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Respirable Particle Counts and Concentrations in Public Transportation in Istanbul, Turkey.

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Abstract— **This study aims to determine the in-vehicle and outdoor fine particle ($PM_{2.5}$) concentration and particle number concentration (PNC) for six size ranges (0.3-0.5 µm, >0.5-1.0 µm, >1.0-3.0 µm, >3.0-5.0 µm, >5.0-10 µm, and >10 µm). The measurement campaign was conducted in the morning and evening onboard the Metrobus, red-bus and outdoors. $PM_{2.5}$ concentration in the Metrobus and red bus were observed as 58.8±10.2 µg/m3 and 76.2±30.9 µg/m3 respectively, and the outdoor value was about 2 times more. For both types of public transportation, the ratio of the amount of internal environment PM and the amount of external environment PM displayed a high level of correlation (red-bus/outdoors, R=0.97; Metrobus/outdoors, R=0.88) with the PM size. The number of commuters, vehicle ventilation type and outdoor air entering the vehicles probably caused the differences in in-vehicle particle concentrations.**

Keywords—*public transportation, air quality, $PM_{2.5}$, particle number concentration*

I. Introduction

Transportation often constitutes a major part of daily life, especially in large cities. Public transportation is an important microenvironment for commuters' exposure, as many people spend a certain percentage of their day inside motor vehicles [1]. Time activity pattern studies show that time spent in-transit constitutes roughly 5-10% of the day in cities and roughly 0.8-10% of the day in developing countries [2, 3]. The air pollutant concentrations encountered by commuters are much higher than the concentrations measured at background fixed monitoring stations [4, 5, 6, 7]. Recently, exposure to air pollutants inside motor vehicles has become a subject meriting consideration [8, 9, 10]. Commuters and drivers are exposed to several air pollutants, such as particulate matter, including organic and inorganic aerosols, carbon monoxide, volatile organic compounds, poly aromatic hydrocarbons, black carbon, ozone and nitrogen dioxide. The study at hand was conducted to determine $PM_{2.5}$ and particle number concentrations on different public transport vehicles. The results of this preliminary study will supply fundamental information for further research on exposure onboard public transportation. Furthermore, there are currently no laws regulating indoor air quality in Turkey, and this study can provide references for regulations on indoor air quality management.

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II. Material and Methods

A. *Study Domain*

Home to 16 million, Istanbul is Turkey's most populous city. Its' traffic is very congested, with registered vehicles numbering around 3.5 million [7]. The study area is located in Istanbul's European side between the districts of Avcılar and Bakırköy, which include dense commercial and residential areas. The D-100 highway passes through these areas. Figure 1 shows the traffic routes along the D-100 highway between Avcılar and Bakırköy. In this area, there is massive human density during commute times every day, with daily traffic averaging approximately 100,000 vehicles. The most preferred means of public transportation in this area are metrobuses and buses, therefore the sampling study was carried out for both modes of transport.

Figure 1. The study domain along the D-100 highway (*between the arrows)

The Metrobus is a rapid transit route in Istanbul consisting of a busway comprised by dedicated lanes closed to other traffic. The busway is used by a number of Metrobus lines, which operate within the closed system carrying 800,000 people daily. The Metrobuses are 2007 Mercedes–Benz models with 349–HP engines (Euro 4–5) and air conditioning is used for ventilation. Standard bus transportation is accomplished through red buses that feature old technology, including a pre–Euro model engine and a natural ventilation type. Detailed information about the study area was provided in a previous study [8].

B. *Particulate Matter Measurement*

In this study, particle number concentrations (PNC) were measured using a handheld airborne particle-counting device (Model 3016, Lighthouse, Fremont, USA). The real-time particle counter utilizes a light scattering method and a laser diode optical sensor to detect and count particles in six size ranges (0.3-0.5 µm, >0.5-1.0 µm, >1.0-3.0 µm, >3.0-5.0 µm, >5.0-10 µm, and >10 µm). The instrument's flow rate is 2.83 L/min. Particles with diameters less than 0.3 cannot be detected.

$PM_{2.5}$ (mass of particulate matter in particles 2.5 µm in aerodynamic diameter or less) concentrations were measured using a portable real-time aerosol monitor (pDR 1200 model, Thermo, USA). The flow rate was adjusted to 4 L/min for $PM_{2.5}$ concentration monitoring and the data-logging interval was set at 10 s.

Calibration of the instrument was completed before the field study for particle counting quality assurance. We used a 0.2-micron, 0.1 CFM purge filter. An average of no more than 1 count per one-minute sample was observed. The portable real-time aerosol monitor pDR 1200 was calibrated against a Partisol FRM Air Sampler (Model 2000, Thermo, USA) in the laboratory for quality assurance of the $PM_{2.5}$ measurements. The correlation coefficient (r) between the two methods is 0.99.

The measurement campaign was conducted for 3 days (March 24 and April 3-4, 2009) in the morning and evening onboard the Metrobus, red-bus and outdoors. Inside the vehicle, the measurements were carried out at the same point that is away from the vehicle door and passenger circulation. The particle measurement instruments' sampling heads were positioned in the personal breathing zone, which is usually considered to be within 30 cm of the mouth, during monitoring (Adams et al., 2001). No measurements were conducted on rainy days. Measurements were obtained twice a day, during the morning (08:00–10:30) and the evening (17:00–17:30). Vehicle windows were closed and air conditioning in operation during all of the data collection inside the Metrobus. The air conditioning speed was kept at medium during the study. Inside the red-bus, the windows were open and there was no air conditioning system.

$PM_{2.5}$ concentration and PNC measurements were performed for a period of 15 minutes during morning and evening rush hour periods. The sampling campaign was conducted in March-April. The particle counter recorded the relative humidity and temperature. To ensure a representative sampling in-vehicle during the sampling campaign, we carried out a preliminary field study.

III. Results

This study investigated the particle concentrations both in-vehicle and in outdoor areas. During the sampling periods, humidity was measured between 45-50%, and temperatures measured ranged between 20-24°C.

Figure 2 presents the $PM_{2.5}$ concentration measurement results for the morning and evening periods in the Metrobus, red-bus and outdoors. During the measurement period, no significant change in $PM_{2.5}$ concentrations outdoors was observed. On the other hand, an increase in $PM_{2.5}$ concentrations was observed in the Metrobus and red-bus during the measurement period from the first station to the route's end. For $PM_{2.5}$, a moderate positive correlation was observed during travel in Metrobus and red-bus. The number of passengers increased during the travel period, starting from the first stop. As the Metrobus in particular proceeds along a dedicated route separated from general traffic and thus enables speedier travel, a journey beginning with an average 70 passengers can increase to at least one and half number that by the time the vehicle reaches its last stop. In contrast, the red-buses are lower in preference because they both travel in heavy traffic and have more stops than the Metrobus. The red-bus completes its travel route with fewer passengers compared to the Metrobus.

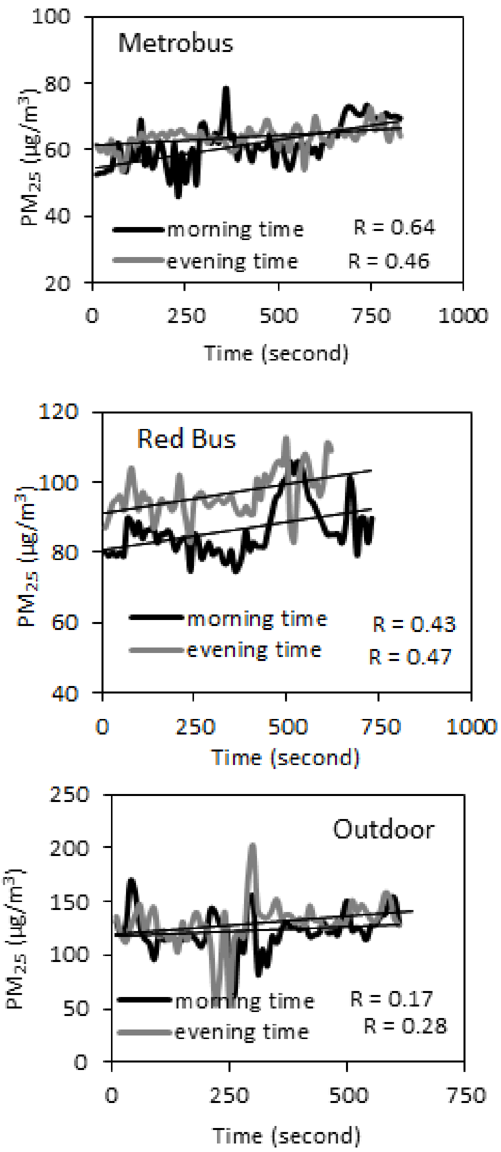

Fig 2. Concentrations of $PM_{2.5}$ in the morning and evening inside the (a) Metrobus (b) red-bus and (c) outdoors during the travel time.

According to the $PM_{2.5}$ results, we did not observe a statistically significant difference between the morning and evening; for this reason, all data were analyzed together. The in-vehicle and outdoor particulate matter concentrations, temperature and relative humidity are summarized in Table 1. While $PM_{2.5}$ concentration in the Metrobus was observed as 58.8±10.2 µg/m3, the red-bus value was 1.5 times more and the outdoor value was about 2 times more.

Table 1: Concentrations of $PM_{2.5}$ (µg/m3), temperature (oC), and relative humidity (RH, %) measured in the Metrobus, red-bus and outdoors.

Airborne sample[a]	Metrobus			Red-bus		
	Mean	*Median*	*SD*	*Mean*	*Median*	*SD*
$PM_{2.5}$	58.8	56.5	10.2	76.2	69.0	30.9
Temperature	22	22	3	23	24	3
Relative Humidity	47	48	5	37	38	8
Airborne sample[a]	Outdoors			I/O[b]		
	Mean	*Median*	*SD*	*M/O*	R/O	
$PM_{2.5}$	99.7	96.0	29.7	0.6	0.8	
Temperature	17	16	3	1.3	1.3	
Relative Humidity	41	40	14	1.1	0.9	

[a]Number of samples: N: 36 for the Metrobus, N: 36 for the red-bus, N: 12 outdoors. The arithmetic mean, median and standard deviation (SD) are presented for all parameters.
[b]I/O: in-vehicle (Metrobus-M or red-bus-R) and outdoor measurements ratio.

The Metrobus is a public transport vehicle equipped with a mechanical air conditioning system delivering continuous internal recirculation independent of the outside environment. The red-bus is a public transport vehicle that travels with windows open at all times and delivers air conditioning via continuous contact with the external environment. Therefore, it was observed that the red-bus contained a $PM_{2.5}$ value close to that of the outdoor environment, while the Metrobus had a value approximately half of the outdoor concentration.

Generally, the previous studies were related to subway that is the common transport type in urban areas. However, it's different in İstanbul, the most preferred public transport types are metrobus and bus. These transport types are of concerned for their risk of droplet transmission of infectious diseases. As in other studies; we observed that the PM2.5 concentrations experienced by commuters are much higher than concentrations measured at fixed monitoring stations [6, 7, 11]. In the previous study carried out in Avcılar-Istanbul, the daily average $PM_{2.5}$ concentration was determined as 39 µg/m3 at the fixed monitoring station [12]. In Turkey, a $PM_{2.5}$ limit has not yet been specified. However, we observed that the $PM_{2.5}$ levels measured in the Metrobus, red-bus and outdoors were higher than the ambient air $PM_{2.5}$ standard declared by the United States Environmental Protection Agency (US-EPA), defined as 35 mg/m^3 for a 24-h arithmetic mean.

In this study, PNC were also measured in six size ranges (0.3-0.5 µm, >0.5-1.0 µm, >1.0-3.0 µm, >3.0-5.0 µm, >5.0-10 µm, and >10 µm). Figure 3 displays the ratios of the count results according to the 6 different particle size inside the Metrobus and red-bus to the measurements conducted outdoors. The amount of PM smaller than 3 µm in the Metrobus was approximately one-half that of the outdoors. The PNC in the 3-10 µm size range in the Metrobus was similar to that of the external environments. The PNC bigger than 10 µm in the Metrobus was measured as 1.5 times higher than outdoors. While PNC smaller than 1 µm in the red-bus was similar to the external environment, the PNC bigger than 1 µm was measured as 1.3-1.9 times higher than the outdoor environment. Ventilation was accomplished through an air conditioning system in the Metrobus, but by the natural method of opening windows in the red-bus. In the Metrobus system, the vehicle stops very near the platform where passenger drop-off and pick-up is carried out. Therefore, the coarse street dust raised during passenger boarding may be carried along inside the Metrobus. For both types of public transportation, the ratio of the amount of internal environment PNC to the amount of external environment PNC displayed a high level of correlation (red-bus/outdoors, R=0.97; Metrobus/outdoors, R=0.88) with the particle size. Any passenger traveling in the red-bus was being exposed to more outdoor environment-related particle pollution than a passenger traveling in the Metrobus.

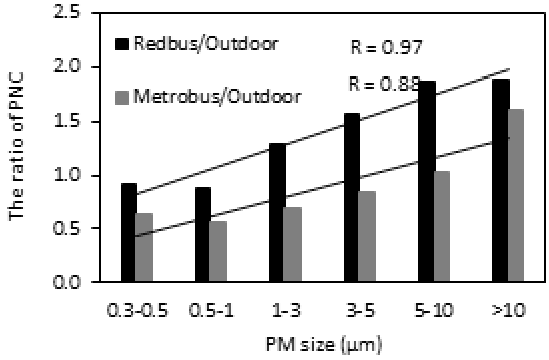

Figure 3: The ratio of PNC in the Metrobus and red-bus to the Outdoors.

IV. Conclusion

This study determined the PNC and $PM_{2.5}$ concentrations onboard vehicles of public transportation in Istanbul. The study showed that the differences in in-vehicle PM concentrations between the Metrobus and red-bus were probably caused by the vehicle ventilation type, passenger number and outdoor air entering the vehicles. The results of this study provide basic information for further research on exposure assessment. Furthermore, due to the variability of particle with environmental conditions in-vehicle is recommended to consider the factors (such as ventilation, seasonal differences, etc.) in detail.

Acknowledgment (Heading 5)

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