INDOOR/OUTDOOR PARTICLE NUMBER CONCENTRATIONS UNDER CONDITIONS OF VEHICLES AND METEOROLOGY

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ABSTRACT

The intermittent particle concentration measurements were conducted in an apartment including three bedrooms on the fourth floor of a building 50-m away from the center of a busy road. There were no people and pet living in the study apartment during study periods. Two bedrooms were chosen for this study. One room (R1) has a window directly facing the road. Another room (R2) has a window facing the street directly through a space of about 1 m. Number concentration and size distributions of particles (15.7-661 nm) were determined by using a system of TSI Scanning Mobility Particle Sizer. Larger particles were determined by using a TSI Aerodynamic Particle Sizer model 3321 (0.5-20 µm). The study results showed that traffic volume, wind speed and direction were key factors affecting outdoor and indoor pollutant number concentrations. The average outdoor, R1 and R2 particle number concentrations were 19322, 7785, 1967 particles/cm^3, respectively for particles of 15.7-661 nm and 288, 132, 33 respectively for particles of 0.5-20 µm. Peak indoor and outdoor particle number concentrations occurred as high traffic volume and the apartment located downwind as well as under calm wind conditions. Indoor/outdoor particle number concentration-based ratios of particles ranging sizes of 15.7-661 nm and 0.5-20 µm are 0.70±0.30 and 0.84±0.28, respectively at R1 and those were 0.14±0.05 and 0.15±0.05, respectively at R2. The bedroom with the window not facing the road directly was less affected than the bedroom with the window facing the road.

Key words: *Apartment, Indoor/outdoor particle concentration, Meteorology, Vehicle*.

TÓM TẮT

Nghiên cứu sự biến đổi nồng độ hạt bụi được thực hiện trong một căn hộ gồm ba phòng ngủ nằm trên tầng 4 của một toàn nhà cách đường giao thông khoảng 50 m. Không có người và gia súc sống trong căn hộ này. Hai phòng ngủ được chọn để thực hiện nghiên cứu này, Một phòng ngủ (R1) có cửa sổ đối diện trực tiếp với nguồn. Một phòng khác (R2) có cửa sổ hướng ra đường thông qua một khoảng không khoảng 1 m. Nồng độ theo số hạt từ 15,7 – 661 nm và 0,5 – 20 µm được đo bằng máy đo hạt TSI. Kết quả nghiên cứu thể hiện rằng lưu lượng giao thông, hướng gió và tốc độ gió là các tác nhân quan trọng ảnh hưởng nồng độ hạt bụi trong và ngoài nhà. Nồng độ hạt bụi trung bình của môi trường xung quanh, R1, R2 lần lượt là 19322, 7785, 1967 hạt/cm^3 đối với hạt có kích thước 15,7-661 nm và 288, 132, 33 hạt/cm^3 đối với hạt có kích thước 0,5-20 µm. Nồng độ hạt bụi đạt cực đại khi lượng xe tăng cao, khi căn hộ nằm dưới gió và khi đứng gió. Tỷ lệ nồng độ hạt bụi trong nhà (R1) và ngoài nhà là 0,70±0,30 (hạt bụi 15,7-661 nm) và 0,84±0,28 (hạt bụi 0,5-20 µm). Tỷ lệ nồng độ hạt bụi trong nhà (R2) và ngoài nhà là 0,14±0,05 (hạt bụi 15,7-661 nm) và 0,15±0,05 (hạt bụi 0,5-20 µm). Như vậy, phòng ngủ có cửa sổ hướng trực tiếp ra đường bị ô nhiễm hơn phòng ngủ có cửa sổ hướng gián tiếp ra đường.

Từ khoá: *Căn hộ, Nồng độ hạt bụi trong nhà, Nồng độ hạt bụi ngoài nhà, Khí tượng, Xe cộ.*

INTRODUCTION

Vehicle emissions are comprised of pollutants in gaseous and particle forms, which are complex in chemistry, and contain many compounds. The main gaseous pollutant emissions include hydrocarbon, CO, NO_x and SO_2. The primary particulate matter emitted from the sources into the air in solid or liquid form often includes aggregates of ultrafine particles with respect to urban areas and highly used traffic routes. Atmospheric particles originating from vehicle emissions vary and depend on the type of fuel on which the vehicle operates, its specific composition and other characteristics, as well as lubricating oil used and its composition. There are thus differences between particles originating from diesel and petrol vehicles. Particle number size distributions generated from combustion sources include vehicles operating on diesel and petrol. Most of the particle number emitted by diesel and petrol engines have the size ranging from 10 nm to 100 nm (Morawska et al., 1998; Ristovski et al., 1998). Particles from compressed natural gas emissions are smaller than from diesel and petrol emissions and range from 10 nm to 70 nm (Ristovski et al., 2000).

Diesel engines are a major source of particulate matter. The composition varies depending on engine type, operating conditions, fuel and lubricating oil composition and whether an emission control system is present. Particles emitted from petrol vehicles are mostly carbonaceous spherical submicrometre agglomerates consisting of a carbon core with various associated organic compounds. The main components of the particle phase include soot and ash which consist of trace elements such as lead, iron, chlorine, organic compounds, and a low-to-medium boiling fraction of engine oil (Zinbo, 1995). Light-duty vehicle particle emission spectra contained Na^+ and K^+. Total particle number concentration is related directly to traffic density and decreases significantly during a traffic slowdown (Zhu et al., 2002b). Different speeds of vehicles affect particle number concentrations emitted. The faster the vehicle speeds, the higher particle number concentration emitted from liquid petroleum gas and diesel vehicles. Particle number concentration emitted from petrol vehicles, however, is lower. The major contributors to the primary particles are on-road vehicles.

Recent studies provided a unique opportunity to evaluate pollutant contributions of vehicle exhaust to indoor environments. In the absence of known indoor aerosol sources, the indoor/outdoor ratios are mostly related to aerosol particle size distributions determined under meteorological conditions, distance from source, effects of temperature, and ventilation conditions. Wind speed and direction are important in determining the number of ultrafine particles near the roads. The stronger the wind, the lower the total particle number concentration (Zhu et al., 2002). Lower nighttime temperatures may also result in higher emission factors for particle numbers (Kittelson, 1998). Higher particle number concentrations during the night may be at lower wind speeds and a lower atmospheric mixing height, thus weaker atmospheric dilution effects (Zhu et al., 2005). A study showed that both atmospheric dispersion and coagulation contributed to the rapid decrease in particle number concentration and change in particle size distribution with increasing distance from the freeway (Zhu et al., 2002). Particle number concentration decreased to approximately 50% its original value at somewhere between 100 and 150 m (Hitchins et al., 2000; Zhu et al., 2002).

The objective of this study was to determine effects of traffic volume, meteorological conditions on indoor and outdoor particle number concentrations and calculate indoor and outdoor particle number concentration ratios.

EXPERIMENT

The intermittent particle concentration measurements were conducted in an apartment on the fourth floor of a building 50-m away from the center of a busy road that has three bedrooms (14 m^2/room) in which two bedrooms were used for monitoring. The main road included a 4-lane highway and 6-lane ground road. The experiment site was in Seoul, Korea. A monitoring site (R1) was in a bedroom with a window directly facing the road. A reference site (R2) was in another bedroom with a window facing the road but through a small space (1 m). The apartment windows were elevated higher than the highway. The apartment chosen for monitoring meteorological parameters was monitored at top of this building. The heights of measurement locations, ground road and highway are shown in Figure 1.

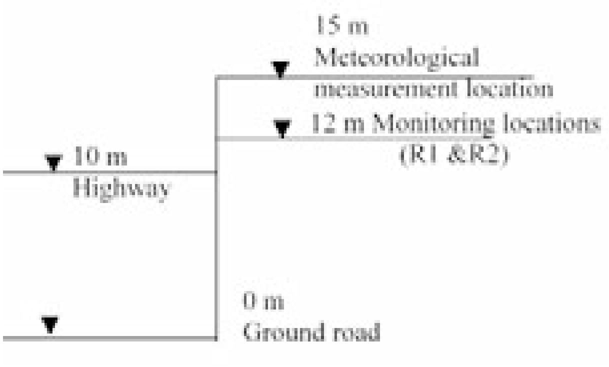

Figure 1. The heights of measurement locations, ground road and highway

No ventilation was applied for all study sites during monitoring periods. Study locations are bordered by many low houses along the ground road. The back of the monitoring locations is a tree hill, so air quality of the study area was considered not to be affected by other roads. The apartment has been used for 5 years. It means that concentrations of airborne volatile organic compounds originating from the construction materials are generally very low (Järnström et al., 2006). There were no people or animal living in the monitoring apartment during study periods of four weeks. Generally, the experimental studies were conducted without known indoor pollution sources. The apartment was visited at around 9:00 p.m. to 9:30 p.m. to check instruments, flow and download data. Indoor environment of the apartment is affected by vehicle exhaust from the road with wind from south-western (225 - 360^o) to north-eastern (0 – 45^o) direction at which the apartment is located downwind.

Number concentration and size distributions of particles (15.7-661 nm) were determined by using a system of Scanning Mobility Particle Sizer (SMPS, TSI). The system was a TSI SMPS 3936 combined with a TSI Long Differential Mobility Analyzer model 3081 and a TSI Condensation Particle Counter model 3025A (15.1-661 nm). Larger particles were determined by using a TSI Aerodynamic Particle Sizer model 3321 (0.5-20 µm) and a Portable Aerosol Spectrometer model 1.109 (0.25-30 µm) of GRIMM Aerosol Technik GmbH & Co. KG. All instruments used to measure particles were operated with 2-minute scanning time at 5-minute interval time. Indoor temperature and humidity were measured by using a temperature and humidity meter model SK-L200TH II of SATO Keiryoki MFG. Co. Ltd with a 5-minute time resolution. All instruments, at 1.5-m sampling inlet high, were put at the center of the bedrooms at which it is assumed that indoor air environments are well-mix condition. Outdoor particle number concentrations were measured by another TSI system as the same instruments measuring indoor particle number concentrations. The outdoor measurement instruments were put at the balcony (facing the road) of this floor. Meteorological data (wind direction and speed, humidity, and temperature) was measured by using a Wind Monitor, model 05106 of R. M. Young Company and a CR10X Measurement and Control Module Operator of Campbell Scientific Inc. with 1-minute interval time during monitoring periods. A digital camera was also used for monitoring traffic volume and jam.

RESULTS AND DISCUSSION

Effect of traffic volume

Average traffic volume of about 160,000 vehicles per day pass these locations from Monday to Saturday, and about 130,000 vehicles/Sunday. Variation of traffic volume was nearly unchanged for every week as shown in Figure 2. Traffic jam sometimes occurred on the highway. Most vehicles passing this area were 4- and 7-seat cars. Heavy-duty vehicles, mostly buses and construction trucks, took 3.5% from 6 a.m. to 11 p.m. and 0.9% for remaining time. Average speeds of vehicles passing this area on the highway and the ground road were 72 and 42 km/hr, respectively. Quantity of vehicles on the ground road was 37±6% of total traffic volume. Vehicles that used gasoline, diesel, and LPG were 60%, 27% and 12.5%, respectively (MOCIE, 2004).

Figure 2 clearly shows that increasing and decreasing trend in outdoor and indoor concentrations were closely related to traffic volume. Peak indoor and outdoor particle number concentrations occurred during the traffic rush hours as well as traffic jam time on the road, especially on the highway. Variations of outdoor and indoor particle number concentrations were following a similar trend with concentrations increased at morning traffic rush hours (7-9 a.m.) and evening rush hours (7-10 p.m.). The lowest concentrations occurred in early morning at about 3-5 a.m. when traffic volume was also the lowest.

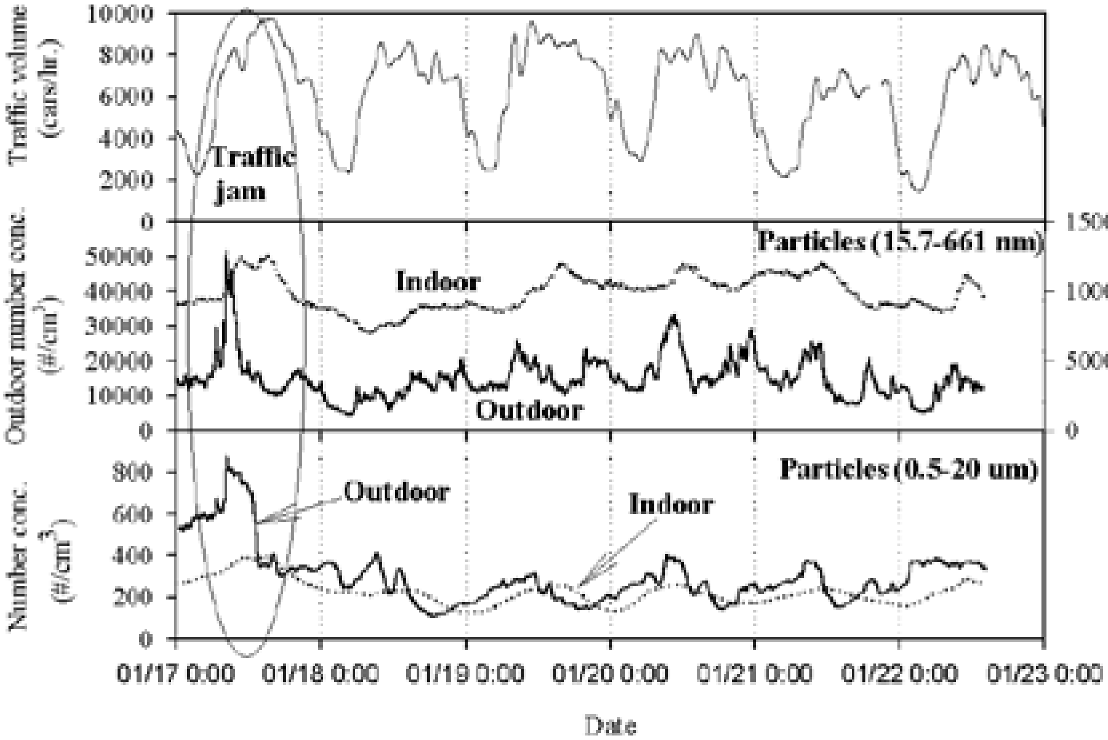

Figure 2. Variations of outdoor and R1 indoor particle number concentrations

Effects of wind speed and direction

Figure 3 shows that the increasing and decreasing in trend outdoor and indoor particle number concentrations were closely related to wind direction and speed. Outdoor and indoor peak particle number concentrations occurred when the apartment was located downwind from the road as well as in calm wind conditions. For example, outdoor particle number concentrations for all sizes studied increased very quickly under calm wind condition and high traffic volume. Also, particle number concentration increased when the apartment was located downwind on this day. Particle number concentration increased in calm wind condition with traffic jam during the time from 9 to 12 p.m. When the apartment was located downwind, it was observed that the stronger wind carried higher indoor particle number concentrations. This meant that penetration of outdoor particles increased during these periods. In contrast, when the apartment was located upwind, the stronger wind carried lower outdoor pollutant concentrations. However, indoor particle number concentrations did not decrease quickly as outdoor concentrations. Outdoor particle number concentrations decreased very quickly when the apartment was located downwind in strong wind condition although traffic volume was not changed. These results are in good agreement with previous studies (Zhu et al., 2005; Hasegawa et al., 2004). However, indoor pollutant concentrations did not decrease quickly as outdoor concentrations.

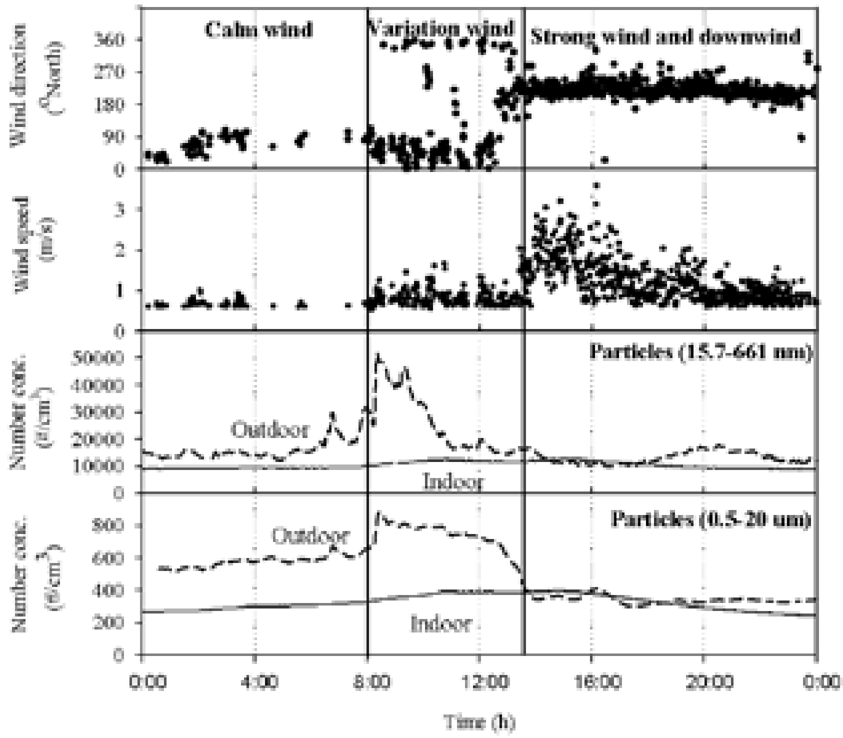

Figure 3. Variations of outdoor and R1 indoor particle number concentrations

Increasing and decreasing trends in outdoor particle size distribution were mostly observed for particles in sizes of 15.7-200 nm, especially on ultrafine particles as presented in Figure 4. Size distributions of ultrafine particles increased quickly at 8-9 a.m when traffic volume increased, as compared with particle size distributions at 3-4 a.m. Size distribution of ultrafine particles decreased quickly because wind direction changed even though traffic volume was unchanged. The result of study is in good agreement with the result of Charron and Harrison (2004), but not consistent with the result of Janhäll et al. (2004).

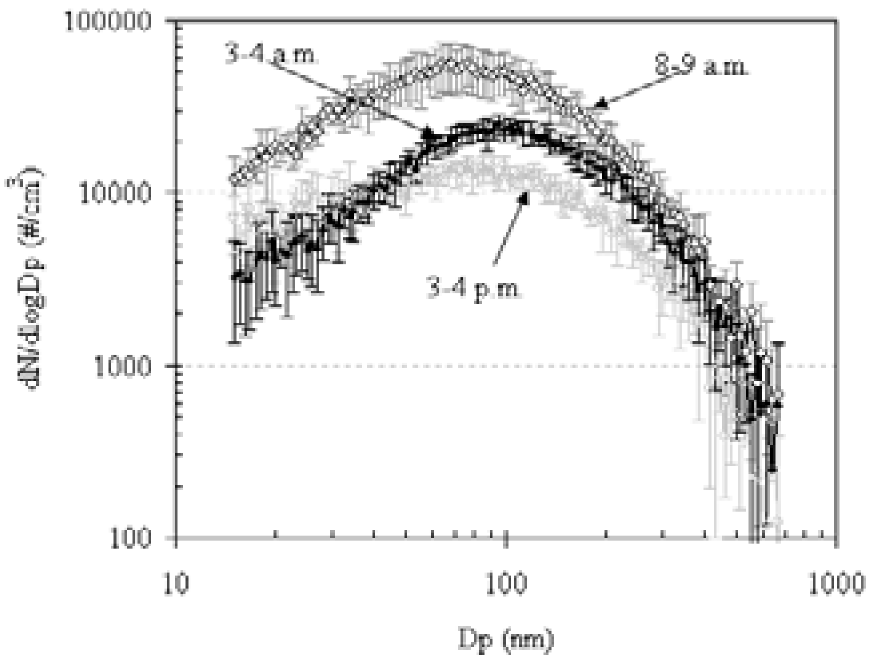

Figure 4. Average outdoor particle size distributions at 3-4 am, 8-9 am, and 3-4 pm

Table 1 shows averaged outdoor and indoor pollutant concentrations during monitoring periods. Averaged outdoor particle number concentration was higher than R1 indoor particle number concentrations which was higher than those in R2 indoor. Based on standard deviation, variation of concentrations at R1 indoor was greater than that in R2 indoor. It was concluded that the room with the window looking forward the road is more influenced by outdoor pollutants than the other. A small buffering space extended for the room R2 substantially reduced indoor particle concentration.

Table 1. Summary of pollutant concentrations during monitoring periods

Pollutants	Locations		
	Outdoor	R1 indoor	R2 indoor
Particles (15.7-661 nm) (particles/cm^3)	19,322±4,649	7,785±531	1,967±133
Particles (0.5-20 µm) (particles/cm^3)	288±33	132±18	33±5

Effects of temperature and humidity

Outdoor average values of temperature (0-8^{o}C) and relative humidity (50-70%) measured during monitoring periods were low. Indoor temperature (20^{o}C) and relative humidity (40%) were stable. A study reported that aerosol optical properties increased from 1.2–3.2 times with increasing relative humidity from 70 to 95% as compared with at 50% of relative humidity (Yoona et al., 2006). Temperature correlated negatively with the smaller particles (10-60 nm) (Janhäll et al., 2004). Figure 5 presents outdoor particle concentration variations temperature and relative humidity variations under temperature and relative humidity conditions. Temperature variation was opposite to relative humidity variation. When temperature decreased, relative humidity increased; and in contrast, temperature increased when relative humidity decreased. Temperature is the lowest at 6-8 am at which relative humidity was the highest. Variation of particle number concentration was not following trends of temperature and humidity. Thus, it is concluded that the relationship between pollutant concentrations and temperature and relative humidity was not found out in this study.

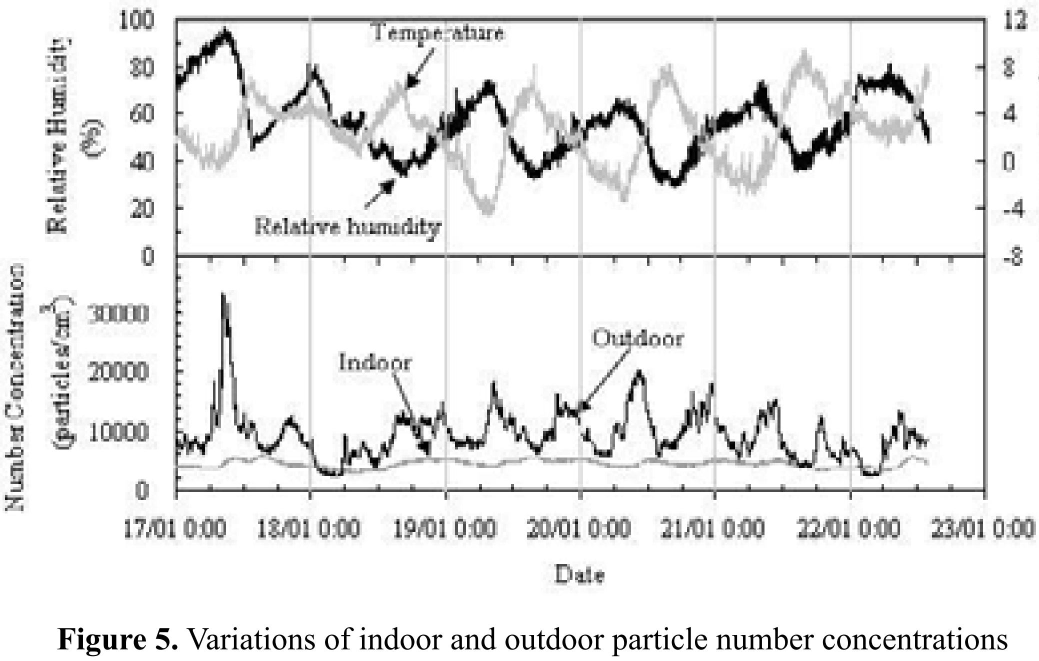

Figure 5. Variations of indoor and outdoor particle number concentrations and outdoor temperature and humidity

Indoor and outdoor particle number concentration ratio

Penetration of particles into the apartment was dependent on particle sizes. Indoor/outdoor (I/O) particle number concentration-based ratios of particles ranging sizes of 15.7-661 nm and 0.5-20 µm are 0.70±0.30 and 0.84±0.28, respectively at R1. In some special cases, ratios of all study particle sizes were higher than 1.0. I/O ratio of ultrafine particles higher than 1.0 occurred in the early morning. This higher I/O ratio of larger particles (0.5-20 µm) mostly occurred in the afternoon. Indoor/indoor (R2/R1) ratios of number concentration-based particles ranging in sizes of 15.7-661 nm and 0.5-20 µm were 0.18±0.04 and 0.19±0.03, respectively. This showed that penetration of all study particle sizes into two bedrooms was very stable. The result obviously presented that pollution of particles in the bedroom with the window facing the road was much higher those of the bedroom with the window not facing the road. Results of I/O ratios (for R1) and R2/R1 indoor ratios were used to calculate I/O ratios (for R2) by multiplying R1 I/O ratios. I/O ratios of number concentration-based particles ranging in sizes of 15.7-661 nm and 0.5-20 µm were 0.14±0.05 and 0.15±0.05, respectively at R2.

CONCLUSION

The bedroom with the window not facing the road directly was less affected than the bedroom with the window facing the road. Outdoor and indoor pollutant number concentrations were affected by traffic volume, wind speed and wind direction. Peak indoor and outdoor particle number concentrations occurred as high traffic volume and the apartment located downwind as well as under calm wind conditions. When the apartment was located upwind, outdoor particle number concentrations were sometimes lower than those indoor under the low traffic volume conditions. In the absence of known indoor pollution sources, indoor air environment was affected by outdoor air. However, outdoor pollutant concentrations are not always higher than indoor pollutant concentrations as the building located upwind.

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