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# Investigation of Air Quality at Lithgow Correctional Centre

Report for

Corrective Services New South Wales

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## ABBREVIATIONS

<b>C</b>	Concentration
<b>CO</b>	Carbon monoxide
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>CPC</b>	Condensation Particle Counter
<b>DustTrak</b>	Model 8520, 8530, 8534 DustTrak Aerosol Monitor
<b>I/O</b>	Indoor to Outdoor ratio of concentration (particle number or mass)
<b>IA</b>	Indoor Air
<b>IAQ</b>	Indoor Air Quality
<b>ILAQH</b>	International Laboratory for Air Quality and Health
<b>LCC</b>	Lithgow Correctional Centre
<b>Max</b>	Maximum
<b>Min</b>	Minimum
<b>NT</b>	Philips Aerasense <i>NanoTracer</i> (NTs)
<b>NEPM</b>	National Environment Protection Council
<b>PN</b>	Particle number concentration
<b>OA</b>	Outdoor Air
<b>PM</b>	Particulate Matter
<b>PM<sub>2.5</sub></b>	Mass concentration of particles with an aerodynamic diameter smaller than 2.5 µm
<b>QUT</b>	Queensland University of Technology
<b>RH</b>	Relative Humidity [%]
<b>SA</b>	Supply Air
<b>SMPS</b>	Scanning Mobility Particle Sizer
<b>SD</b>	Standard Deviation
<b>T</b>	Temperature [°C]
<b>TVOC</b>	Total Volatile Organic Compounds
<b>VOC</b>	Volatile organic compounds

## 1. EXECUTIVE SUMMARY

This project was conducted at Lithgow Correctional Centre (LCC), NSW, Australia. Air quality field measurements were conducted on two occasions (23-27 May 2012, and 3-8 December 2012), just before and six months after the introduction of smoke free buildings policies (28 May 2012) at the LCC, respectively. The main aims of this project were to: (1) investigate the indoor air quality; (2) quantify the level of exposure to environmental tobacco smoke (ETS); (3) identify the main indoor particle sources; (4) distinguish between PM<sub>2.5</sub> / particle number from ETS, as opposed to other sources; and (5) provide recommendations for improving indoor air quality and/or minimising exposure at the LCC.

The measurements were conducted in Unit 5.2A, Unit 5.2B, Unit 1.1 and Unit 3.1, together with personal exposure measurements, based on the following parameters:

1. Indoor and outdoor particle number (PN) concentration in the size range 0.005-3 µm
2. Indoor and outdoor PM<sub>2.5</sub> particle mass concentration
3. Indoor and outdoor VOC concentrations
4. Personal particle number exposure levels (in the size range 0.01-0.3 µm)
5. Indoor and outdoor CO and CO<sub>2</sub> concentrations, temperature and relative humidity

In order to enhance the outcomes of this project, the indoor and outdoor particle number (PN) concentrations were measured by two additional instruments (CPC 3787) which were not listed in the original proposal.

### **Summary of the Main Findings and Conclusions from the Study**

The following average PM<sub>2.5</sub> and PN concentration levels covered all particle sources.

#### **1. Outdoor particle concentration**

- Outdoor overall 24 hr average PM<sub>2.5</sub> concentration:
  - was lower (about 30%) during the first round than the second round;
  - was lower than the advisory NEPM ambient air quality 24 hr standard (25 µg m<sup>-3</sup>) for both rounds;
  - however, it can potentially exceed the advisory NEPM ambient air quality annual standard (8 µg m<sup>-3</sup>).
- Outdoor overall 24 hour average PN concentration:
  - was lower (about 30%) during the first round than the second round; and
  - was lower than the average worldwide urban ambient air concentration, as reported in the literature (7.3 × 10<sup>3</sup> particle cm<sup>-3</sup>) and was comparable with rural ambient air concentrations (4.8 × 10<sup>3</sup> particle cm<sup>-3</sup>) (Morawska et al., 2008) for both rounds.

#### **2. Indoor particle concentration**

- Indoor overall 24 hour average PM<sub>2.5</sub> concentration:
  - for Unit 1.1, the first round was higher (more than 100%) than the second round;
  - for Unit 5.2A, the first round were lower (about 50%: 30% due to outdoor, 20% due to indoor) than the second round;
  - for Unit 5.2B, the first round were lower (about 10 times) than the second round;
  - indoor 71 µg m<sup>-3</sup> in Unit 5.2B exceeded the advisory NEPM ambient air quality 24 hr standards (25 µg m<sup>-3</sup>) in the second round; and
  - for Unit 3.1, the indoor annual average PM<sub>2.5</sub> concentrations can potentially exceed the advisory NEPM ambient air quality annual standards (8 µg m<sup>-3</sup>).
- Indoor overall 24 hour average PN concentration:
  - for both Unit 5.2A and Unit 5.2B was lower (about 3 times and 5 times) during the first round than the second round, respectively;

- was comparable with the overall average 24 hour concentration levels ( $3.7 \sim 4.8 \times 10^{-3} \text{ p cm}^{-3}$ ) in a mechanically ventilated building (He et al., 2011) during the first round ( $4.9 \sim 5.1 \times 10^{-3} \text{ p cm}^{-3}$ ); and
- was significantly higher than the concentration levels in a mechanically ventilated building during the second round ( $18.2 \sim 24.0 \times 10^{-3} \text{ p cm}^{-3}$ ).

#### 4. Personal exposure levels

The average personal exposure concentration level:

- was significantly lower during the second round than the first round for rovers;
- for **officers in Unit 5.2**, was significantly higher during the second round than the first round; and
- was slightly higher in **Health centre** during the second round than the first round, which could be partially due to differences in the outdoor particle concentration levels between the two rounds.

#### 5. Possible indoor particle sources

- Smoking (during the first round), cooking, washing and cleaning activities.
- There were strong indoor particle sources in Unit 5.2B, in terms of both particle number and particle mass, during the second round.

#### 6. Indoor and Outdoor VOC concentration levels

The VOC measurement results showed that both indoor and outdoor nicotine concentration levels were below the detection limit ( $0.92 \mu\text{g m}^{-3}$ ) of the methods used in this project.

#### 7. General Conclusions

Outdoor average  $\text{PM}_{2.5}$  and PN concentrations during the first round were lower than those measured during the second round. Outdoor average  $\text{PM}_{2.5}$  was lower than the advisory NEPM ambient air quality 24 hr standard ( $25 \mu\text{g m}^{-3}$ ) for both rounds, however it can potentially exceed the advisory NEPM ambient air quality annual standard ( $8 \mu\text{g m}^{-3}$ ). Outdoor average PN concentrations were lower than the average urban ambient air concentration and comparable with rural ambient air concentrations.

Air exchange rates in each Unit were different between the two rounds, due to the different seasons. For example, in the summer, the ventilation systems were turned off.

After taking into consideration increased outdoor concentrations, the indoor concentrations in Unit 1.1 were still lower than outdoor levels during the second round. This implies that, in terms of  $\text{PM}_{2.5}$ , the air quality in Unit 1.1 might have improved after the introduction of the smoke free buildings policies and the rovers' particle number exposure levels were also reduced.

There were strong indoor particle sources in Unit 5.2B during the second round. However, the absence of other visible or identifiable sources indicates that the particles originated from the activities of the Unit 5.2B inmates – most likely smoking. This indicates the need for more work to be done to ensure enforcement of the smoke free buildings policies.

#### 8. Recommendations:

- When the ventilation system is turned off in Unit 5.2, open the side door whenever possible during working hours.
- Turn on the ceiling fan when staff feel that indoor concentrations are high or there is a distinct smell.
- In the Unit offices, turn on the air conditioning when officers have concerns about indoor air quality.
- The current smoking area outside the 'Industries Textiles' building is too close to the building itself and it would be better to relocate it further away from the building.

- It would be better if vacuum cleaning activities in the 'Industries Textiles' building could be conducted after the inmates' had finished their work.
- Air exchange rate in the 'Officers' Station, Industries ' needs to increase by turning on the air conditioning more regularly or increasing supply air.
- In general, when NEPM ambient air quality standards are exceeded, for outdoors, this is outside the control of the LCC. However, for indoors, when it comes from indoor sources, increase the air exchange rate by turning on the ventilation system and ceiling fans or opening the side doors, when possible (such as in Unit 5.2). For other units, keep the windows in the kitchen rooms open.

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## **2. PROJECT BACKGROUND AND AIM**

### **1. Background**

Cigarette smoking is permitted for inmates in correctional centres because an inmate's cell is considered their home (rather than a public place), and it is also viewed as a passive management strategy. However, this practice is in conflict with providing a safe working environment for correctional centre staff, from air quality point view. Therefore, Corrective Services NSW (CSNSW) has requested an investigation into indoor air quality at the Lithgow Correctional Centre (LCC), for the purposes of conducting a human health risk assessment.

In order to gain an understanding of existing indoor air quality in the facility, and to assess the exposure of correctional centre staff to environmental tobacco smoke (ETS), measurements of indoor air quality, including particulate matter, at the LCC were required. The results of this investigation are expected to be used by the LCC for air quality control and management.

The main aims of the research project were to: (1) investigate the indoor air quality; (2) quantify the level of exposure to environmental tobacco smoke (ETS); (3) identify the main indoor particle sources; (4) distinguish between  $PM_{2.5}$  and particle number from ETS, as opposed to other sources; and (5) provide recommendations for improving indoor air quality and/or minimising particle exposure at the LCC.

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### **3. OBJECTIVES OF THE PROJECT**

In order to monitor and quantify pollution levels, the specific objectives of the project were as follows:

- 1) Measure particulate pollutants and VOCs in Outdoor Air (OA) at the Unit 5.2 yard
- 2) Measure particulate pollutants and VOCs in Indoor Air (IA) in Unit 5.2, and Unit 1.1 and Unit 3.1 (during the second round only)
- 3) Measure personal particle exposure levels for some staff
- 4) Compare the results with AQ guidelines, as well as other OA concentrations measured around the world
- 5) Report the outcomes to the Corrective Services New South Wales

These objectives are not identical to those outlined in the original proposal, due to the different circumstances that were encountered in the field. For example, following low participation rates by staff during the first round, Ms Ashleigh Cussen made a great effort to encourage staff to take part the personal particle exposure measurements during the second round. Therefore, the number of participants was significantly higher during the second round.

#### **APPROACH**

1. About one week of air quality field measurements were conducted on two occasions (23-27 May 2012, 3-8 December 2012), just before and six months after the introduction of smoke free buildings policies (28 May 2012) at the LCC, respectively.
2. The data were comprehensively analysed using statistical methods and conclusions were drawn in relation to the effect of the smoke free buildings policies on indoor air quality at the LCC.

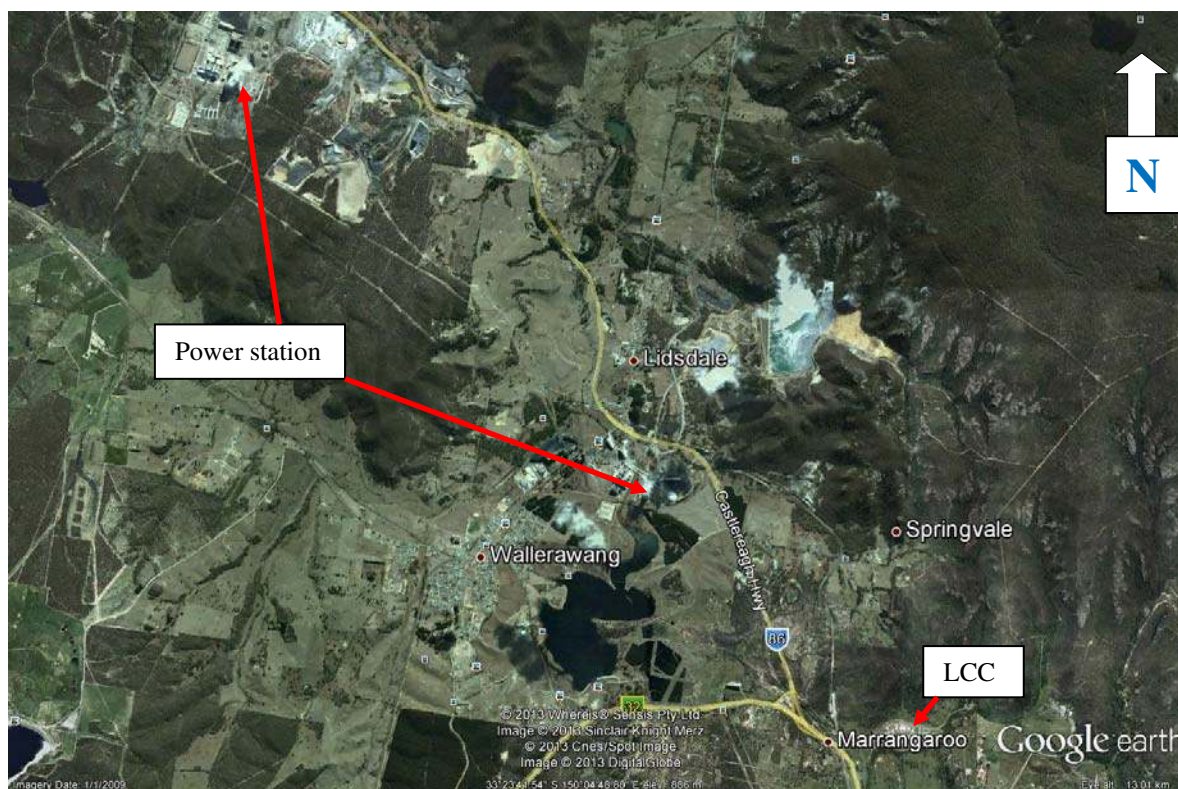
#### **STEPS TAKEN**

1. Site visit to conduct a preliminary assessment of the LCC buildings and finalise the design of the experimental part of the project.
2. Measurement of outdoor and indoor concentration levels of:
  - Particle number ( $< 3 \mu\text{m}$ );
  - $\text{PM}_{2.5}$  (mass concentration of particles with an aerodynamic diameter  $< 2.5 \mu\text{m}$ );
  - CO and  $\text{CO}_2$ ; and
  - VOCs (including nicotine).
3. Measurement of personal particle number exposure levels.
4. Measurement of ventilation rate.
4. Data analysis and interpretation.
5. Preparation of a report detailing the findings, recommendations and conclusions.

## 4. EXPERIMENTAL PROCEDURES

### 4.1. LCC location

The LCC is located at about 150 km to the North West of Sydney. It is situated approximately 700m to the east of a motorway and there are two power stations to the North-West of the LCC. The distance between the LCC and the two power stations were about 4.2km and 11km, respectively (See Figure 1). The nearby motorway and power stations are potential sources of pollution at the LCC, especially when the wind direction is from the NW.



**Figure 1.** Location of the LCC and nearby outdoor pollutant sources (motorway, power stations).

### 4.2. Instrumentation and parameters measured

- 1) Measurements of indoor and outdoor time series of total particle number concentration in the size range 0.005 - 3 $\mu$ m were conducted using two TSI Model 3787 Condensation Particle Counters (CPC, TSI Incorporated, St. Paul, MN, USA). Two units were used in order to conduct simultaneous monitoring at different locations. These two CPCs were not listed in the original project proposal but were used in order to enhance the outcomes of the project.
- 2) Time series of indoor and outdoor particle mass concentration (PM<sub>2.5</sub>) were simultaneously measured by three TSI Model 8520 or 8530 or 8534 DustTrak aerosol monitors (TSI Incorporated, St. Paul, MN, USA). Since the DustTrak operates on the principle of light scattering, its response is highly dependent on the size distribution and refractive index of the sampled aerosol. This instrument was factory-calibrated with Arizona dust particles and it was reported that for finer aerosols, such as those commonly encountered in indoor air, the instrument's response can be significantly higher than the true PM<sub>2.5</sub> value (Ramachandran et al., 2000). In order to obtain values closer to the true PM<sub>2.5</sub> concentration, all of the PM<sub>2.5</sub> data collected by the DustTrak

during this project were corrected by using the following equation, which has been previously reported in the literature by Morawska et al. (2003):

$$PM_{2.5} = 0.394 PM_{2.5}(\text{DustTrak}) + 4.450 \quad (1)$$

(with  $R^2 = 0.83$ )

- 3) Four Philips Aerasense Nanotracers (NTs) measured the time series of total particle number concentrations in the size range 0.01 – 0.3  $\mu\text{m}$  for different staff (personal particle exposure level measurements) or locations (indoor particle concentration levels).
- 4) Time series of indoor and outdoor CO, CO<sub>2</sub>, temperature and relative humidity were measured by three TSI Q-Traks (TSI 8554).
- 5) In order to determine air exchange rates, the velocity of supply air inside the rooms, as well as air at the ventilation system intakes, were measured by an Anemometer (TSI 9545), when possible.
- 6) Indoor and outdoor VOC samples were collected for the qualitative analysis of Volatile and Semivolatile Organic Compounds (VOC and SVOC), as well as nicotine. Active sampling was conducted on stainless steel desorption tubes that were filled with Tenax TA (Chrompack), using a Chematec FLEC pump which operated at 150 ml min<sup>-1</sup>, for 60 min. The tubes were cleaned by purging them with helium at 300°C for 1 h. The samples were subsequently analysed in the laboratory by a process which includes tube thermal desorption (300°C, 10 min; Perkin Elmer ATD 400) into a GC/MS system (Shimadzu QP2010). The compounds were separated on a HP-5 MS column (60 m x 0.25 mm, 0.25  $\mu\text{m}$ ). Initial qualitative analyses were based on a PBM library search, with mass spectra and retention data obtained from authentic compounds used to confirm the results. The detection limit of this method for nicotine was 0.92  $\mu\text{g m}^{-3}$ .

All instruments were tested and calibrated in the laboratory before the field measurements were conducted, and comparative tests for all particle measurement instruments were conducted simultaneously during the last day of field measurements, as well as in laboratory. If the raw data needed to be corrected, the correction calculations were conducted before the data were included in the database. In this report, the results are presented based on the corrected NT, DustTrak and Q-Trak data. Details of the settings for each instrument are given in **Appendix A**.

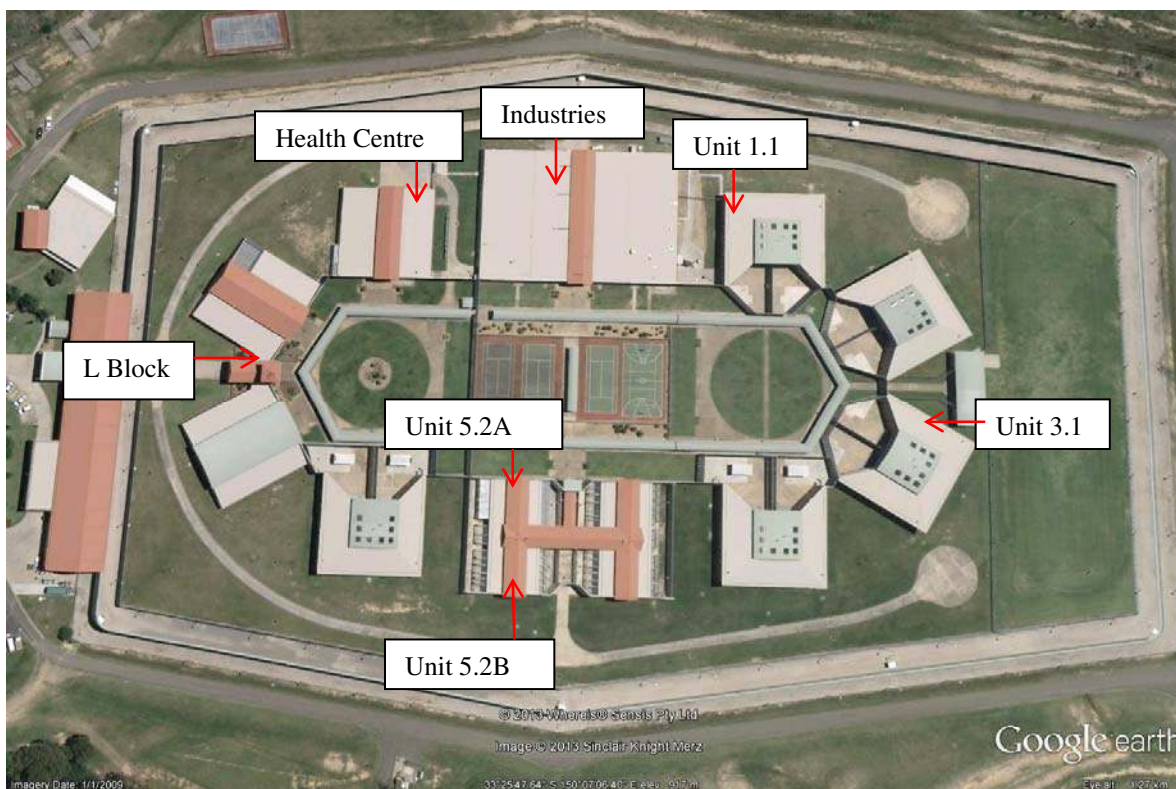
### 4.3. Sampling locations and sampled air

Particle characteristics of indoor and outdoor air were measured at various locations (see Figure 2), including:

- (i) outdoors - Unit 5.2 yard;
- (ii) indoors - Unit 5.2A and Unit 5.2B; Unit 1.1 and Unit 3.1 (during the second round only)

During the first round, the outdoor sampled air was delivered to the instruments via a 1 m long piece of conductive tubing, with an inner diameter of 6 mm. During the second round, the outdoor sampled air was delivered directly to the instruments.





**Figure 2.** Location of the sampling sites.

NTs were used for three types of measurements:

- (i) Personal particle exposure level, which was conducted for some staff members (prison officer, nurse) who each wore the NT for about 7 ~ 8 hours during their working hours;
- (ii) Monitoring the particle concentration levels in the Health centre, L block and Unit 5.2 officers' station for more than 24 hours; and
- (iii) Investigations of short term particle concentration levels in the Industries.

#### 4.4. Time of the measurements

The field measurements were conducted on two occasions, from 23 May to 27 May 2012 and from 3 December to 8 December 2012, which were just before and six months after the introduction of smoke free buildings policies (28 May 2012) at the LCC, respectively.

#### 4.5. Methodology for investigation of indoor particle sources

Four methods were employed for the investigation of indoor particle source, including:

4. Analysis of long term (hours) average I/O ratios. If average indoor concentration levels were higher than outdoor levels, it meant that there were indoor sources.
5. Comparison of indoor and outdoor particle concentration time series data. If indoor concentration peaks occurred during a time period where there were no outdoor concentration peaks, it implied that there were indoor particle sources during that time period.
6. Combining indoor activities records with indoor and outdoor particle concentration time series data, so that indoor particle sources could be identified.
7. Field observations and testing.

#### 4.6. Data processing and analysis

The results from the particle measurements were grouped according to their outdoor and indoor location, along with the time period of the measurements, and the average concentrations were calculated as follows:

8. Based on real-time CPC, DustTrak and Q-Trak concentration data, total 24h average indoor and outdoor concentrations were calculated for each indoor location.

9. Based on real-time NT concentration data, average personal exposure levels were calculated for each staff member who wore the NT, as well as the total 24h average indoor concentrations, if the NT was located indoor for 24 hours.

All statistical analyses (correlation, regression, t-test and One-Way ANOVA) were conducted using Excel or a statistical analysis software package – SPSS for Windows version 10 (SPSS Inc.). A level of significance of  $p = 0.05$  was used for all statistical procedures.

In addition, since there are currently no IAQ standards for particulate pollution levels in Australia, the 'reference' levels for IAQ were based on:

- (i) a comparison of the measured data with the results of other indoor and outdoor air quality assessments based on **data presented in the literature**;
- (ii) the ambient air quality standards (NEPM Advisory Standards); and
- (iii) the WHO air quality guidelines for Europe (second edition, 2000).

## 5. RESULTS AND DISCUSSION

### 5.1. Meteorological Conditions

The average and range of temperature and relative humidity for both measurement rounds are given in **Table 1**. All relevant information about the meteorological parameters is presented in **Appendix B**, from which it can be seen that the dominant wind direction for both rounds was NW, which was from the direction of the motorway and power stations. Meteorological conditions remained fairly constant throughout the two measurement periods, with the exception of rain on 25 May 2012.

**Table 1.** The average and range of temperature and relative humidity parameters in the first round and second round, based on Bureau of Meteorology data.

	Temp. (°C)		RH(%)	
	Average	Range	Average	Range
23-27/05/2012	8.3	6.3 - 12.1	66	45 - 83
03-08/12/2012	17.7	12.6 - 24.3	44	34 - 63

### 5.2. Outdoor Air

#### 5.2.1. Average outdoor particle concentration

The daily variation of 24 hour average outdoor particle number (PN) and PM<sub>2.5</sub> concentrations for Unit 5.2 yard are presented in **Figure 3**. Comparison of overall 24 hour average outdoor particle number (PN) and PM<sub>2.5</sub> concentrations are presented in **Table 3**. From **Figure 3** and **Table 2**, it can be seen that daily 24 hr average PN concentrations varied between the days for both rounds, with an overall 24 hour average of  $(4.55 \pm 1.47) \times 10^{-3}$  and  $(6.67 \pm 1.4) \times 10^{-3}$  particles cm<sup>-3</sup> for the first round and the second round, respectively. It can be seen from **Table 2** that the daily 24 hr average PM<sub>2.5</sub> concentrations also varied between the days for both rounds, with an overall 24 hour average of  $8 \pm 4 \mu\text{g m}^{-3}$  and  $12 \pm 1 \mu\text{g m}^{-3}$  for the first round and the second round, respectively. However, the daily 24 hour average PM<sub>2.5</sub> concentrations showed less variation during the second round.

In addition to our measurements, average 24 hour concentration data for PM<sub>2.5</sub> were collected by the NSW EPA station at Richmond for both rounds, with a ratio of about 0.69 between the two rounds. This was very close to the ratio that was calculated based on the project results (0.68, see **Table 2**), which shows that, in general, average outdoor particle concentration levels in the first round were lower than those measured during the second round.

**Table 2.** Comparison of overall 24 hour average outdoor particle concentrations (PM<sub>2.5</sub> and particle number) in the first and second round, as well as ratios between the first and second round.

	PM <sub>2.5</sub> ( $\mu\text{g m}^{-3}$ )		F/S Ratio	PN ( $\times 10^3 \text{ p cm}^{-3}$ )		F/S Ratio
	First	Second		First	Second	
Average	<b>8</b>	<b>12</b>	<b>0.68</b>	<b>4.55</b>	<b>6.67</b>	<b>0.68</b>
S.D	4	1		1.47	1.40	
Min	5	10		3.12	5.38	
Max	13	13		6.56	8.95	
Median	<b>8</b>	<b>12</b>	<b>0.57</b>	<b>4.27</b>	<b>6.08</b>	<b>0.70</b>

F/S: First round / Second round

Based on these data, the following can be concluded:

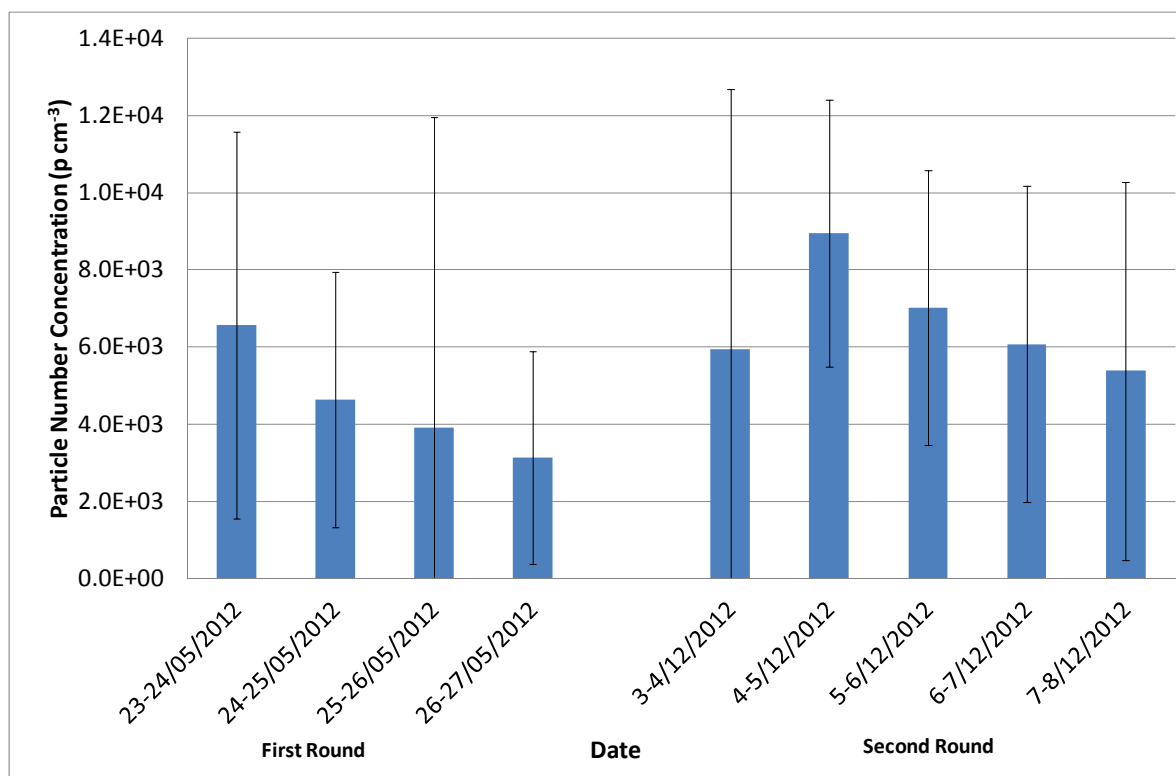
- Outdoor overall 24 hr average PM<sub>2.5</sub> concentration:
  - was lower (about 30%) during the first round than the second round;
  - was lower than the advisory NEPM ambient air quality 24 hr standard (25 µg m<sup>-3</sup>) for both rounds; and
  - however, it can potentially exceed the advisory NEPM ambient air quality annual standard (8 µg m<sup>-3</sup>).
  
- Outdoor overall 24 hour average PN concentration:
  - was lower (about 30%) during first round than the second round;
  - was lower than the average worldwide urban ambient air concentration, as reported in the literature (7.3 ×10<sup>3</sup> particle cm<sup>-3</sup>) for both rounds and was comparable with rural ambient air concentrations (4.8 ×10<sup>3</sup> particle cm<sup>-3</sup>) (Morawska et al., 2008).

These average PM<sub>2.5</sub> and PN concentration levels covered all particle sources.

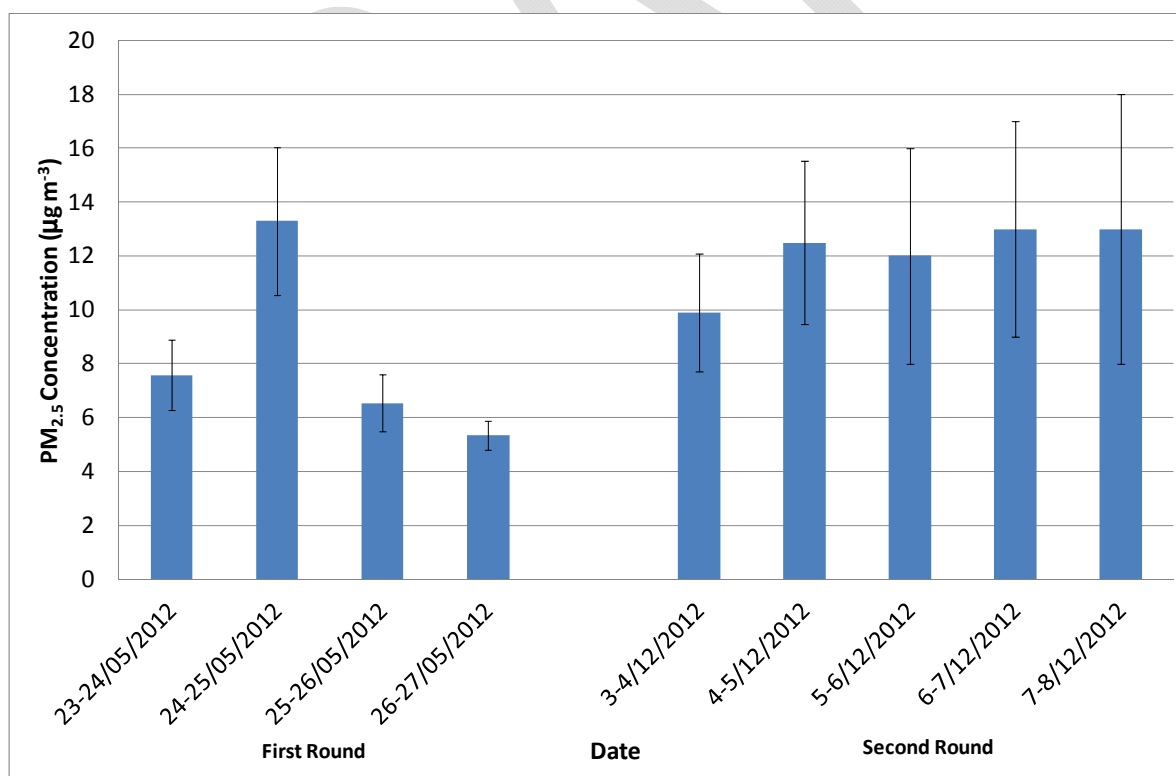
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(a)



(b)



**Figure 3.** Daily variation of 24 hour average (a) outdoor particle number and (b) PM<sub>2.5</sub> concentration in the Unit 5.2 yard.

### **5.2.2. Diurnal variation of outdoor particle number and $PM_{2.5}$ concentration**

Overall average diurnal variation of outdoor particle number and  $PM_{2.5}$  concentration in the first round and second round are shown in **Figure 4 and 5**, respectively. From **Figure 4 and 5**, it can be seen that:

- The time series of outdoor particle number concentration showed different diurnal variation patterns between the two rounds. The two peaks (7:00-8:00 and 18:00-19:00) observed during the first round disappeared during the second round, which implies that there were different outdoor particle number sources between the two rounds.
- Time series of outdoor  $PM_{2.5}$  concentration also showed different diurnal variation patterns between the two rounds. The two peaks (at about 6:00 and 17:00) in the second round were not observed during the first round and there were irregular diurnal variation patterns during both rounds. It supports the hypothesis that there were different outdoor particle mass sources between the two rounds.

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**Figure 4.** Average diurnal variation of outdoor particle number concentration during the first (top) and second (bottom) round.

**Figure 5.** Average diurnal variation of outdoor PM<sub>2.5</sub> concentration during the first (top) and second (bottom) round.

### 5.3. Indoor Air

#### 5.3.1. Average indoor PM<sub>2.5</sub> concentration

Indoor PM<sub>2.5</sub> concentrations were measured for more than 24 hours in four locations. A summary of overall average 24 hour indoor PM<sub>2.5</sub> concentrations measured during the first and second round are given in **Table 3**.

**Table 3.** A summary of overall average 24 hour indoor PM<sub>2.5</sub> concentrations ( $\mu\text{g m}^{-3}$ ) during the first and second round at four locations.

	Unit 1.1		Unit 5.2A		Unit 5.2B		Unit 3.1	
	First	Second	First	Second	First	Second	First	Second
Average	17	7	8	13	6	71	N/A	22
S.D	3	2	0	1	1	43	N/A	14
Min	8	5	8	12	5	40	N/A	13
Max	34	8	8	14	66	101	N/A	38
Median	16	7	8	13	6	71	N/A	14

N/A: no data available

From **Table 3** it can be seen that indoor overall 24 hour average PM<sub>2.5</sub> concentration:

- for Unit1.1, was higher (more than 100%) during the first round than the second round;
- for Unit 5.2A and Unit 5.2B, was lower (about 50% and about 10 times) during the first round than the second round, respectively;
- for Unit 5.2B, exceeded the advisory NEPM ambient air quality 24 hr standards ( $25 \mu\text{g m}^{-3}$ ) during the second round ( $71 \mu\text{g m}^{-3}$ ); and
- for Unit 3.1, indoor annual average PM<sub>2.5</sub> concentrations could potentially exceed the advisory NEPM ambient air quality annual standard ( $8 \mu\text{g m}^{-3}$ ).

The quality of the air we breathe affects our health. High concentrations of the major air pollutants are associated with respiratory problems such as coughs, bronchitis, asthma and, in severe cases, developmental problems in children, and even death. The economic

benefits from reducing air pollution include savings in health expenditure and fewer sick days by employees. Even small improvements in air quality can achieve benefits for human health and wellbeing (NEPM). Therefore, actions to reduce indoor sources are needed.

### 5.3.2. Average indoor PN concentration

Indoor particle number concentrations were measured for more than 48 hours in two locations. A summary of the overall average 24 hour indoor PN concentrations measured during the first and second round are given in **Table 4**.

**Table 4.** A summary of overall average 24 hour indoor PN concentrations ( $\times 10^3$  p cm<sup>-3</sup>) measured during the first and second round.

	Unit 5.2A		Unit 5.2B	
	First	Second	First	Second
<b>Average</b>	<b>5.13</b>	<b>18.2</b>	<b>4.88</b>	<b>24.0</b>
<b>S.D</b>	0.66	3.34	1.56	2.13
<b>Min</b>	4.42	15.9	2.12	22.5
<b>Max</b>	5.72	20.6	13.5	25.5
<b>Median</b>	5.24	18.2	4.62	24.0

From **Table 4** it can be seen that indoor overall 24 hour average PN concentration:

- for both Unit 5.2A and Unit 5.2B, were lower (about 3 times and 5 times) during the first round than the second round, respectively;
- were comparable with the overall average 24 hour concentration levels ( $3.7 \sim 4.8 \times 10^{-3}$  p cm<sup>-3</sup>) in a typical mechanically ventilated building (He et al., 2011) during the first round ( $4.9 \sim 5.1 \times 10^{-3}$  p cm<sup>-3</sup>); and
- were significantly higher than the concentration levels in a typical mechanically ventilated building during the second round ( $18.2 \sim 24.0 \times 10^{-3}$  p cm<sup>-3</sup>).

### 5.3.3. Diurnal variation of indoor PN and PM<sub>2.5</sub> concentration

For indoor PN diurnal variation:

- in general, more regular variation patterns were observed in Unit 5.2A than in Unit 5.2B for both rounds;
- in Unit 5.2A, similar variation patterns were observed for both rounds, with high concentration levels around noon (12:00); and
- in Unit 5.2B, different variation patterns were observed during each round. For example, in addition to the noon peak, a second concentration peak was observed in the evening during the second round.

For indoor PM<sub>2.5</sub> diurnal variation:

- in general, there was no clear or regular variation pattern for both rounds and both indoor locations; and
- in Unit 5.2B, there was a large concentration peak in evening during the second round (which was also the case for PN).

An example of diurnal variation in indoor particle number and PM<sub>2.5</sub> concentrations is shown in **Figure 6**.

**Figure 6.** Time series of indoor particle number and PM<sub>2.5</sub> concentrations in Unit 5.2B on 7 and 8 December 2012.

#### 5.4. Indoor and Outdoor Comparison

A summary of overall average 24 hour indoor and outdoor ratios of PM<sub>2.5</sub> and PN concentrations during the first and second round at four locations is presented in **Table 5**.

**Table 5.** Summary of the overall average 24 hour indoor and outdoor ratios of PM<sub>2.5</sub> and PN concentrations during the first and second round at four locations.

	Unit 1.1		Unit 5.2A		Unit 5.2B		Unit 3.1	
	First	Second	First	Second	First	Second	First	Second
PM <sub>2.5</sub>	1.24	0.61	1.11	1.12	1.06	5.46	N/A	1.72
PN	N/A	N/A	1.02	2.45	1.57	4.18	N/A	N/A

N/A: no data available

Indoor levels were higher than outdoor levels for both particle number and particle mass concentrations at the four locations, both before and after the introduction of the smoke free buildings policies, except for Unit 1.1 during the second round. Based on these ratios, it can be seen that indoor air quality:

1. in Unit 1.1 improved, from a particle mass point view, with a reduction in the impact of indoor generated particles;
2. in Unit 5.2A was unchanged, from a particle mass point view, but it decreased from particle number point of view;
3. in Unit 5.2B deteriorated and was clearly impacted by indoor generated particles, from both a particle mass and particle number point view; and
4. there were indoor particle sources in Unit 5.2A, Unit 5.2B and Unit 3.1, respectively.

An example of the comparison of indoor and outdoor particle number and PM<sub>2.5</sub> concentrations in Unit 5.2B from 6-7 December 2012 is presented in **Figure 7** and **Figure 8**, respectively.

**Figure 7.** Comparison of indoor and outdoor particle number concentrations in Unit 5.2 from 6-7 December 2012.

**Figure 8.** Comparison of indoor and outdoor PM<sub>2.5</sub> concentrations in Unit 5.2 from 6-7 December 2012.

## 5.5. Personal exposure levels (particle number)

In total, there were 3 and 9 rovers (officer who took part in the personal exposure measurements) during the first and second round, respectively. A summary of average personal exposure levels ( $\times 10^3$  p  $\text{cm}^{-3}$ ) during the first and second round, for three types of staff members, is given in **Table 6**. With information relating to the Health Centre, this included the NTs worn by nurses out of the Health Centre during medication rounds of the accommodation units.

**Table 6.** Summary of average personal exposure levels ( $\times 10^3$  p  $\text{cm}^{-3}$ ) during the first and second round, for three types of staff members.

	Rovers		Officer in Unit 5.2		Health Centre	
	First	Second	First	Second	First	Second
Average	11.6	7.35	3.12	11.46	2.31	3.80
S.D	4.77	5.05	2.35	5.61	2.01	0.90
Min	8.10	1.37	0.41	7.49	0.18	3.17
Max	17.1	15.43	22.3	15.4	16.9	4.83
Median	9.72	4.66	2.33	11.5	1.74	3.40

**Table 6** shows that average personal exposure level:

- for **rovers**, was significantly lower during the second round than the first round;
- for **officers in Unit 5.2** offices station, was significantly higher during the second round than the first round; and
- in the **Health centre**, was higher during the second round than the first round, which could be due to increases in the outdoor particle concentration level during the second round.

A summary of average rovers' personal exposure levels ( $\times 10^3$  p  $\text{cm}^{-3}$ ) during the day (7am – 15:00pm) versus overnight (15:00pm – 7:00am) in the first and second round is given in **Table 7**.

**Table 7.** Summary of average rovers' personal exposure levels ( $\times 10^3$  p  $\text{cm}^{-3}$ ) during the first and second round.

	First		Second	
	Day	Overnight	Day	Overnight
Average	13.4	8.10*	10.6	4.16
S.D	5.18		9.10	3.14
Min	9.72		3.78	1.37
Max	17.1		27.9	9.22
Median	13.4		5.56	4.17

\* There is only one average overnight data.

Based on the **Table 7** results, there was a difference in exposure during the day versus overnight. In general, exposure during the day was higher than overnight. However, it should be noted that there was a big variation in exposure levels during both the daytime and overnight.

The time series data of NT indicated that the average exposure level during the medication rounds was higher (more than two times) than in Health centre. An example of the difference between the particle exposure levels is given in the **Figure 9**.

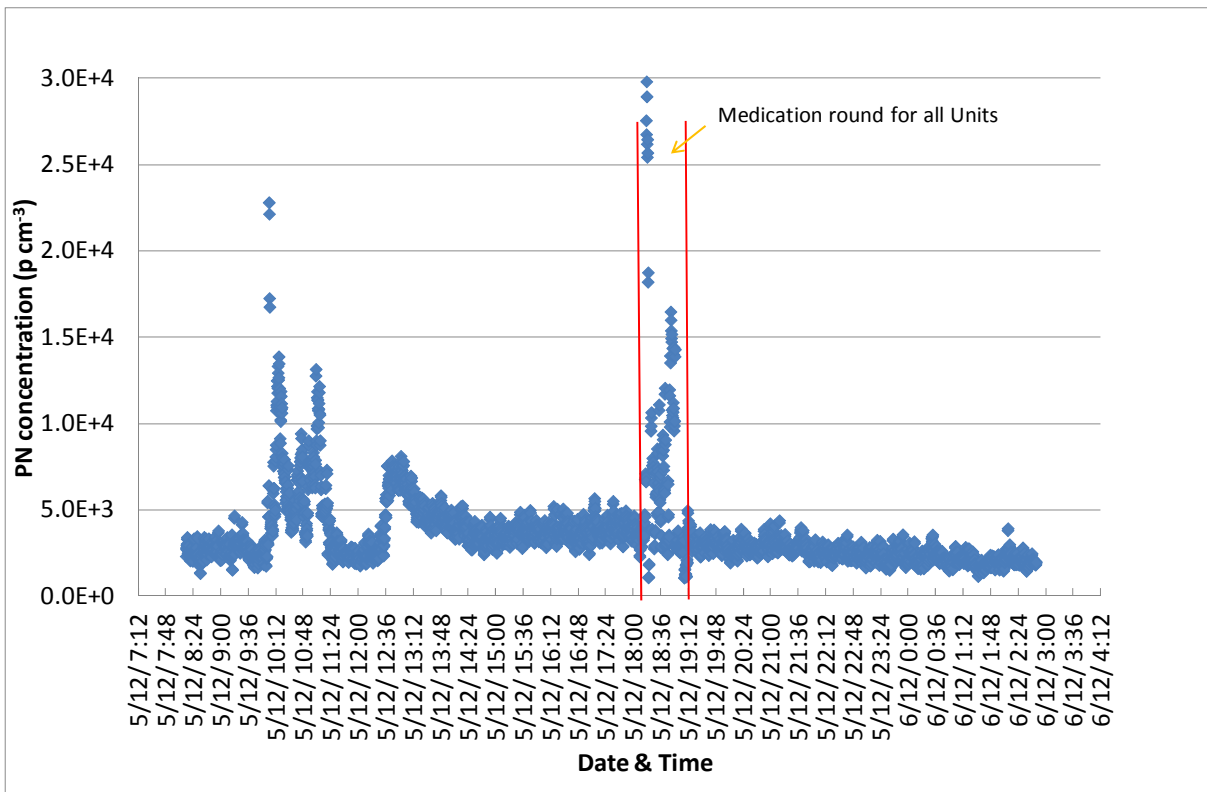
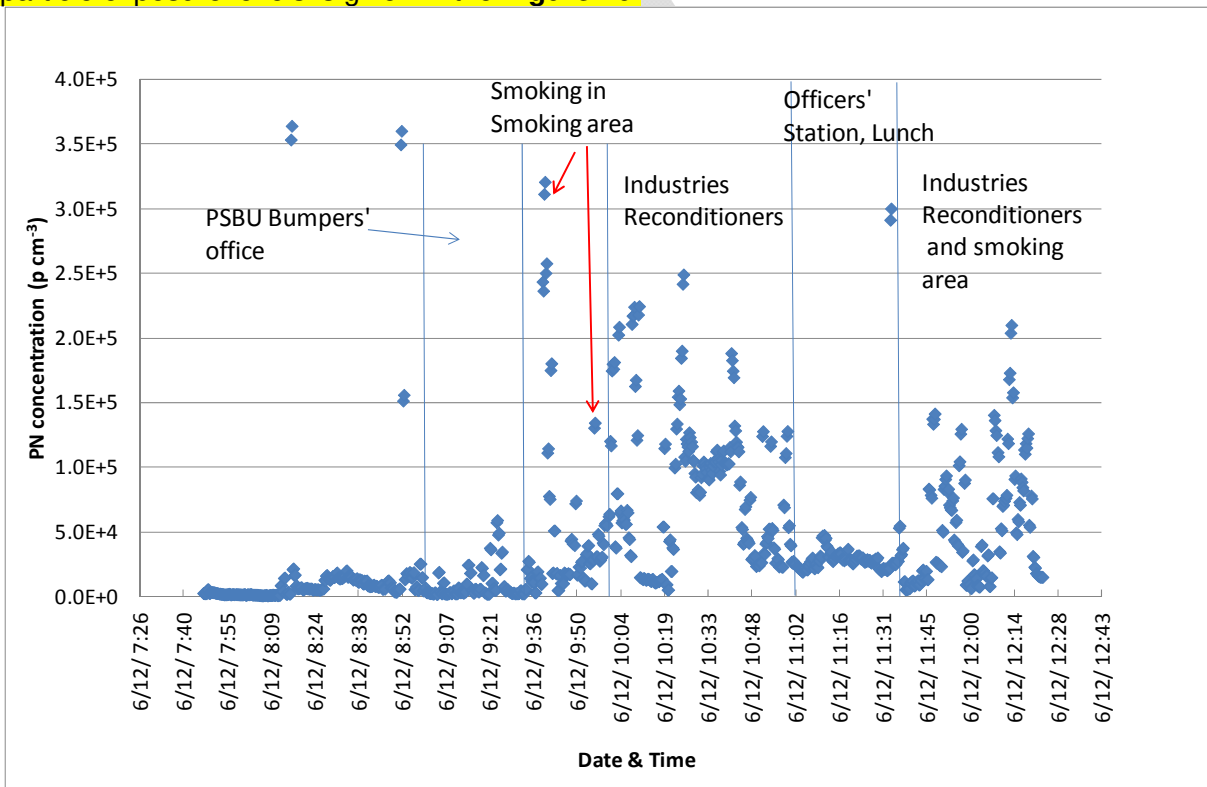


Figure 9 Time series of PN concentrations measured by a NT.

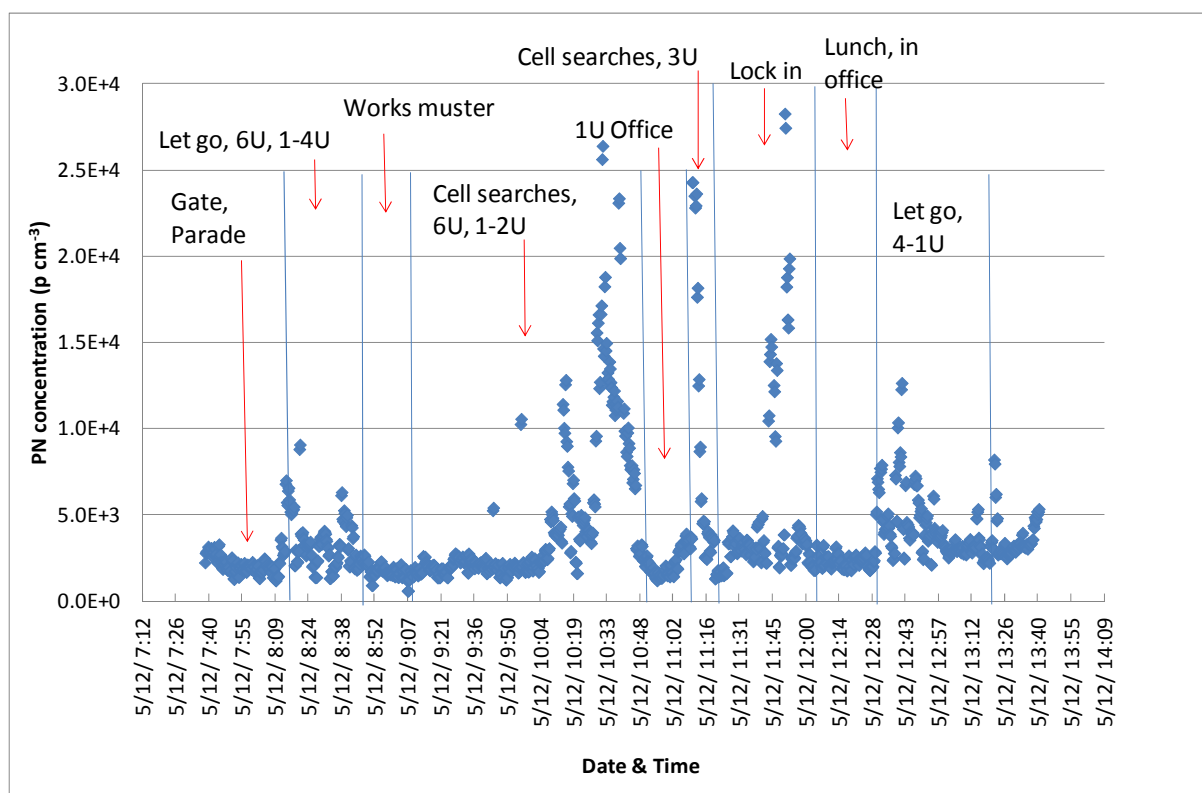
From the **Figure 9**, it can be seen that exposure levels during the medication round were significantly higher than those during other periods in the Health centre. The peaks during 10.00 -11.00am and 12:30pm - 13:00pm are likely to be due to cleaning activities and cooking activities, respectively.

The time series data of NT also showed that the average exposure level during the smoking was significantly higher than background level. An example of the effect of smoking on the particle exposure levels is given in the **Figure 10**.



**Figure 10** Time series of PN concentrations measured by a NT which wore by an officer.

Based on the time series data of NT and rovers, activity record, the average exposure level during each activity or location can be obtained. An example of the difference between the particle exposure levels during each activity is given in the **Figure 11**.



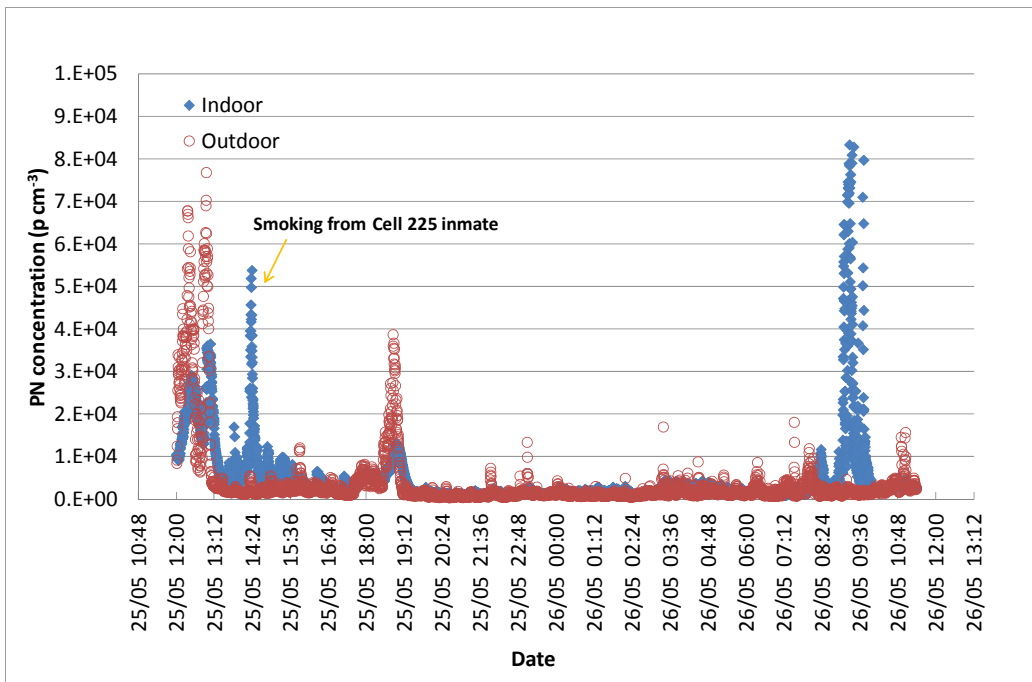
**Figure 11** Time series of PN concentrations measured by a NT which wore by a rover.

From the Figure 11, it can be seen there are clear particle exposure level differences between the activities. In general, indoor exposure levels are higher than outdoors. Cell exposure levels are higher than other indoors.

## 5.6. Possible indoor particle sources

Based on the time series of indoor and outdoor particle number concentrations and limited activities records, the presence of indoor particle sources were identified in the units, including smoking (during the first round), cooking, washing and cleaning activities. There were strong indoor particle sources in Unit 5.2B, for both particle number and particle mass, during the second round. The time series data indicated that inmates in Unit 5.2B generated a large number of particles after Unit 5.2 officers left the building. Indoor smoking was identified as a possible indoor particle source in the first round only. The **Figure 12** presents an example of the effect of indoor smoking on indoor air:





**Figure 12** Time series of PN concentrations measured in Unit 5.2A from 25-26 May by a CPC.

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## 5.7. Indoor and Outdoor VOC, CO and CO<sub>2</sub> concentration levels

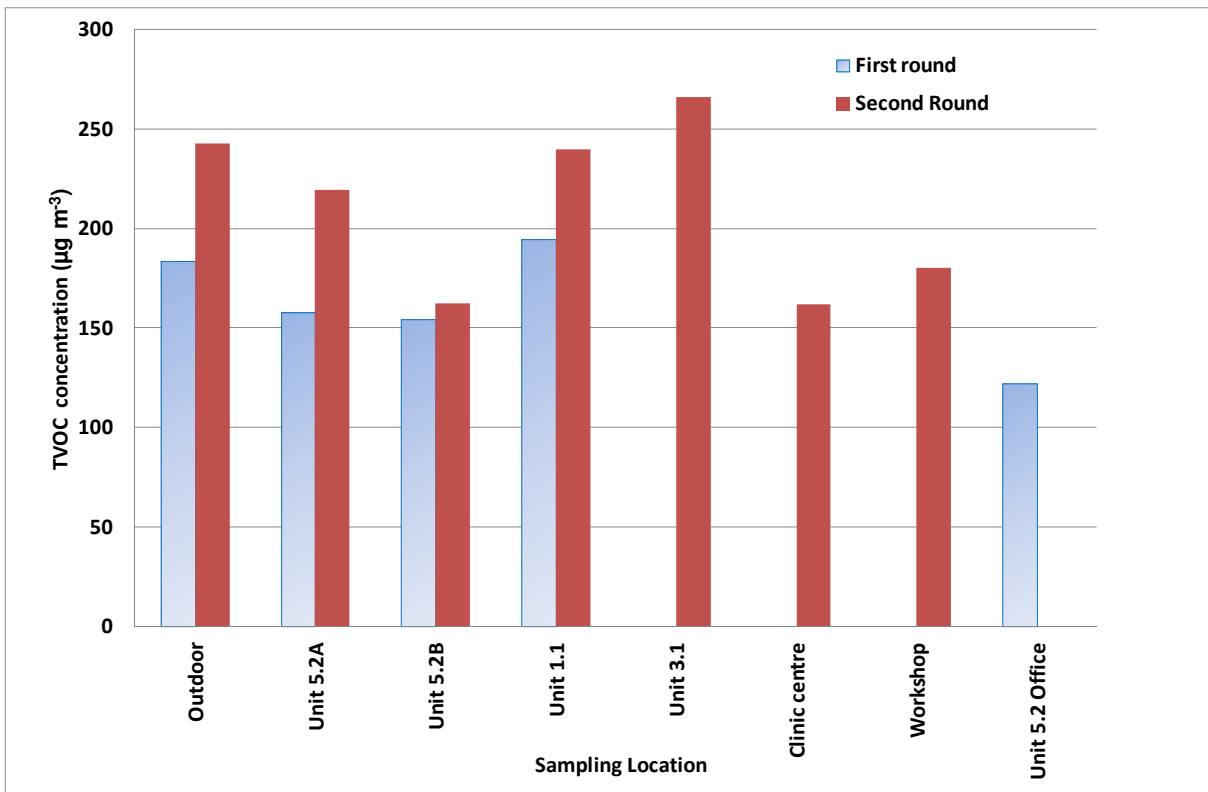
### 5.7.1. Average VOC concentration levels

In total, 12 (9 indoor and 3 outdoor) and 25 (19 indoor and 6 outdoor) VOC samples were collected during the first and second rounds, respectively. The outdoor sampling location was the Unit 5.2 yard and there were seven indoor locations, namely Unit 5.2A, Unit 5.2B, Unit 3.1 (second round only), Unit 1.1, Health Centre (second round only), Industries Textiles area (second round only) and Unit 5.2 officers' station (first round only). About 50 VOC compounds were identified during the measurements and three of the four BTEX were identified and quantified. BTEX refers to the chemicals *Benzene*, *Toluene*, *Ethylbenzene* and *Xylene*. The primary man-made sources of BTEX compounds are from motor vehicle and aircraft emissions, and cigarette smoke. BTEX compounds are also created and used during the processing of petroleum products and during the production of consumer goods such as paints and lacquers, thinners, rubber products, adhesives, inks, cosmetics and pharmaceutical products. Average TVOC, *Benzene*, *Toluene* and *Xylene* concentrations measured during the first and second round are given in **Figures 13 -16**, respectively. More detail of this comparison is given in **Appendix C**. The VOC measurement results showed that:

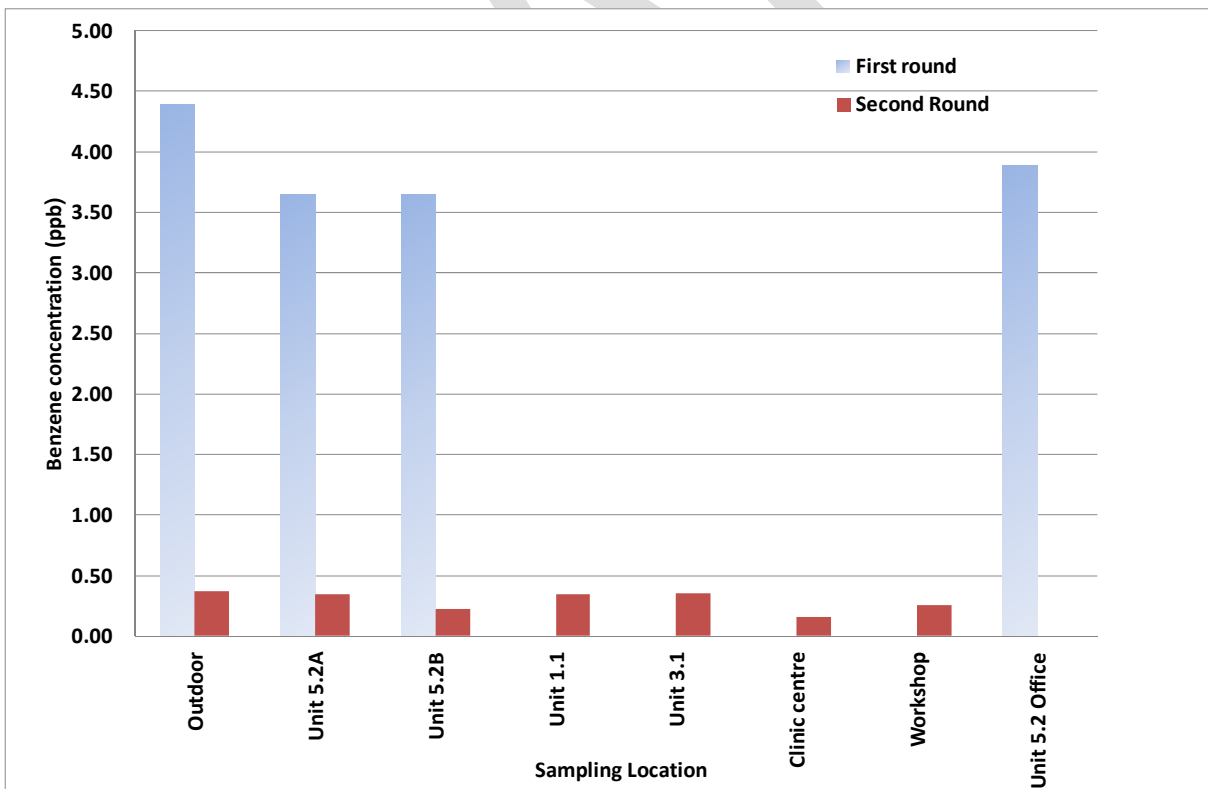
- for both indoor and outdoor TVOC, *Toluene* and *Xylene* concentration levels in the second round were higher than those in the first round;
- in general, outdoor VOC concentration levels were higher than indoor levels, except for *Xylene* during the first round (the ratios for which are given in **Table 8**); and
- both indoor and outdoor nicotine concentration levels were below the detection limit ( $0.92\mu\text{g m}^{-3}$ ) of the methods used in this project.

**Table 8.** Summary of indoor and outdoor ratios of TVOC, *Toluene* and *Xylene* concentration.

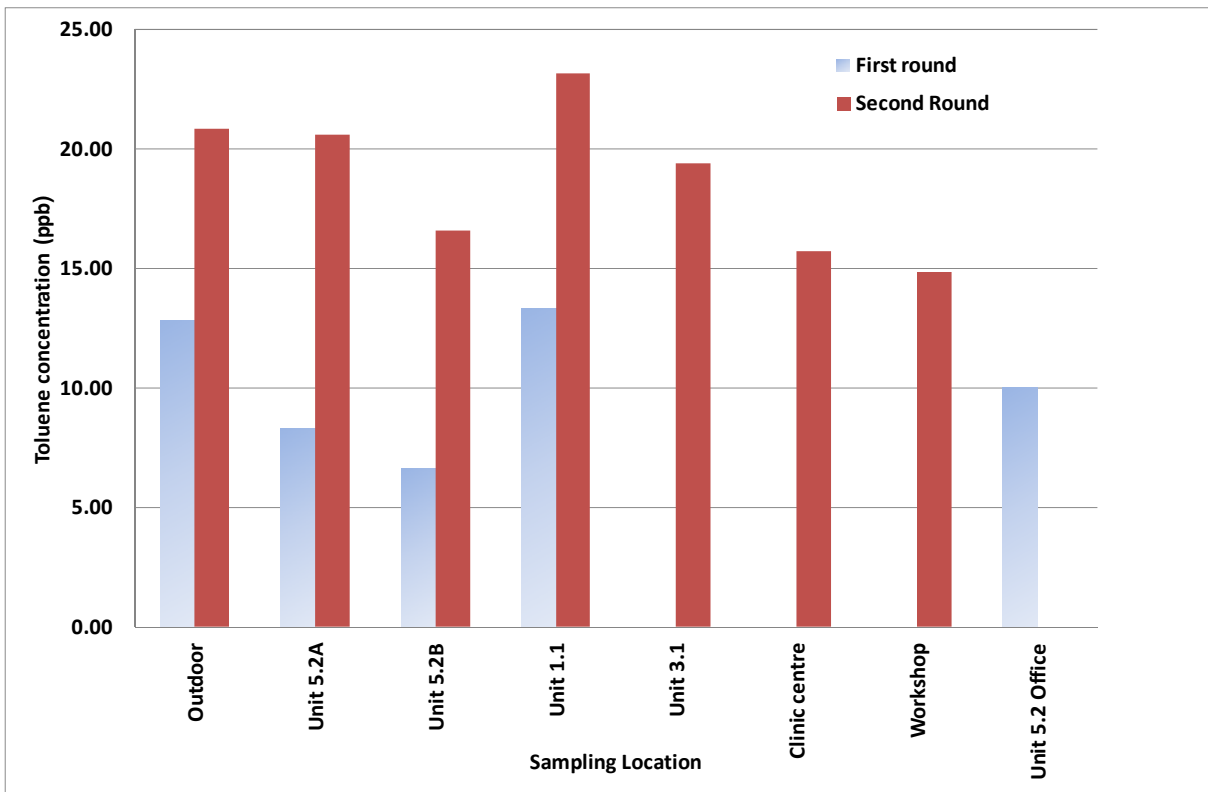
	<b>TVOC</b> <b>(<math>\mu\text{g m}^{-3}</math>)</b>	<b>Benzene</b> <b>(ppb)</b>	<b>Toluene</b> <b>(ppb)</b>	<b>Xylene</b> <b>(ppb)</b>
First round	0.86	0.85	0.74	1.36
Second round	0.84	0.75	0.88	0.57



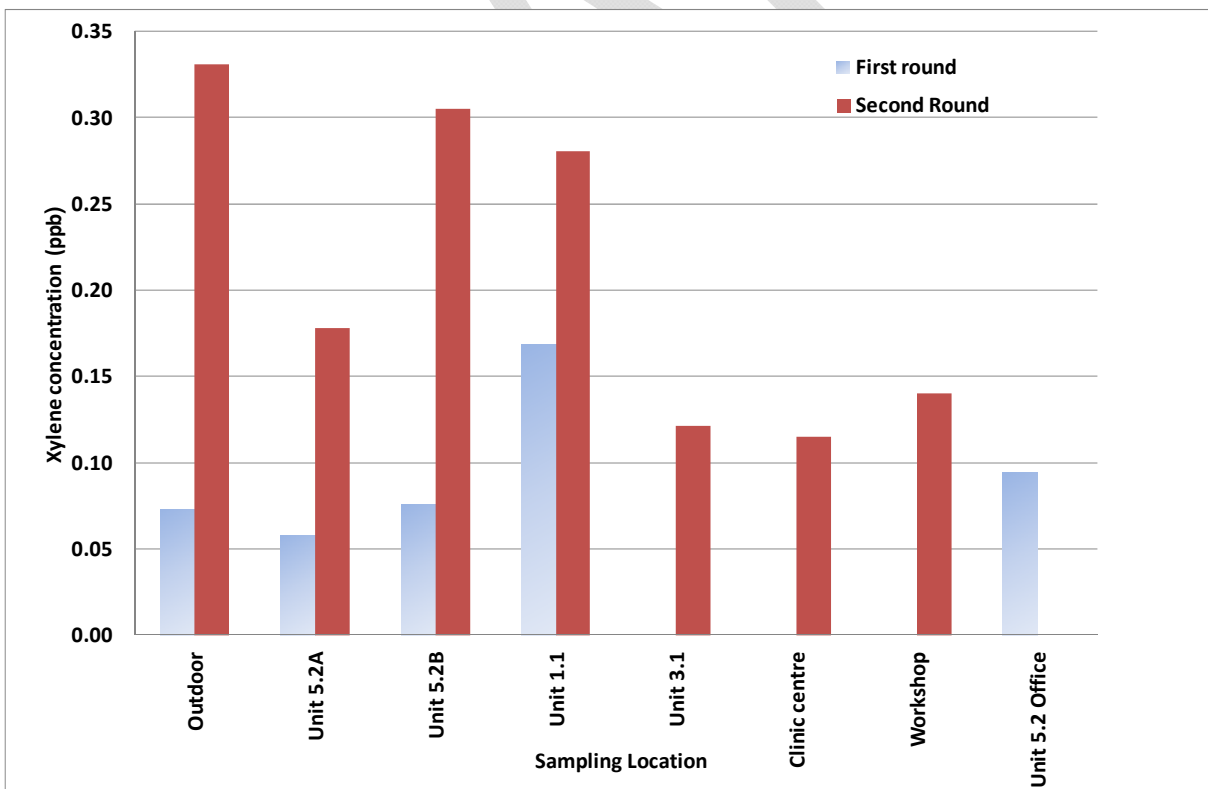
**Figure 13.** Average TVOC concentrations during the first and second round at different locations.



**Figure 14.** Average Benzene concentrations during the first and second round at different locations.



**Figure 15.** Average *Toluene* concentrations during the first and second round at different locations.



**Figure 16.** Average *Xylene* concentrations during the first and second round at different locations.

Apart from BTEX chemicals, there are other chemicals also related to EST, however they can also be generated by other sources. Therefore, they can not be used to identify ETS. In addition, these 50 VOC compounds are not the only chemicals related to EST. Actually, EST

contains hundreds of VOCs and most of them have various sources in the ambient atmosphere. However, BTEX were the only VOCs detected in the samples and are listed as 'Air Toxics' by the National Environment Protection Council (known as the 'Air Toxics NEPM').

BTEX is an important indication of air quality in regard to VOC, but it is not an exclusive indication of ETS, since it may also come from other sources, such as engine emissions and solvent use. Also, different sources may exist for individual BTEX chemicals and therefore, it is not unusual to observe inconsistent trends for individual BTEX chemicals.

Although it is clear that the TVOC and BTEX chemicals are toxic and have adverse health effects on exposed people, unfortunately there are no standards that quantify safe levels of exposure to these chemicals in Australia. The "Air Toxics NEPM" uses the term "monitoring investigation levels", which means that if these levels are exceeded, then further investigation may be appropriate, but exceedance does not indicate that adverse health effects will occur.

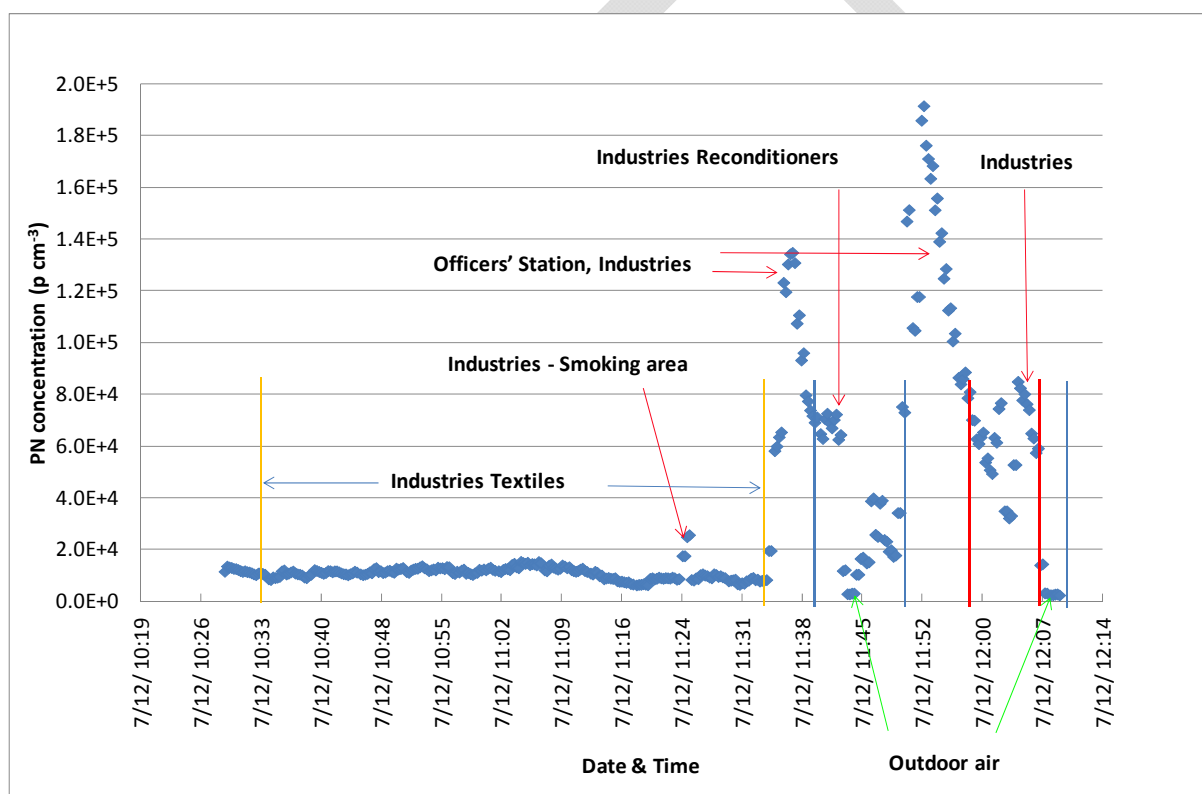
#### **5.7.2. Average CO and CO<sub>2</sub> concentration levels**

Both overall 8hr indoor and outdoor CO concentration levels were lower than 1 ppm and significantly lower than the advisory NEPM ambient air quality 8 hr standard (9 ppm) for both rounds. Indoor overall CO<sub>2</sub> concentration level was higher than outdoor level and less than 400ppm.

## 5.8. Spatial Variation of Particle Number Concentration in the Industries

Particle number concentrations (0.010-0.3 $\mu\text{m}$ ) were measured by a NT at different locations inside the Industries building during working time. The measured time series of particle concentrations is presented in **Figure 17**. The results indicate:

- Indoor particle number concentration levels were higher (about 4 ~ 50 times) than outdoor particle concentration levels.
- Particle concentration level varied from location to location within the building.
- Particle concentration levels:
  - in the officers' station (average about  $(107 \sim 139) \times 10^3$  particle  $\text{cm}^{-3}$ ) were considerably higher than at any other locations.
  - in the smoking area were higher (about 100%) than the those in 'Industries - textiles' area.
  - in the 'Industries Reconditioners' area were higher than those in the 'Industries - textiles' area.
- The indoor particle sources were cooking, painting and vacuuming for the Officers' Station, Industries Reconditioners and Industries Textiles areas, respectively.



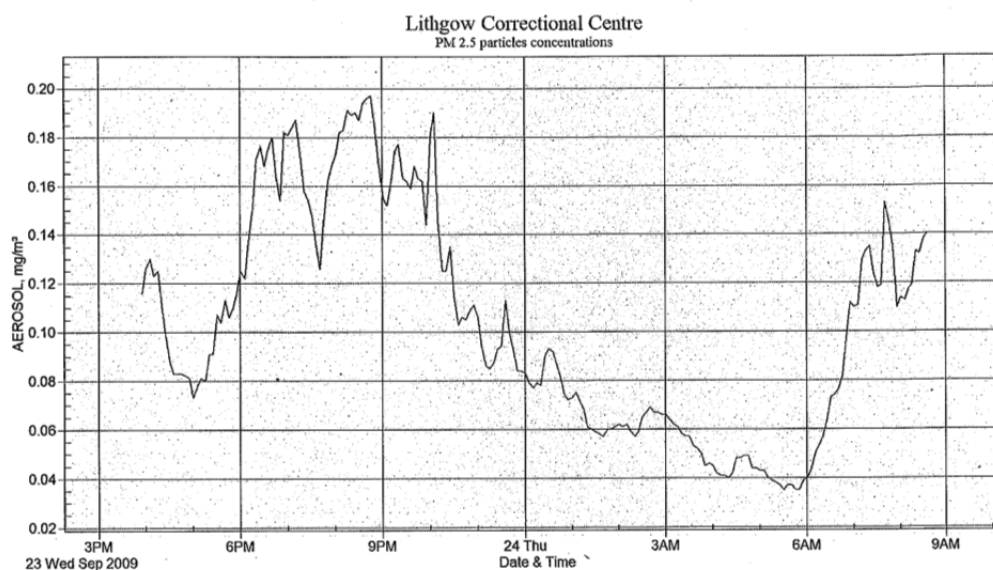
**Figure 17.** Time series of particle number concentrations in different locations within the Industries building.

## 5.9. Difference in Ventilation between the First and Second Round

The first and second rounds were conducted during the winter and summer, respectively. During winter, the mechanical ventilation systems were turned on in all of the Units, however they were turned off during the summer. Therefore, the air exchange rates in these units was expected to be different between the two rounds.

## 5.10. Discussions

- From an air quality measurement point view, Unit 5.2 may not have been the best location for the main indoor measurements, since the number of inmates was relatively low (about 5 - 6 in Unit 5.2A and 3 - 4 in Unit 5.2B) during the first round and therefore, the Unit 5.2 inmates generated much lower particle levels than inmates in the other Units. This can be seen from **Table 3** for PM<sub>2.5</sub> concentration levels and **Table 5** for I/O ratios. However, the number of inmates in Unit 5.2 during the second round (about 8 - 10 in Unit 5.2A and 10 - 12 in Unit 5.2B) were significantly higher than those during the first round. This significant difference in inmate numbers between the two rounds made the comparison of concentration levels between the two rounds more complex. In hindsight, Unit 2.2 and Unit 3.1 may have been better locations for the main indoor measurements, if inmate numbers were relatively stable between the two rounds.
- It would have been better if the two rounds were conducted during the same season, be it winter or summer, since ventilation systems at the LCC operated in a completely different during the summer and winter months.
- Fisher and Matthews conducted an investigation into ETS at the LCC from 23-24 September 2009 using a TSI DustTrak 8520 to measure indoor PM<sub>2.5</sub> concentrations in Unit 1. Based on a comparison of the time series of indoor PM<sub>2.5</sub> concentrations reported in **Figure 6** (for Unit 5.2B during the second round) with the figure reported by Fisher and Matthews (for Unit 1), it can be seen that there was good agreement between the two diurnal variation patterns. This implies that the inmates' indoor particle generation activity patterns in the two Units were very similar for the two measurement periods and therefore, it is likely that the inmates in Unit 5.2B were smoking during the second round measurements conducted for this project, which was after the introduction of smoke free buildings policies.



- Chapter 8 (Indoor Air Pollutants) of the WHO Air Quality Guidelines for Europe (second edition, 2000) includes the following paragraph on environmental tobacco smoke (ETS):

*"Populations at special risk for the adverse health effects of ETS are young children and infants, asthmatics, and adults with other risk factors for cardiovascular disease. Levels of exposure where these effects have been observed are indicated by nicotine levels of 1–10 µg/m<sup>3</sup> (nicotine has been demonstrated to be a reliable marker of ETS levels)."*

Mr Gary Rhyder conducted another ETS investigation at the LCC in 2009 by taking two air samples (of 318 and 303 minutes duration, respectively) and analysing the average nicotine concentration levels. He reported that average nicotine concentration levels were <0.06 µg m<sup>-3</sup> and 1.7 µg m<sup>-3</sup>, respectively. In fact, the second value of 1.7 µg m<sup>-3</sup> should be 0.17 µg m<sup>-3</sup> based on the reported raw data (0.05/(303×0.99)×1000=0.17 µg m<sup>-3</sup>). In the current project, both indoor and outdoor nicotine concentration levels were below the detected limit (0.92 µg m<sup>-3</sup>) of the methods used, however these results are comparable with the previous values and they confirm that the average nicotine concentration levels at the LCC were below 1 µg m<sup>-3</sup>.

## **6. OVERALL CONCLUSION**

Average outdoor particle concentration levels were found to be in general typical for the environment investigated. However, average indoor particle concentration levels in some locations were higher than typical or exceed the NEPM standard. Nicotine concentration levels were below 0.92 µg m<sup>-3</sup> (the detection limit of the methods). The nature of the project was more complex than other indoor air quality studies since it was conducted in a very specific environment. Due to these complexities, the measurements were not always conducted according to ideal designs. Despite of this, the data showed some clear trends and possible reduction of particle concentrations in some units after the introducing smoke free buildings policies, however, there was a strong deterioration in other units, which may point out to the need for a better enforcement of the smoke free buildings policies.



## **Acknowledgments**

We would like to thank Ms Ashleigh Cussen for her great help during the field measurements, especially in finding and co-ordinating volunteers for the personal exposure measurements. The assistance of officers from the LCC, especially those that participated in personal exposure measurements, is gratefully acknowledged. Members from ILAQH, in particular Chantal Labbe and Rachael Appleby, are thanked for their assistance with this project. We would also like to thank Prof Boguang Wang from the Department of Environmental Engineering at Jinan University, P.R China, for his assistance in relation to the VOC analysis aspects of the project.

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- He, C; Morawska, L; Tran Q; McGarry, P. (2011) The Effect of indoor and outdoor particle sources on indoor air quality of a new multilevel office building in the vicinity of a busway. *Proceeding of the 12th International Conference on Indoor Air Quality and Climate*, Austin, USA.
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## Appendix A: Instrument Settings with photos

### **WCPC 3787**

flow 0.6 L/min

sample time: 20s in the first round and 10s in the second round for outdoor air; 10s for indoor air

### **DustTrak**

inlet nozzle PM<sub>2.5</sub>

logging interval 30 s for outdoor air

logging interval 10s for indoor air

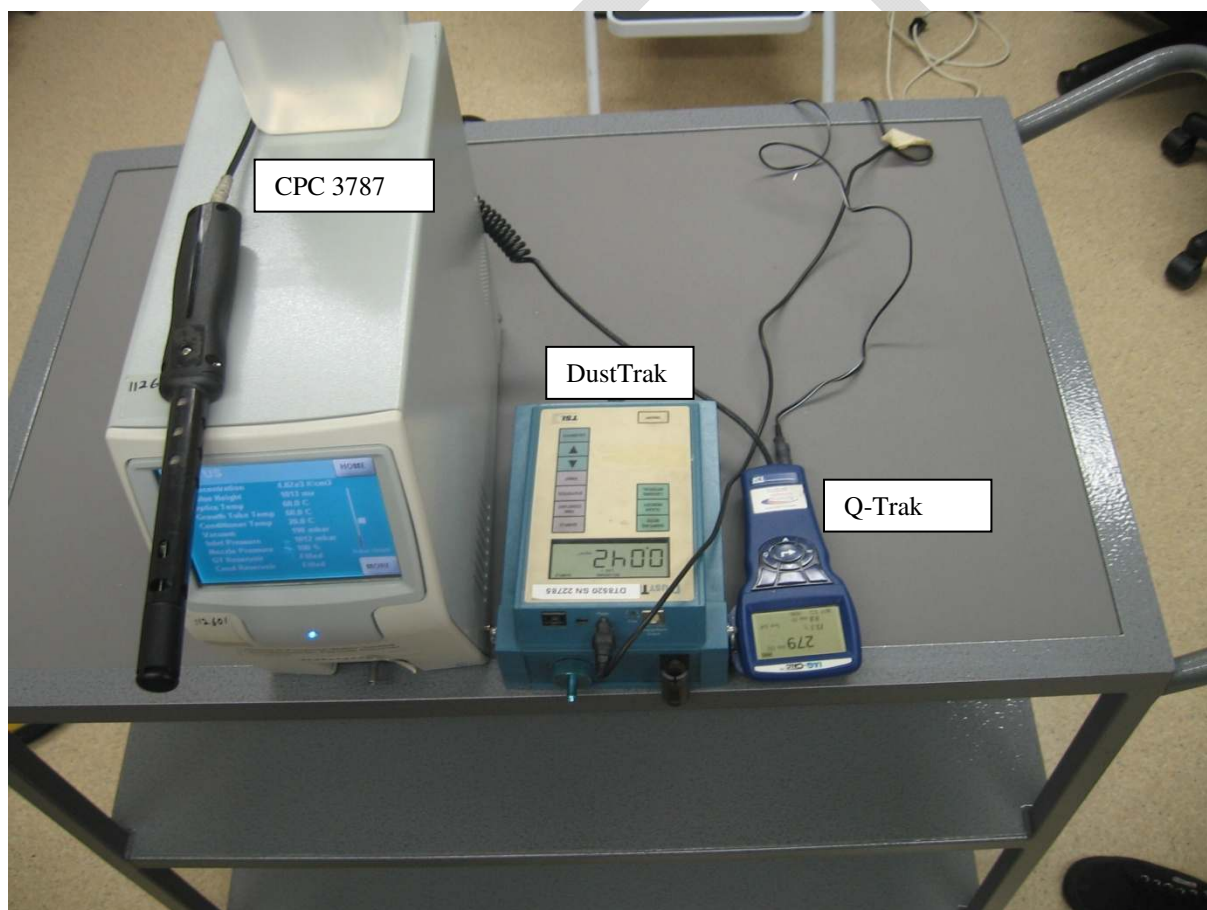
time constant 1s

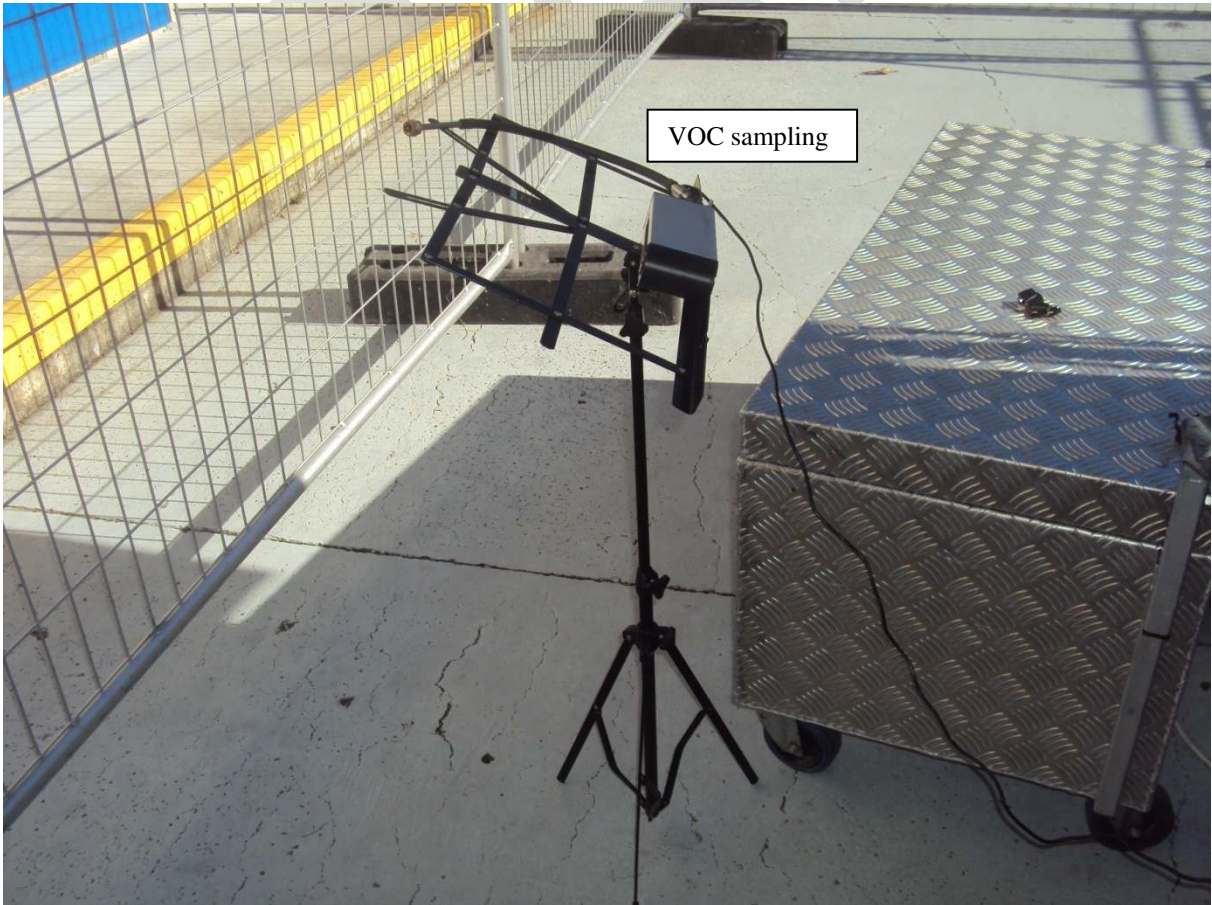
### **Q-Trak**

logging interval 30 s for both indoor and outdoor

### **NanoTraser**

advanced model: sample time -16s





## Appendix B: Lithgow meteorology data during the measurement at LCC

Date	Day	Temps		Rain mm	Evap mm	Sun hours	Max wind gust		9 am					3 pm							
		Min	Max				Dir	Spd km/h	Time local	Temp °C	RH %	Cld 8 <sup>th</sup>	Dir	Spd km/h	MSLP hPa	Temp °C	RH %	Cld 8 <sup>th</sup>	Dir	Spd km/h	MSLP hPa
		°C	°C																		
<b>May</b>																					
23	We	2.8	15.7	0					9.2	54	0	NW	17		14.9	36	0	NW	11		
24	Th	-0.2	12.5	0					6.2	76	6	NW	4		10.9	90	8	N	13		
25	Fr	6.4	10.1	27.6					7.0	61	7	NW	26		7.7	54	7	NW	37		
26	Sa	4.0	9.0	0.4					4.8	68	8	W	28		7.5	75	8	W	15		
27	Su	0.8	11.9	0					6.0	80	4	Calm			9.0	66	7	SW	11		
<b>December</b>																					
3	Mo	14.0	27.6	1.0					14.6	94	8	Calm			25.9	34	5	W	37		
4	Tu	11.7	20.8	0					13.4	60	0	WNW	46		19.9	20	1	WNW	41		
5	We	6.4	17.7	0					10.2	44	1	W	52		14.9	37	3	W	37		
6	Th	2.4	23.3	0					11.4	49	1	Calm			22.2	18	1	SW	7		
7	Fr	8.8	20.8	0					12.4	76	8	NNW	9		18.9	49	8	N	9		
8	Sa	7.4	27.9	0					16.9	72	1	Calm			27.3	23	6	WNW	15		



**Appendix C:** Summary of the overall average indoor and outdoor TVOC, *Benzene*, *Toluene* and *Xylene* concentrations during the first and second round.

	First				Second			
	TVOC ( $\mu\text{g m}^{-3}$ )	Benzene (ppb)	Toluene (ppb)	Xylene (ppb)	TVOC ( $\mu\text{g m}^{-3}$ )	Benzene (ppb)	Toluene (ppb)	Xylene (ppb)
<b>Outdoor</b>	184	4.39	12.9	0.07	243	0.38	20.8	0.33
<b>Unit 5.2A</b>	158	3.65	8.32	0.06	219	0.34	20.6	0.18
<b>Unit 5.2B</b>	154	3.65	6.63	0.08	162	0.23	16.6	0.30
<b>Unit 1.1</b>	195	nd	13.3	0.17	240	0.35	23.2	0.28
<b>Unit 3.1</b>	N/A	N/A	N/A	N/A	266	0.36	19.4	0.12
<b>Nurse Station</b>	N/A	N/A	N/A	N/A	162	0.16	15.7	0.11
<b>Industries</b>	N/A	N/A	N/A	N/A	180	0.26	14.9	0.14
<b>Office</b>	122	3.88	10.00	0.09	N/A	N/A	N/A	N/A

N/A: no data available, nd: not detected.

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