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Temporal Variations in Airborne Particulate Matter Levels at an Indoor Bus Terminal and Exposure Implications for Terminal Workers

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ABSTRACT

This study investigates temporal variations in PM levels in Taipei bus terminal and assesses exposure levels for bus terminal workers. Measurement results show that temporal variations in PM levels in the waiting room and on the platform of this indoor bus terminal were strongly associated with bus traffic volume. The PM_{10}, $PM_{2.5}$, and ultrafine particle (UFP) levels on the bus platform were 1.9, 2.0, and 1.2 times higher than those inside the waiting room, respectively. Additionally, PM_{10} and $PM_{2.5}$ levels on the platform were approximately 2.3 and 2.8 times higher than those at an ambient monitoring station, respectively. Measurement results indicate that the major PM source inside this bus terminal is diesel buses and that PM can be trapped in this semi-confined bus terminal to a far greater extent than in typical open-air bus stations. Daily PM exposure levels for station ticket inspectors who check passenger tickets in the waiting room and manage arriving and departing buses on the bus platform are assessed. Daily PM exposure levels for station ticket inspectors during different shifts are calculated based on average PM levels and working time spent in the waiting room and on the platform. Based on observational results, station ticket inspectors spend approximately 80–85% and 15–20% of their working time in the waiting room and on the platform, respectively. Daily PM_{10} and $PM_{2.5}$ exposure levels for station ticket inspectors were approximately 1.3–1.5 and 1.6–1.8 times higher than those in the outdoor atmosphere, respectively. Additionally, daily UFP exposure levels for station ticket inspectors were approximately 5.6–7.2 times higher than those in the urban background. Measurement results demonstrate that potential health risk induced by PM is high for station ticket inspectors who work for long periods at this indoor bus terminal.

Keywords: PM_{10}; $PM_{2.5}$; Ultrafine particle; Bus terminal; Station ticket inspector; Exposure level.

INTRODUCTION

Airborne particulate matter (PM) has been associated with various adverse health conditions, including respiratory and cardiovascular disease (Duhme *et al.*, 1998; Pope *et al.*, 2004; Dominici *et al.*, 2006). Studies have indicated that the size of airborne particulate matter is a crucial factor in the degree to which this material affects one's health. The particulate matter PM_{10} (particle size < 10 μm) and to a greater degree $PM_{2.5}$ (particle size < 2.5 μm) is capable of reaching conductive airways and adversely influencing the respiratory system (Duhme *et al.*, 1998). Moreover, ultrafine particles (UFP; particle size < 0.1 μm) are associated with greater toxicity on a per-mass basis than larger particles (Delfino *et al.*, 2005; Oberdörster *et al.*, 2005; Nel *et al.*, 2006). Studies have shown that UFPs can be transported by the blood to the organs, such as the liver, within 4–24 h following exposure (Oberdörster *et al.*, 2002). Transport of UFPs to the brain via the olfactory nerve has also been demonstrated (Oberdörster *et al.*, 2004). Furthermore, toxicological studies have also linked $PM_{2.5}$ and UFPs to the induction of oxidative DNA damage via systemic oxidative stress (Risom *et al.*, 2005; Bräuner *et al.*, 2007; Møller *et al.*, 2008). Thus, exposure to airborne PM is a serious environmental risk for cardiopulmonary disorders and lung cancer.

Motor vehicles have been recognized as a dominant source of ambient PM in urban areas (Charron and Harrison, 2005; Abu-Allaban *et al.*, 2007; Ning and Sioutas, 2010). Bus stations often present high concentrations of PM released as a result of the incomplete combustion of fuel when buses decelerate, idle and accelerate (Yip *et al.*, 2006; Kinsey *et al.*, 2007; Jayaratne *et al.* 2009; Richmond-Bryant *et al.*, 2009; Wang *et al.*, 2010). See *et al.* (2006) showed that average levels of $PM_{2.5}$ and UFP in a major bus interchange increased by a factor of 2.3 and 5.1, respectively, during operating hours compared to non-operating hours. This increase in the level of $PM_{2.5}$ and UFP during operating

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hours was attributable to emissions from diesel buses. Kinsey *et al*. (2007) demonstrated that $PM_{2.5}$ emissions from buses were generally higher during continuous idle compared to post-restart. The restart and immediate departure of buses demonstrated the lowest emissions of $PM_{2.5}$. Li *et al*. (2009) noted that 3 h time-averaged UFP levels at a school bus depot were 4.7 times higher than at a reference site in March (cold weather) and 2.2 times higher in May (warm weather). It was suggested that higher particle emissions in March could be related to increased engine idling in cold weather. Wang *et al*. (2011) compared the $PM_{2.5}$ and UFP levels at an open station and canyon station, showing that source contribution was greater than atmospheric dispersion associated with the design of the stations. $PM_{2.5}$ levels at canyon station and open station were 4.2 times and 2.5 times higher than at the reference point, respectively. According to these studies, passengers waiting at the bus station could be exposed to high levels of PM.

Air quality inside bus stations is an important health concern for passengers, as many commuters spend a considerable amount of time waiting for buses and many public transportation facilities are now located in semi-confined or completely confined spaces, often inside massive commercial buildings. The Taipei Bus Station, Taiwan's largest transfer station for intercity bus, is unlike any other station worldwide. The station is within a massive 24-story building (an 18-story building with six underground floors) housing a business hotel, shopping mall, several cinemas, offices, private residential suites, and over 900 parking spaces. However, air quality inside this terminal must be monitored as it serves over 45,000 passengers and over 2,500 buses enter, exit, and idle inside the building daily. The PM emitted directly from buses can accumulate within this semi-confined space, and adverse health effects on both passengers and workers.

Cheng *et al*. (2011) had demonstrated the short-term exposure levels of PM_{10}, $PM_{2.5}$, UFP and CO_2 for passengers at this indoor bus terminal. This study investigates temporal variations in PM levels at this indoor bus terminal and exposure implications for bus terminal workers during different work shifts.

MATERIAL AND METHODS

Sampling Location

The Taipei Bus Station is a main transportation hub for over 50 bus routes to eastern, central, and southern Taiwan, with a daily volume of approximately 2,500 scheduled buses, serving over 45,000 passengers daily. The concourse on the ground floor of this bus terminal has ticket counters and a bus information center as well as several gift and souvenir shops. The central areas of the second, third, and fourth floors are passenger waiting rooms. Buses drive around the waiting rooms within a bus lane inside the building. Each floor has 16 platforms surrounding the waiting room. Passengers pass through the gates between the waiting room and the platform to board buses or debus. Buses enter the building and drive to the second floor lane, and exit the station from the third floor taking a route to the ground floor or exiting directly onto an elevated expressway from the third floor via a connecting overpass.

Most passengers spend a considerable amount of time, in some cases up to 1 h, in the waiting room. Moreover, station workers are on the platform or in the waiting room for approximately 8 h during their shift. A previous study demonstrated that PM levels in the waiting rooms on the second, third, and fourth floors did not differ significantly at this bus terminal (Cheng *et al*., 2011). Therefore, two monitoring sites in this study were in the waiting room and on the platform (referred to as outside the waiting room) on the second floor of the bus terminal (Fig. 1). The waiting room is air-conditioned by a central ventilation system; however, the platform is not. Air on the platform circulates with outside air via natural and mechanical ventilation.

Sampling Equipment and Data Collection

In this study, two sets of sampling instruments were used simultaneously to monitor PM levels inside the waiting room and on the platform. Each set included a Grimm Series 1.108 OPC (Grimm Tech., Inc., Douglasville, GA, USA) and a TSI Model 3007 CPC (TSI Inc., Shoreview, MN, USA). The Grimm 1.108 OPC was used to determine PM_{10} and $PM_{2.5}$ levels, and the TSI 3007 CPC was used to measure UFP levels.

The Grimm 1.108 OPC measures particle mass concentrations according to an optical size of 0.23–20 μm in 15 different size ranges. The PM_{10} and $PM_{2.5}$ levels were calculated as fractions of the mass size distributions (Cheng and Lin, 2010; Cheng and Li, 2010). The measured mass size distribution was also fitted using DistFit software (Chimera Tech., Inc., Forest Lake, MN, USA) to determine the mass median diameters. Additionally, the TSI 3007 CPC measured particles 0.01 to > 1.0 μm, with a maximum concentration detection limit of 10^5 particles/cm^3, and a 50% size detection threshold of 0.01 μm. According to the manufacturer, the accuracy of concentration readings for up to 10^5 particles/cm^3 is ± 20%. Hämeri *et al*. (2002) suggested that coincidence loss of the TSI 3007 CPC would be serious at concentrations up to 4×10^5 particles/cm^3 and measurements must be corrected. However, this CPC is portable and convenient for the field measurements of environmental UFPs.

The PM_{10}, $PM_{2.5}$, and UFP levels inside and outside the waiting room were measured simultaneously. Both sets of monitoring instruments were placed 1.5 m above the floor in the center of the waiting room and on the platform near the boarding gate. The logging interval for all measurements was 1 min. Measurements were taken continually for approximately 3 days during July 15–18, 2010, to determine real-time variations in PM levels. The alcohol cartridge in the TSI 3007 CPC was refilled every 4 h to maintain normal operations throughout the sampling period. Outdoor PM_{10} and $PM_{2.5}$ levels were measured hourly by an ambient air-quality monitoring station at Wanhua Station, approximately 900 m from the Taipei Bus Station. These measurements were adopted as the reference PM_{10} and $PM_{2.5}$ levels of the urban atmosphere in Taipei. These concentrations of PM_{10} and $PM_{2.5}$ were measured hourly using an automatic Met One BAM 1020 beta gauge monitor (Met One, Inc., Grants

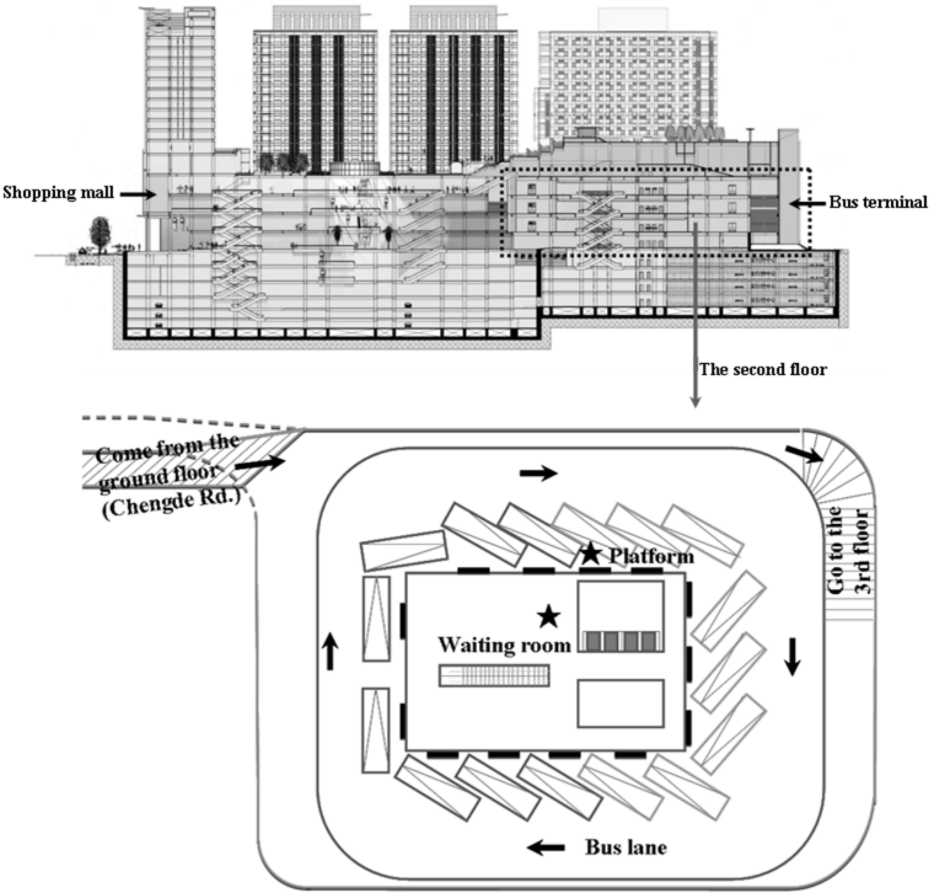

Fig. 1. Schematic diagram of monitoring locations at the Taipei Bus Station. Monitoring locations are marked by asterisks.

Pass, OR, USA) deployed in the air-quality monitoring network of Taiwan. Hourly traffic data of the bus terminal was obtained from the Bus Station Administration.

Data Quality Assurance

The performance of the two Grimm 1.108 OPCs and the two TSI 3007 CPCs employed in this study were compared at the bus station, prior to field monitoring. Results indicate that $PM_{2.5}$ levels measured by the No. 2 OPC were approximately 0.93 times lower than those measured using the No. 1 OPC. Additionally, the UFP levels measured by the No. 2 CPC were approximately 1.02 times higher than those measured using the No. 1 CPC. However, statistical results suggest that responses between the two OPCs and between the two CPCs were very consistent ($R^2 = 1.00$ for OPC and $R^2 = 0.98$ for CPC). To obtain the same responses as monitor No.1 (OPC or CPC), all readings of monitor No. 2 (OPC or CPC) were corrected using the comparison results obtained in this study.

Furthermore, the response of light-scattering dust monitors was influenced by aerosol parameters, such as the refractive index, and the shape, density, and size of particles. To acquire accurate quantitative measurements of aerosol concentrations, the Grimm 1.108 OPC was compared with an equivalent method using the target aerosol under the same environmental conditions as those used to evaluate PM_{10} and $PM_{2.5}$ levels. During field monitoring, a Met One E-BAM sampler (Met One, Inc., Grants Pass, OR, USA) was placed beside the Grimm 1.108 OPC in the waiting room in the bus terminal as a reference sampler to assess the performance of the Grimm 1.108 OPC. The Met One E-BAM sampler is an automatic air monitor based on beta attenuation. The beta attenuation approach has been certified by the Environmental Protection Agency (EPA) of Taiwan as an effective method (Taiwan EPA NIEA A206.10C). Statistical results indicate that the calibration factor for concentrations of mass obtained using the Grimm 1.108 OPC was 1.38 ($R^2 = 0.97$). Raw data obtained from both Grimm OPCs regarding mass size distributions was corrected using a calibration factor of 1.38, to yield “real” PM_{10} and $PM_{2.5}$ levels and mass size distributions in the bus terminal.

Exposure Levels Analysis for Station Workers

Bus terminal workers work in three shifts—day shift (8:00–16:00), afternoon shift (16:00–24:00), and night shift (00:00–8:00). In this study, daily PM exposure levels for station ticket inspectors who check passenger tickets and manage arriving and departing buses were assessed for each shift. During working hours, station ticket inspectors usually stand at the boarding gate in the waiting room when checking passenger tickets and handled bus departures on the platform. The time station ticket inspectors spent in the waiting room and on the platform during different shifts was observed. Daily PM exposure levels for station ticket inspectors during different shifts were calculated based on average PM levels and working time spent in the waiting room and on the platform:

$$C_{\text{exposure}} = \frac{\sum C_i \cdot t_i}{\sum t_i} \tag{1}$$

where C_i is average PM level at location *i*, and t_i is the working time spent at location *i*.

Statistical Methods

An independent sample t-test was applied to test differences in PM levels between the two sampling locations. Moreover, an independent sample t-test was also applied to test differences in PM levels between different monitoring periods or work shifts. A significance level of 0.05 was used for all statistical tests. The Pearson product moment correlation coefficient (R_{Pearson}) was also applied to determine the strength of correlations between PM levels at the two sampling locations.

RESULTS AND DISCUSSION

Meteorological Conditions

During the monitoring period, hourly average temperatures inside the waiting room and on the platform were 24.1–25.8°C (mean = 25.1°C) and 29.0–34.6°C (mean = 32.4°C), respectively. Hourly average relative humidity inside the waiting room and on the platform was 60.3–68.4% (mean = 64%) and 50.4–75.3% (mean = 60.5%), respectively. Larger profiles for temperatures and relative humidity on the platform compared with those in the waiting room were due to variations in outdoor meteorological conditions. Moreover, the temperatures and relative humidity in the waiting room were steadier than those on the platform due to well controlled air conditioning systems.

Temporal Variations in PM_{10}, $PM_{2.5}$, and UFP Levels in the Waiting Room and on the Platform

Table 1 lists the 1 h average PM_{10}, $PM_{2.5}$, and UFP levels inside the waiting room and on the platform during the sampling period. Analytical results show that PM levels on the platform were significantly higher than those in the waiting room ($p < 0.001$ for all PM). PM_{10} and $PM_{2.5}$ levels on the platform were 1.9 and 2.0 times higher than those in the waiting room, respectively ($p < 0.001$ for both PM_{10} and $PM_{2.5}$). Furthermore, UFP levels on the platform were also roughly 1.2 times higher than those inside the waiting room ($p < 0.001$). Compared with PM_{10} and $PM_{2.5}$ levels measured at the Wanhua monitoring station, PM_{10} and $PM_{2.5}$ levels on the platform were approximately 2.3 and 2.8 times higher, respectively ($p < 0.001$ for both PM_{10} and $PM_{2.5}$). The levels of PM_{10} and $PM_{2.5}$ levels inside the waiting room were also 1.2 and 1.4 times significantly higher than those at the monitoring station, respectively ($p < 0.001$ for both PM_{10} and $PM_{2.5}$). The UFP background levels in the typical urban environment were approximately 1.0×10^4 particles/cm^3 (Morawska *et al*., 2008; Xu *et al*., 2011). The UFP levels in the bus terminal were about 6–7 times higher than urban background levels, and these levels approached those near sites of heavy traffic (Beckerman *et al*., 2008; Buonanno *et al*., 2009; Hagler *et al*., 2009; Cheng *et al*., 2010; Cheng and Li, 2011).

Fig. 2 presents temporal fluctuations in average PM_{10}, $PM_{2.5}$, and UFP levels taken at 10-min intervals inside the waiting room and on the platform throughout the monitoring period. Fig. 2 also shows the number of buses entering the bus terminal hourly. Measurement results show that PM levels varied markedly and irregularly during the sampling period, particularly on the platform. The PM levels on the platform rose rapidly after 5:00 and declined after 22:00. Fluctuations in traffic volume were more regular than PM levels. Hourly traffic volume at the bus terminal was 15–170 vehicles/h (mean = 107 vehicles/h), with traffic volumes peaking slightly between 12:00 and 20:00. The lowest traffic volume was during the early hours. Based on measurement results, fluctuations in PM levels on the platform were caused by PM emitted from buses and from natural and mechanical ventilation. However, a positive relationship existed between hourly PM levels and hourly traffic volumes on the platform ($R_{\text{Pearson}} = 0.55$, $p < 0.001$ for PM_{10}; $R_{\text{Pearson}} = 0.54$, $p < 0.001$ for $PM_{2.5}$ and $R_{\text{Pearson}} = 0.61$, $p < 0.001$ for UFP). Measurement results reveal that vehicles generated

Table 1. Hourly average PM_{10}, $PM_{2.5}$ and UFP levels in the waiting room and on the platform.

	Mean[a] (S.D.[b])	Min–Max[c]	Median	Q_1–Q_3[d]
In the waiting room				
PM_{10}, µg/m^3	36.8 (11.2)	17.6–63.4	38.1	27.2–45.8
$PM_{2.5}$, µg/m^3	25.7 (7.7)	12.6–41.4	26.1	18.5–31.9
UFP × 10^4, particles/cm^3	6.4 (1.3)	3.6–9.9	6.4	5.3–7.2
On the platform				
PM_{10}, µg/m^3	69.1 (28.6)	27.3–141.9	66.2	45.9–109.5
$PM_{2.5}$, µg/m^3	51.7 (25.4)	15.3–123.8	49.8	31.3–69.8
UFP × 10^4, particles/cm^3	7.8 (2.2)	2.2–12.6	8.1	6.3–9.6
At the outdoor monitoring station				
PM_{10}, µg/m^3	30.0 (12.9)	13.2–83.5	28.6	22.8–36.4
$PM_{2.5}$, µg/m^3	18.5 (7.2)	6.2–34.8	18.3	12.3–24.8

a: Observation number N = 72; b: Standard deviation; c: Minimal value–maximal value; d: First quartile value–third; quartile value.

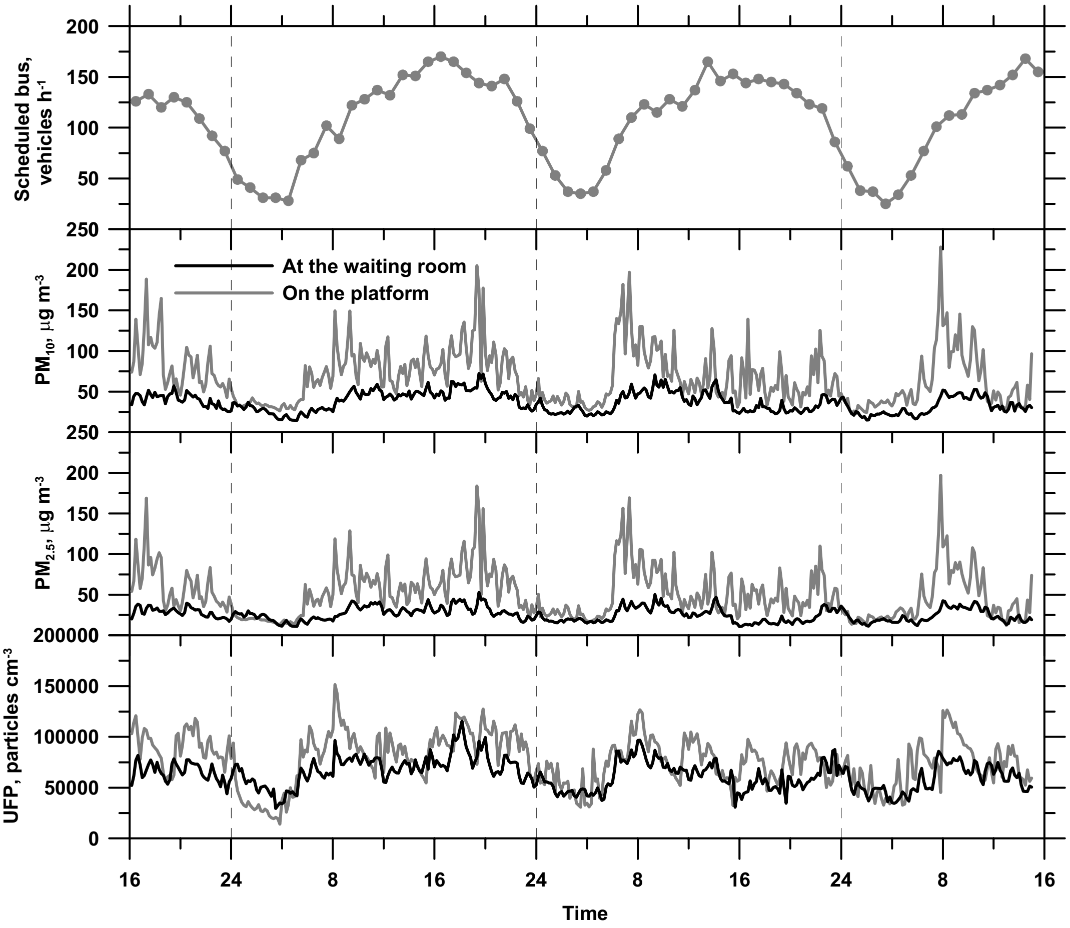

Fig. 2 Temporal fluctuations in traffic volume at the bus terminal, and PM_{10}, $PM_{2.5}$, and UFP levels inside the waiting room and on the platform.

PM directly, and the major PM source on the platform was diesel buses. Additionally, fluctuations in PM levels between the waiting room and platform were similar. A strong positive relationship existed between hourly PM levels on the platform and in the waiting room ($R_{Pearson} \geq 0.75$, $p < 0.001$ for all PM). This PM inside the waiting room can be transferred from platforms through open gate doors that allow passengers to board buses or debus. The UFP levels inside the waiting room were closer than PM_{10} and $PM_{2.5}$ levels to measured levels on the platform, indicating that UFPs are more easily transferred from platforms than fine or coarse PM.

Comparison of $PM_{2.5}$ and UFP Levels at Different Bus Stations

Few studies have investigated PM levels on bus platforms. Table 2 summarizes the mean and range of $PM_{2.5}$ and UFP levels on bus platforms at different bus stations worldwide. Wang *et al.* (2011) compared $PM_{2.5}$ and UFP levels at two bus stations—a "canyon" station (Mater Hill Station) and an "open" station (South Bank Station)—on the South East Busway in Brisbane, Australia. Daily average $PM_{2.5}$ levels at the "canyon" station and "open" station were 4.2 times and 2.5 times higher than those at the reference site, indicating that source contribution was greater than atmospheric dispersion associated with station design. In this study, $PM_{2.5}$ and UFP levels on the platform inside the bus terminal were approximately 2–3 times higher than those acquired by Wang *et al.* (2011) under similar traffic volumes. See *et al.* (2006) determined that average $PM_{2.5}$ and UFP levels were 2.3 and 4.8 times higher, respectively, during operating hours (5:30–0:30) than those during non-operating hours (0:30–5:30) at a major bus interchange in Singapore with an average traffic volume of approximately 300 buses per hour. In this study, average $PM_{2.5}$, and UFP levels on the platform were only 2.6 and 1.7 times higher, respectively, during 6:00–24:00 than those during 00:00–6:00. However, $PM_{2.5}$ and UFP levels during 0:00–6:00 on the platform were approximately 1.1 and 4.6 times higher than those acquired by See *et al.* (2006) during non-operating hours. The $PM_{2.5}$ and UFP levels on the platform during 6:00–24:00 were also 1.3 and 1.6 times higher than those acquired by See *et al.* (2006) during operating hours. A comparison of these measurement results indicates that PM levels in the bus terminal within this semi- confined terminal were significantly higher than those in an open-air bus interchange, even though the traffic volume in this study was only one-third that in the study by See *et al.* (2006). Clearly, PM is trapped and accumulated in semi-confined or completely confined spaces to a greater degree than in an open space.

Table 2. Mean and range of $PM_{2.5}$ and UFP levels on bus platforms for different bus stations.

Monitoring period	Bus volume, vehicles/h	$PM_{2.5}$, μg/m^3	UFP × 10^4, particles/cm^3	Monitoring Environment
Boon Lay bus interchange, Singapore (See et al., 2006)				
Station operating period (05:30–00:30)	300	47.8 (37.2–67.8)	5.3 (1.3–17.0)	At the outdoor unsheltered bus bay
Station non-operating period (00:30–05:30)	–	20.4 (17.7–23.1)	1.1 (0.5 – 8.9)	
South Bank bus station, Brisbane (Wang et al., 2011)				
Fine day	89 (0–179)	32 (11–58)	4.8 (0.5–11.9)	On the sheltered bus platform at an open space
Rainy day		18 (5–44)	4.6 (0.4–10.3)	
Mater Hill bus station, Brisbane (Wang et al., 2011)				
Fine day	86 (0–184)	29 (9–81)	4.7 (0.5–12.7)	On the sheltered bus platform at a semi-open space below street level
Rainy day		22 (5–62)	4.5 (0.5–11.5)	
Taipei bus terminal, Taipei (This work)				
During the day (6:00–24:00)	125 (60–156)	61.2 (24.1–123.8)	8.7 (5.2–12.6)	On the bus platform inside a massive commercial building
At night (00:00–6:00)	49 (30–87)	23.4 (15.3–31.5)	5.1 (2.2–7.8)	

PM Levels and Mass Size Distributions Inside the Waiting Room and on the Platform during Different Shifts

Table 3 compares the hourly average PM_{10}, $PM_{2.5}$ and UFP levels during the three shifts in the waiting room and on the platform. Statistical results demonstrate that PM_{10}, $PM_{2.5}$ and UFP levels were not significantly different between day shift and afternoon shift in the waiting room (all $p \geq 0.080$) and on the platform (all $p \geq 0.379$). Additionally, PM_{10}, $PM_{2.5}$ and UFP levels during both day shift and afternoon shift were significantly higher than those during night shift in the waiting room (all $p \leq 0.003$) and on the platform (all $p \leq 0.002$). Fig. 3 shows the average particle mass size distribution measured inside the waiting room and on the platform during the three shifts. The measured size distribution was fitted with DistFit software. A comparison of the mass size distribution between the waiting room and platform indicates a higher fraction of large coarse PM (> 10 μm) in the waiting room; however, the mass size distribution of fine PM in the waiting room was similar to that on the platform. These results indicate that large coarse PM in the waiting room were re-suspended by the movement of passengers, and fine PM was likely transferred from its source outside the waiting room. However, the levels of fine PM in the waiting room were lower than those on the platform. Measurement results indicate a bimodal particle size distribution with a major accumulation mode of 0.24 μm and a minor coarse mode of 2.93 μm on the platform. Measurement results also showed far less coarse PM in the waiting room than fine PM during night shift compared to day or afternoon shift. The low levels of coarse PM in the waiting room during night shift can be attributed to a decrease in the number of active passengers. Moreover, the fine PM on the platform decreased to a far greater degree than coarse PM during night shift compared to day or afternoon shift. The low levels of fine PM on the platform can be attributed to a decrease in the emissions from diesel buses in the early hours.

Kittelson (1998) noted a particle size distribution similar to that of the current study, showing most diesel exhaust particle was associated with the accumulation mode in 0.1–0.3 μm diameter range. The coarse mode accounted 5–20% of diesel exhaust particle mass. Morawska *et al.* (1999) demonstrated a particle size distribution with a bimodal distribution pattern, showing a dominant mode at about 0.3 μm and a minor mode at about 3.5 μm near the traffic source. Accordingly, the fine and the coarse PM on the platform were primarily attribution to bus emissions and the re-suspension of dust by bus, respectively.

Exposure Implications for Bus Terminal Workers during Different Shifts

Table 4 shows daily PM_{10}, $PM_{2.5}$ and UFP exposure levels for station ticket inspectors during the three shifts. Table 4 also shows amount of time station ticket inspectors spent in the waiting room and on the platform during each shift. Based on field observation results, station ticket inspectors spent approximately 80% and 20% of their working time in the waiting room and on the platform, respectively, during day shift and afternoon shift. Roughly

Table 3. Hourly average PM_{10}, $PM_{2.5}$ and UFP levels in the waiting room and on the platform during the three shifts.

Location	Day shift (8:00－16:00) Mean (S.D.[a])	Day shift (8:00－16:00) Min–Max[b]	Afternoon shift (16:00－24:00) Mean (S.D.)	Afternoon shift (16:00－24:00) Min–Max	Night shift (00:00－8:00) Mean (S.D.)	Night shift (00:00－8:00) Min–Max
In the waiting room						
PM_{10}, μg/m^3	44.1 (7.8)	29.3–59.8	39.5 (10.3)	26.0–63.4	26.9 (7.5)	17.6–48.5
$PM_{2.5}$, μg/m^3	29.9 (6.5)	17.5–41.1	26.5 (7.9)	12.6–41.4	20.8 (5.8)	13.9–35.5
UFP × 10^4, particles/cm^3	6.9 (0.9)	4.6–8.2	6.7 (1.3)	4.7–9.9	5.5 (1.3)	3.6–8.5
On the platform						
PM_{10}, μg/m^3	76.7 (21.3)	36.9–113.2	78.2 (24.3)	43.8–141.9	52.4 (32.3)	27.3–135.8
$PM_{2.5}$, μg/m^3	57.7 (18.3)	24.1–90.8	60.7 (21.9)	31.8–123.8	36.8 (28.7)	15.3–113.0
UFP × 10^4, particles/cm^3	8.4 (1.8)	5.2–12.6	8.9 (1.5)	5.8–11.2	6.1 (2.3)	2.2–10.6

a: Standard deviation, b: Minimal value－maximal value.

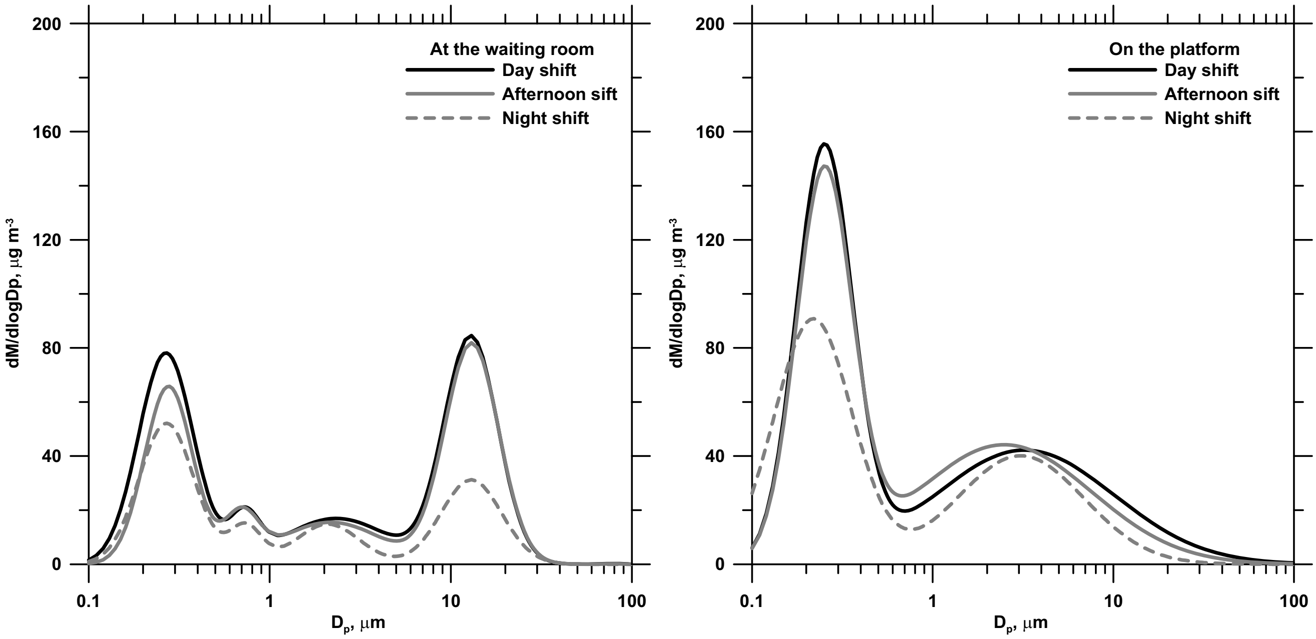

Fig. 3 Average particle mass size distribution measured inside the waiting room and on the platform during the three shifts.

Table 4. Daily PM_{10}, $PM_{2.5}$ and UFP exposure levels for station ticket inspectors during the three shifts.

Work shift	Working time, % In the waiting room	Working time, % On the platform	Daily exposure level PM_{10}, μg/m^3	Daily exposure level $PM_{2.5}$, μg/m^3	Daily exposure level UFP × 10^4, particles/cm^3
Day shift	81.4	18.6	50.3[a] (30.7–69.9)[b]	35.2 (18.8–50.5)	7.2 (4.7–9.0)
Afternoon shift	79.8	20.2	47.2 (29.6–79.1)	33.3 (16.4–57.9)	7.1 (4.9–10.2)
Night shift	85.2	14.8	30.7 (19.1–61.6)	23.2 (14.1–47.1)	5.6 (3.4–8.8)

a: Mean value; b: Minimal value–maximal value.

4–5 buses departed hourly from each platform in the terminal during day shift and afternoon shift. Station ticket inspectors spent most of their time at the boarding gate in the waiting room checking passenger tickets and spent approximately 3 min on the platform for each departing bus. During night shift, only 1–2 buses departed hourly from each platform. Nevertheless, a station ticket inspector handled two platforms during night shift. Therefore, station ticket inspectors spent approximately 85% and 15% of their time in the waiting room and on the platform, respectively. Notably, station ticket inspectors can be exposed to higher PM levels than those assessed because they spent most of their time at the boarding gate, close to the bus platform, and PM can transfer easily from platforms through gates when gate doors are open to allow passengers to board buses or debus.

Chang *et al.* (2010) identified PM_{10} and $PM_{2.5}$ levels of approximately 38.3 μg/m^3 and 26.7 μg/m^3, respectively, during summer in Taipei City. During the sampling period, the PM_{10} and $PM_{2.5}$ levels during daytime (8:00–24:00) were approximately 33.2 μg/m^3 and 21.3 μg/m^3, respectively, and during night time (00:00–8:00) were approximately 23.7 μg/m^3 and 12.9 μg/m^3, respectively, at the Wanhua monitoring station. Compared with atmospheric PM_{10} and $PM_{2.5}$ levels, daily PM_{10} and $PM_{2.5}$ exposure levels for station ticket inspectors were approximately 1.5 and 1.6 times higher than those in the outdoor atmosphere, respectively, during day shift and afternoon shift. During night shift, daily PM_{10} and $PM_{2.5}$ exposure levels for station ticket inspectors were approximately 1.3 and 1.8 times higher than those in the outdoor atmosphere, respectively. Morawska *et al.* (2008) noted that background UFP levels in a typical urban environment were approximately 1.0×10^4 particles/cm^3. Compared with urban background UFP levels, daily UFP exposure levels for station ticket inspectors were approximately 7.2 times higher than those in the urban background during day shift and afternoon shift, and 5.6 times those during night shift. Cheng *et al.* (2010) demonstrated that the UFP exposure level for toll collectors at a highway toll collection booth was approximately 6.5×10^4 particles/cm^3. UFP exposure levels for station ticket inspectors were similar to those for toll collectors. These comparisons indicate that health risk is high for station ticket inspectors working at this indoor bus terminal.

CONCLUSIONS

The Taipei Bus Station is located inside a modern commercial building. Measurement results indicate that PM is trapped in this semi-confined bus terminal. Temporal variations in PM levels in the waiting room and on the platform are strongly correlated with bus traffic volume, indicating that the major PM source in this bus terminal is diesel buses. Daily PM_{10} and $PM_{2.5}$ exposure levels for station ticket inspectors are approximately 1.3–1.5 and 1.6–1.8 times higher than those in the outdoor atmosphere, respectively. Additionally, daily UFP exposure levels for station ticket inspectors are approximately 5.6–7.2 times higher than those in the urban background. Measurement results implicate that health risk caused by PM, particularly by UFPs, is high for station ticket inspectors who work long term at this indoor bus terminal. Therefore, effective control methods, such as advanced filtration, for PM are needed to safeguard the health of station ticket inspectors working in this indoor bus terminal.

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