULATE MATTER AT A BUS STATION: CONCENTRATION LEVELS AND GOVERNING PARAMETERS

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ABSTRACT
Traffic emissions are an important contributor to ambient air pollution, especially in large cities featuring extensive and high density traffic networks. Bus fleets represent a significant part of inner city traffic causing an increase in exposure to general public, passengers and drivers along bus routes and at bus stations. Limited information is available on quantification of the levels, and governing parameters affecting the air pollution exposure at bus stations. The presented study investigated the bus emissions-dominated ambient air in a large, inner city bus station, with a specific focus on submicrometer particles. The study's objectives were (i) quantification of the concentration levels; (ii) characterisation of the spatio-temporal variation; (iii) identification of the parameters governing the emissions levels at the bus station and (iv) assessment of the relationship between particle concentrations measured at the street level (background) and within the bus station. The results show that up to 90% of the emissions at the station are ultrafine particles (smaller than 100 nm), with the concentration levels up to 10 times the value of urban ambient air background (annual) and up to 4 times the local ambient air background. The governing parameters affecting particle concentration at the station were bus flow rate and meteorological conditions (wind velocity). Particle concentration followed a diurnal trend, with an increase in the morning and evening, associated with traffic rush hours. Passengers' exposure could be significant compared to the average outdoor and indoor exposure levels.

INDEX TERMS
Particles, traffic, emission, bus station, exposure.

INTRODUCTION
Particulate air pollution is associated with adverse effects on human health and the environment. A mounting body of evidence is pointing towards smaller particles in submicrometer and ultrafine size ranges as the main agents causing the health risk. Traffic emissions represent a significant source of air pollution, especially in high density urban agglomerates, where bus fleets are often the most commonly used means of public transport (Adams et al 2002; Corfa et al. 2004). While buses may effectively reduce the number of cars on the roads and in inner cities' areas, the environmental benefits could be offset by their higher emission rates and increased exposure, along the traffic routes and bus stations, to the general public. Limited information is available on the assessment of the impact and contribution of the bus fleets emissions on ambient air quality and exposure. This study focuses on the ambient air characteristics at a busy, inner city bus station. The aim was to

characterise the concentration levels, spatio-temporal variation and the relationship between measured parameters. An intensive, seven day monitoring campaign of particle; traffic; and meteorological characteristics was conducted at the Woolloongabba Bus station in June 2002 in Brisbane. The presented work is part of a larger project, focused on the bus fleets emissions in an urban environment framework.

RESEARCH METHODS

Bus Station

The monitoring campaign was conducted at the Woolloongabba bus station, which is part of the South-East Busway. The station was selected due to its construction design, representative for the other stations; and the site's topography (semi-open, below the street level with canyon like geometry). Approximately 80 m long, 25 m wide and 10 m high, with glass walls and continuously roofed platforms (outbound and inbound), the station's design indicated limited natural ventilation due to the wind thus potentially leading to increased exposure to waiting passengers.

Bus fleet characteristics

The traffic parameters (flowrate, and bus fleet characterisation) were provided by the Busway Management and validated by visual observation. Approximately 1100 busses travelled through the bus station between 7:00 and 18:00 every day, with the maximum frequency during the morning (8:00-9:00) and afternoon (16:00-17:00) traffic rush hours. Approximately 80% of the bus fleet were diesel and 20% CNG powered buses. The buses at the bus station travelled in a stop-start mode.

Sampling locations

Air sampling was conducted at: (i) three fixed locations within the bus station (lead, centre and end of the outbound platform); and (ii) one location outside of the bus station at the street level, representing the background concentration. The outbound platform was selected due to the higher numbers of waiting passengers and frequency of travelling buses. Sampling throughout the platform allowed assessment of pollutants' distribution within the station. The background air sampling was conduced at the street level, approximately 150 m away from the bus station, at a location not directly affected by local traffic. Approximately 30 minute sampling was conducted at each sampling location on the platform in several rounds; and in the morning, afternoon and evening at the street level sampling site. In general, the sampling took place between 7:00 and 18:00 for seven weekdays (Fri 7th June; 11th-14th; 17th-18th 2002).

Instrumentation and measured parameters.

Particle concentration $N_{0.8}$ and size distribution (PSD) in the size range 13-880 nm was measured by a Scanning Mobility Particle Sizer (TSI Model 3071A, CPC 3010) with time resolution 5 minutes. Meteorological conditions, including air temperature, relative humidity, wind velocity and direction were measured by Q-Trak TSI, and a portable meteo-station (Monitor sensors AN2). The equipment was loaded onto a small trolley allowing for quick movement from one sampling location to another. The instruments were calibrated in laboratory prior to the field measurements.

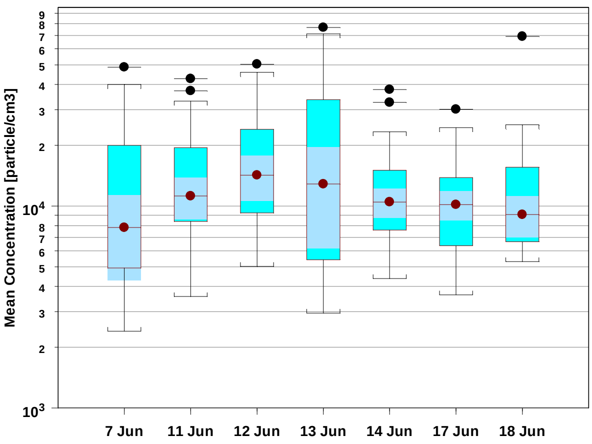
RESULTS AND DISCUSSION

The meteorological conditions during the measuring days were in general stable, with average air temperature; relative humidity and wind velocity measured at the bus platform in the range of 22-25 °C; 50-70% and 1-3 m s^{-1}, respectively. The wind velocity at the platform was in general lower in the morning and at the evening, with a slight increase during the 11:00 - 14:00 time interval.

The bus flow rate at the station showed a diurnal variation, with the highest flow rates at approximately 110 buses per hour (total bus count in both directions) during the morning (7:00-9:00) as well as afternoon (16:00-17:00 pm) traffic rush hours. The lowest flow rate of about 70 buses per hour was observed during the 11:00 - 13:00 time interval.

The basics daily statistics of $N_{0.8}$ data measured at the outbound platform's centre are presented in Figure 1. The concentration varied between individual days, reflecting variation in the meteorological and traffic conditions. The median values range between 8.0×10^4 and 1.5×10^4 particle cm^{-3}. In general, the median values are comparable to the average annual background for Brisbane (Morawska et al. 2002) which is about 1.0×10^4 particle cm^{-3}, however some of individual readings (5 min data measured at the bus platform) exceeded the annual background average by a factor of 10.

Figure 1 Statistics of daily particle number concentration measured at the centre of the outbound platform.



The hourly averages of $N_{0.8}$ levels calculated for the 7 days' data measured at the platform's centre are presented in Figure 2. In general, the initially high levels in the morning decreased during the mid-day hours (12:00 - 14:00), followed by an increase at the afternoon and evening. The same general trend was observed for each individual day. Figure 3 demonstrates the trend, as well as the comparison with background (street) levels for one of the measuring days.

It can be seen that in the morning both, the background and the platform $N_{0.8}$ levels, were comparable and relatively high. This could be associated with increased emissions of the local traffic during the traffic peak hours and also due to increased frequency (flow rate) of the buses travelling through the station. The decrease in the $N_{0.8}$ levels throughout the mid-day (10:00 -14:00) could be linked to the combined effects of: (i) increased wind speed and associated natural ventilation, resulting in higher dilution of the emissions; and (ii) decreased flow rate and frequency of the buses travelling through the bus station. In general, there was a significant inverse (wind velocity) and a direct (bus flow rate) correlation between the measured $N_{0.8}$ levels and wind velocity; and $N_{0.8}$ and bus flow rate, respectively.

Assessment of the homogeneity of $N_{0.8}$ levels measured at different locations throughout the platform (lead, centre and end) showed that the spatial distribution of concentration was not uniform. In general, the levels measured at the platform's centre were up to 1.5 times higher than the levels measured at the platform's lead and the end sides. To obtain a conservative estimate (i.e. worst case scenario) of the exposures at the bus station, readings measured at the platform's centre were used for data analysis.

Figure 2 Hourly particle number concentration $N_{0.8}$ measured at outbound platform (centre).

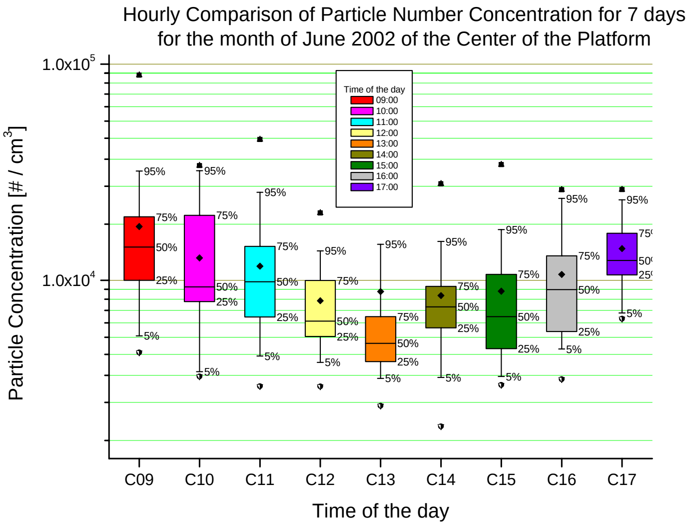
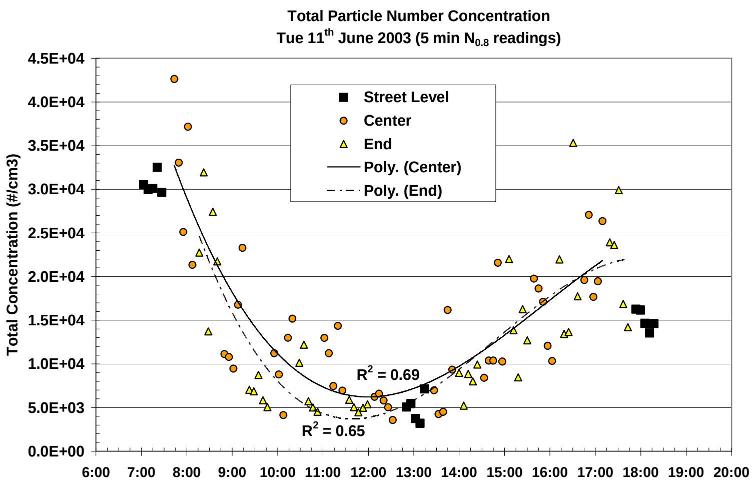


Figure 3 Comparison of the background (street level) versus Platform $N_{0.8}$ levels measured on 11th June 2002.



The daily, time averaged $N_{0.8}$ background data for morning (7:00-9:00); afternoon (12:00-14:00) and evening (17:00-19:00 time intervals are presented in Figure 4. The results reflect the effect of the local traffic emissions (mainly gasoline cars on the roads near the bus station) with the highest $N_{0.8}$ levels observed in the morning, during the traffic peak hours. The median values for 7-day data set, were 3.7×10^4, (morning); 4.5×10^3 (afternoon) and 8.2×10^3 (evening) particle cm^{-3}.

Analysis of the particle size distribution (PSD) measured at the street level (background) and at the bus platform showed that the majority (about 90%) of the emissions were in the ultrafine size ranges (smaller than 100 nm). While the PSD measured at the street level (background) has a dominant peak at about 20-30 nm, which is associated with the gasoline engines' emissions (Ristovski et al. 1998) of local traffic, the bus emissions showed a much broader distribution, with a maximum in the range of 40-90 nm. The spectra are characteristics for a mixture of fresh and aged emissions originating from diesel and CNG bus emissions (Jamriska et al. 2004).

Figure 4 Daily, time averaged (morning, afternoon, evening) background particle number concentration measured at the street level.

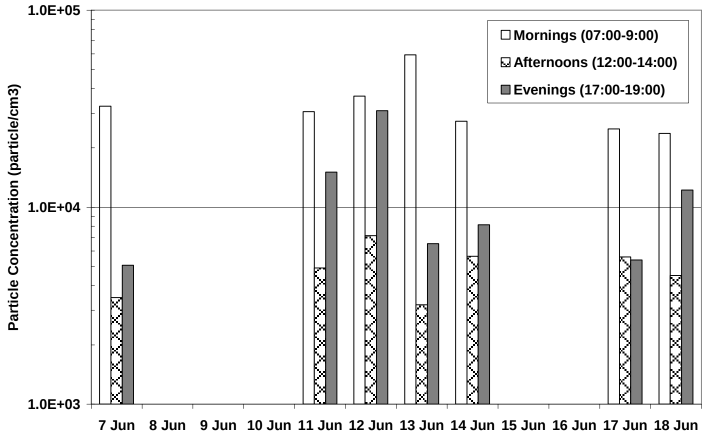
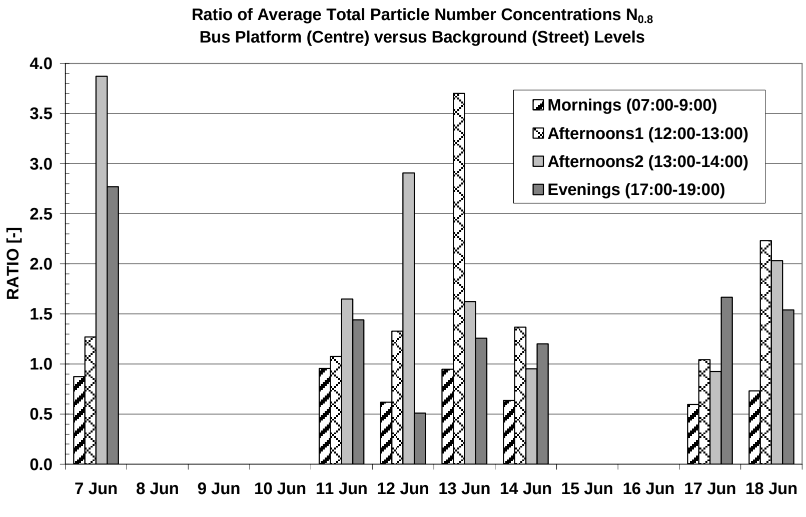


Figure 5 Ratio of average $N_{0.8}$ concentrations measured at the bus station's platform (centre) versus background measured at the street level.



To assess the exposure to passengers and the environment, the measured $N_{0.8}$ levels at the platform were compared to the background levels as presented in Figure 5. The results show that the relative effect of bus emissions at the bus station, quantified by a ratio of $N_{0.8}$ levels measured at the (i) bus station; versus (ii) street (background), varied between 0.5 to 4, depending on the time of the day. The effect was negligible (ratio close to one) for the morning time period (7:00-9:00 am), while it was significant for the afternoon and evening time intervals. In terms of the exposure assessment, the results need to be interpreted with a consideration given to absolute values of the emission levels, measured at the station; street level (local background); and urban ambient air background. The presented results indicate that bus emissions contributed significantly to submicrometer particle number concentrations at the bus station resulting in an elevated exposure to the waiting passengers. The bus emissions dispersed from the bus station area also increase the local ambient air background, potentially leading to a significant increase of exposure to general public outdoors and indoors. Increased attention should be given to the bus stations' design in order to minimise the emissions (eg. reducing the time of bus queuing), maximise the ventilation rate throughout the bus stations, and achieve optimal dispersion of the emissions with a minimum impact on the immediate outdoor and indoor environments.

CONCLUSION AND IMPLICATIONS

In summary, the presented results indicate that bus emissions are a significant contributor to the overall ambient air pollution burden. The pollution levels at bus stations may reach up to 10 times the ambient air (annual) background and up to 4 times the local background levels. Since the bus fleets constitute mainly of diesel powered buses, with the emissions containing carcinogenic and other toxic components, the findings may have serious ramification for the exposed public.

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