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Characteristics of Heavy Metal Concentrations and Indoor Atmospheric Environments in Busan Metropolitan Area, Korea

Jong-Kil Park[1], Yoo-Kuen Kim[2], Hwa-Woon Lee[2], Nan-Sim Jang[2] and Moon-Ki Park[3]

[1]*School of Environmental Science Engineering, Inje Unversity, Gimhae, 621-749, Korea*
[2]*Department of Atmospheric Science, Pusan National University, Busan, 609-735, Korea*
[3]*Department of Environmental Science, Kyungsan University, Kyungsan, Kyungpook, 712-240, Korea*

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The current paper describes the indoor/outdoor air quality in school environments through analyses of the heavy metal concentrations using Inductive Coupled Plasma(ICP). School environments in a heavy traffic area, two industrial areas, quasi-industrial area, and residential area were evaluated.

The results were as follows:

(1) The locations with the highest indoor and outdoor concentrations of heavy metals were the industrial areas followed by the heavy traffic area, residential area, and quasi-industrial area in a descending order of magnitude. Plus, the indoor heavy metal concentrations were higher than the outdoor ones.

(2) The main heavy metal components were Zn, Al, and Ca. Higher concentration levels were found indoors than outdoors. The heavy metal concentrations were also higher in the classrooms than in the corridor or outdoors.

(3) The total heavy metal concentrations in the studied areas were highly dependent on the weather elements, including the relative humidity, mixing ratio, and wet-bulb depression. Accordingly, special ventilation systems are recommended to reduce air pollution in school environments.

Key words : indoor-outdoor air quality, school environment, heavy metals

1. Introduction

Indoor air pollution has various sources, such as the combustion of fossil fuels for heating and cooking, as well as interior decoration and furnishing. Most indoor air pollution, including that of a school environment, depends on the air volume and air quality in the buildings, along with the ventilation ratio and outdoor air quality, especially the indoor/outdoors meteorological conditions[1)]. In a study on the health effects of indoor air quality on large building office workers, Lee *et al.*[2)] found that, in offices with more than 10 people per 100 m^2, forced air ventilation was needed to exchange and clean the air in the office. In particular, the degree of discomfort for indoor air quality is high on a hot afternoon or cloudy day. Consequently, it has already been established that weather conditions and the type and rate of ventilation have a significant influence on indoor air quality.

Since 1970, numerous studies on indoor air pollution have been conducted in Europe and America[3~5)], yet recognition of the importance of indoor air pollution is still lacking in Korea. Only a few studies on suspended particles have been performed in areas such as swimming pools and underground shopping centers[6~8)].

In one previous study, the heavy metal concentration levels in urban school environments were

Corresponding author ; Jong-Kil Park, School of Environmental Science Engineering, Inje Unversity, Gimhae, 621-749, Korea
Phone : +82-55-320-3250
E-mail : envpjk@inje.ac.kr

measured by sampling and analyzing the suspended particulate matter in the indoor and outdoor ambient air of middle school classrooms in Kangseoku and Yangchonku in Seoul, Korea[9]. The concentrations of Cd, Cu, and Pb were found to be the highest in the special education classrooms, followed by the regular classrooms, and finally the outdoors. The indoor particulate matter levels concentrated in the closed indoor spaces were considered to be largely influenced by other outdoor sources, although the sampling times differed due to the analysis of sedimented particulate matter. Park *et al.*[10] also indicated that indoor heavy metal concentrations are equal or higher than outdoor concentrations, regardless of the air sampling site. As such, indoor air pollution is a very serious issue.

Accordingly, the objective of the current study was to determine the characteristics of heavy metal concentrations in relation to indoor atmospheric environments. Schools were selected in different areas(heavy traffic area, residence area, quasi-industrial area, and industrial area) without any apparent heavy metal sources. The effect of weather conditions on the heavy metal concentrations in the indoor/outdoor air in the school environments was also studied. Finally, some proposals are made to improve the air quality in school environments.

2. Methodology And Measurements

2.1 Description of Measurements

Suspended particulate matter sampling was used to measure the heavy metal concentrations. Meteorological observations were made to determine the indoor/outdoor atmospheric conditions of the school environments. The sites investigated are shown in Figure 1.

Within the Busan metropolitan area, the schools selected from an industrial area were Jangrim Elementary School(industrial area I, IA-I) in the Jangrim industrial complex and Hakjang Elementary School(industrial area II, IA-II) in the Hakjang industrial complex, the school selected from a quasi-industrial area(Quasi-IA) was Samlak Elementary School in Samlak-dong, the school selected from a traffic area(TA) was Seo Girls High School near a road with more than six lanes, and the school selected from a residential area(RA) was Bakyang Middle School in Manduck-dong,

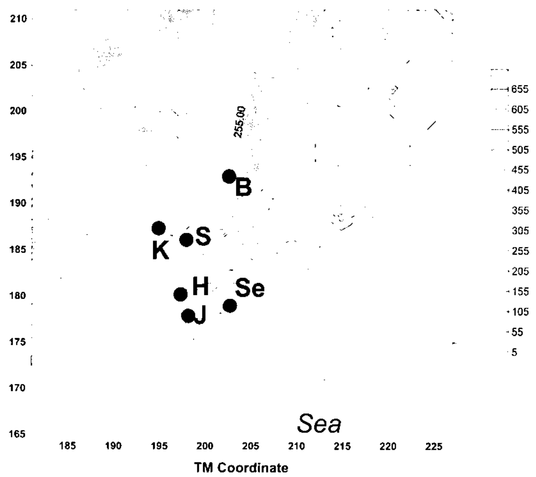


Fig. 1. Locations of air sampling sites. The letters J and H represent Jangrim and Hakjang Elementary School, respectively(industrial area), S represents Samlak Elementary School (quasi-industrial area), Se represents Seo Girl's High School(heavy traffic area), and B represents Baekyang Middle School (residential area).

a densely built-up area. The indoor observation sites were all located in the middle of the first-floor corridor, while the outdoor observation sites were located in the backyard of the schools.

As an index of the indoor atmospheric environment, the dry and wet bulb temperatures were measured using an Asmann thermo-hygrometer at the indoor and outdoor observations sites every Saturday in May, 1994. The observation time interval was 10 minute. Daily meteorological data collected at Gimhae airport, near Busan, was also used to confirm the meteorological data observed at the selected sites.

The indoor/outdoor heavy metal concentrations were measured using a Personal Air Sampler (Gillian Corporation, U.S.A.) with a flow rate of 2 *l*/min and sampling time of 90 minutes. The membrane filter(Millipore Corporation, U.S.A.) was 37 mm in diameter with a 0.8 μm pore size. Before sampling, the filter was dried for 24 hours in a dry-oven and then weighed. The air monitoring cassette(AMC) was constructed on the membrane pad. To prevent breakage of the membrane filter the AMC was covered with a para film, as shown in Figure 2. The suspended particulate matter sampling and meteorological measurements were conducted at the same sites at a height of 1.5 m. All the school windows were closed to obtain distinct differences between the indoor and outdoor air quality measurements. There was no forced ventilation.

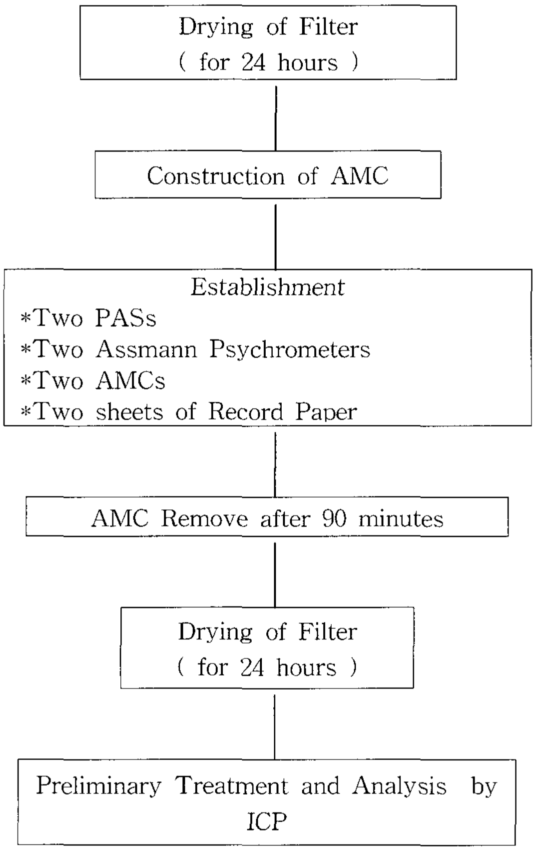


Fig. 2. Process of suspended particulate matter sampling and chemical analysis.

2.2 Methodology

The physical characteristics of the indoor air were determined based on the dry and wet bulb temperature calculated as follows. The Gott-Gratch equation[11] is:

$$\log_{10}E_w = -7.90298(T_s/T-1) + 5.02808\log_{10}(T_s/T) - 1.3816\times 10^{-7}(10^{11.344(1-T/T_s)}-1) + 8.1328\times 10^{-3}(10^{-3.19149(T_s/T-1)}-1) + \log_{10}E_{ws} \quad (1)$$

Using equation (1), the saturation vapor pressure(E_w, mb) is obtained, where T_s is the boiling point(373.16 K), T is the air temperature(℃), and E_{ws} is the vapor pressure of pure water at 1013.25 mb, 373.16 K[11]. The saturation mixing ratio(W_s) and mixing ratio(W) are obtained using equation (2):

$$Ws = 0.622\times(Ew/P-Ew)$$
$$W = Ws\times RH/100 \quad (2)$$

where the air pressure at sampling site P is 1013 mb, due to no difference when compared to the reference site(Gimhae airport).

The heavy metal analysis of the sampled suspended particulate matter was performed using Inductive Coupled Plasma(ICP), after a preliminary treatment, as shown Figure 3. The focus of the analysis was Cd, Zn, Pb, Cr, Ni, Al, Ca, and Mg. The analysis results were then used to investigate the characteristics of the indoor/outdoor heavy metal concentration distribution between the sites

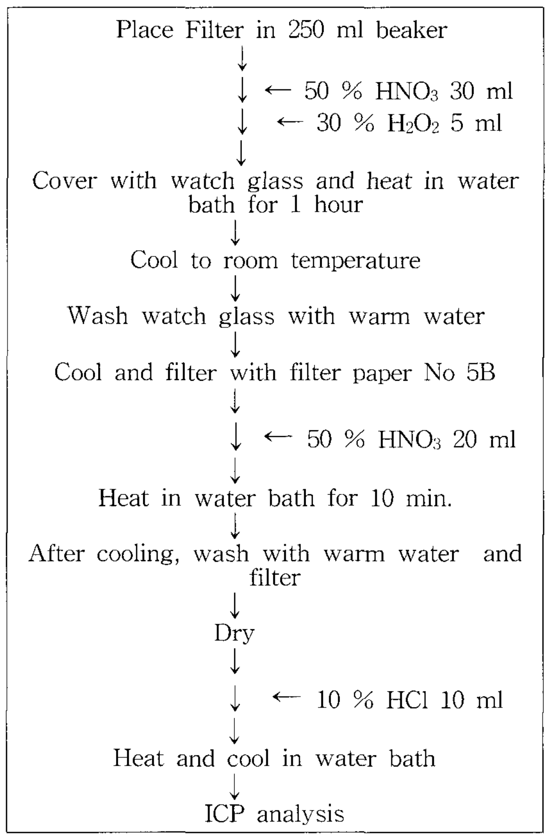


Fig. 3. Preliminary treatment for chemical analysis by ICP.

and the relationship between the weather conditions and the heavy metal concentrations.

3. Results And Discussion

3.1 Heavy metal concentration at each site

Figure 4 shows the concentrations of suspended particulate matter at each site. The area with the highest concentration of heavy metals was industrial area I followed by industrial area II, then the traffic area, residential area, and quasi-industrial area in a descending order of magnitude. In summary, the concentrations in the industrial area were high, yet the concentrations in the quasi-industrial area were lower than those in the traffic and residential areas. One reason for this may have been that a few years earlier, some of the factories in the quasi-industrial area were relocated elsewhere.

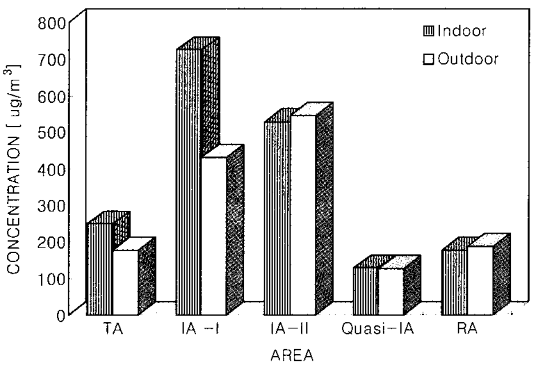
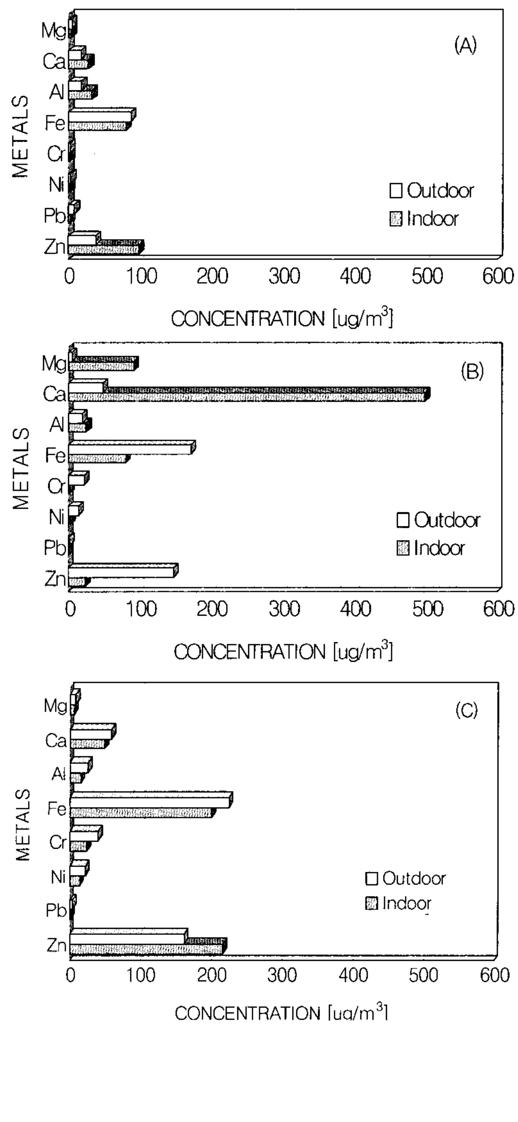


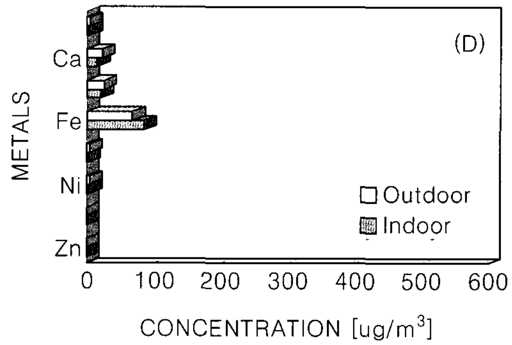
Fig. 4. Indoor and outdoor average concentration of total particulate matter in test areas during observation period.

The concentration of particles in the traffic area was lower than that of the industrial area yet higher than that of the other sites because more suspended particulate matter produced by the combustion of fossil fuels and mechanical turbulence due to motors was sampled. The indoor heavy metal concentrations were also found to be higher than the outdoor concentrations.

Figure 5 shows the concentrations of the heavy metal components detected at each site, i.e. Fe, Al, Ca, Mg, Zn, Pb, Ni, and Cr. At all sites, the concentrations of Fe, Zn, and Ca were high, while the concentrations of Al and Mg were a slightly high. Pb, Ni, and Cr, which are all very toxic to the human body in small amounts, were not detected or only detected in traces. In the case of the traffic area, the concentrations of Fe and Zn were very high, those of Al and Ca were slightly high, and that of Pb was only a trace, yet higher than at the other sites.

The concentration of Ca was much higher at IA-I than at the other sites, while the concentrations of Fe, Zn, and Mg were slightly high. It is possible that the high levels of Ca detected at IA-I were due to the extra activity of the pupils rather than industrial sources, as the indoor concentrations of Ca were higher than the outdoor readings. The concentrations of Fe and Zn were distinctly higher in industrial area II than at the other sites, and





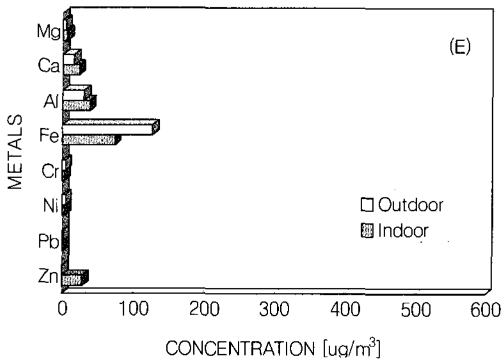


Fig. 5. Indoor-outdoor concentrations of heavy metals observed at A) heavy traffic area, B) industrial area I, C) industrial area II, D) quasi-industrial area, and E) residential area.

the second highest concentration component was Ca. Cr and Ni were also detected in very small amounts, yet not at the other sites. This was possibly because this area is a casting manufacturing district and has many iron and zinc factories.

In quasi-IA, since many factories had been relocated elsewhere, the heavy metal concentrations were distinctly lower and similar to the levels found in the residential area, The concentrations of Fe, Al, and Ca were somewhat high, yet no Pb, Ni, or Cr was detected.

3.2 Indoor/outdoor heavy metal concentrations

Table 1 shows the ratios of the indoor and outdoor concentrations, referred to as the I/Os, and this section summarizes these ratio results. The value of the I/O was different at each site and for each kind of heavy metal. The I/O was higher for Zn, Al, and Ca than for the other components. At each site, the indoor heavy metal concentrations were much higher than the outdoor measurements. Alonza *et al.*[12] conducted tests with all windows and doors kept closed and with no forced ventilation, conditions similar to those used in the current study. Their I/O values were 0.10, 0.24, 0.41, and 0.42, for Ca, Fe, Zn, and Pb, respectively. However, in the present study, the I/O values were high at each site for all the elements, except Pb. This is especially noteworthy, as one of the sites in Alonza *et al.*'s study was not located near heavy traffic or industry, but rather in a building located in a wooded area on a university campus. The results for this site were similar to those for the residential area in the current study, yet the I/O values for all the elements, except Pb, in the residential area were higher than those for the wooded area on the university campus in Alonza *et al.*'s study. Plus, as indicated by Anderson[13], the indoor heavy metal concentrations were 40~95 % higher than the outdoor levels. As such, the current results provide quantified data on the exposure to noxious heavy metals in an indoor school environment. As previously reported by Thompson *et al.*[14], the indoor air quality in large cities, including school

Table 1. Indoor-outdoor relationship of elements in particulate matter observed at each site. The symbol(-) means that the element was not detected. The symbol(*) means that the element was only detected outdoors

Site	Number of runs	I/O							
		Zn	Pb	Ni	Cr	Fe	Al	Ca	Mg
Heavy traffic area	4	2.57	0.33	0.47	0.64	0.93	1.82	1.63	0.95
Industrial area I	4	0.17	0.00	0.17	0.10	0.46	1.30	10.28	16.23
Industrial area II	4	1.34	0.34	0.64	0.60	0.89	0.61	0.83	0.72
Quasi-Industrial area	4	-	-	0.70	0.64	1.25	0.85	0.67	0.73
Residential area	4	*	0.00	0.82	0.59	0.58	1.29	1.45	1.64

environments, is significantly influenced by traffic and the input of air pollutants from outdoors through cracks in the windows and doors.

Accordingly, the data from the current study indicate that the heavy metals with the highest concentrations in school environments are Zn, Al, and Ca. Therefore, it is recommended that special ventilation systems are used to protect the health of teachers and students, instead of the current practice of ventilating through open windows.

3.3 Indoor/outdoor Atmospheric Environments

In the case of school environments in Busan, the area with the highest heavy metal concentrations was the industrial areas followed by the traffic area, residential area, and quasi-industrial area in a descending order of magnitude. Regardless of the site, the indoor heavy metal concentrations were always higher than or equal to the outdoor concentrations. The current study also found serious levels of air pollution in the school environments studied[10]. The highest indoor concentrations of heavy metals were related to Zn, Fe, and Ca. In particular, high levels of Fe and Al were detected at all sites. Therefore, the relationship between the meteorological elements and the heavy metal concentrations of these components was investigated. As such, the wet bulb depression, relative humidity, and mixing ratio were calculated from the dry and wet bulb temperature.

3.4 Air temperature

Figure 6 shows the average indoor/outdoors air temperature during the measurement period. On the transverse axis HTA = high traffic area, IA-I = industrial area I, Quasi-IA = quasi-industrial area, and RA = residential area. Meteorological data obtained from the Gimhae Airport Weather Station, located near the test sites, was used to confirm the accuracy of the air temperatures recorded in the current study. The location of the Gimhae Airport Weather Station is shown in Figure 1.

As shown in Figure 6, the average indoor and outdoor air temperature changes were similar during the measurement period except for the traffic area, which had missing data. The air temperatures obtained from the Gimhae Airport Weather Station were also similar, thereby supporting the observations of the current study.

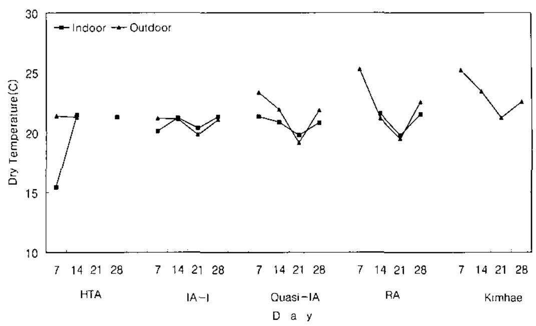


Fig. 6. Distribution of dry temperature(℃) at each site in May, 1994.

3.5 Wet-Bulb Depressions

To analyze the degree of saturation, influencing coagulation, and adsorption of suspended particulate matter in the atmosphere, the average differences between the wet- and dry-bulb temperatures are shown in Figures 7～8. Figure 7 compares the indoor-outdoor wet-bulb depressions(T_d-T_w) at the TA, IA-I, and Quasi-IA sites with that at the residential area(RA). The wet-bulb depressions at the TA, IA-I, and Quasi-IA sites were larger than that at the RA site. The air temperatures at the TA, IA-I, and Quasi-IA sites were lower than those at the RA site(Figure 6), thereby indicating that the actual amount of water vapor and degree of saturation were both low at these sites. The largest wet-bulb depression was recorded at the Quasi-IA area. Accordingly, since the actual amount of water vapor able to coagulate/adsorb dust and heavy metals in the atmosphere was higher at the RA site than at the other sites, the RA site also recorded the lowest wet-bulb depression values.

Figures 8(A)～(B) compare the indoor-outdoor wet-bulb depressions at the IA-I and Quasi-IA sites with that at the heavy traffic site. The wet-bulb depressions at the IA-I and Quasi-IA sites were somewhat larger than that at the TA site, indicating that the degree of water vapor saturation was higher at the TA site than at the IA-I and Quasi-IA sites. Figure 8(C) shows the wet-bulb depressions at the Quasi-IA and IA sites. Although both these sites are industrial areas, the wet-bulb depression at the

IA site was somewhat larger than that at the Quasi-IA site, indicating that the amount and size of the particulate matter emitted in each area differed depending on the kind of industry and working conditions. Consequently, since it is difficult to correlate the degree of saturation with the actual amount of water vapor in the air, the areas with the largest wet-bulb depressions were the IA and Quasi-IA sites, followed by the TA and RA sites in a descending order of magnitude.

When the wet-bulb depression is large, the concentration of heavy metals in the air is high. A large wet-bulb depression indicates a low water vapor saturation, which has a strong influence on the concentration of heavy metals in the atmosphere.

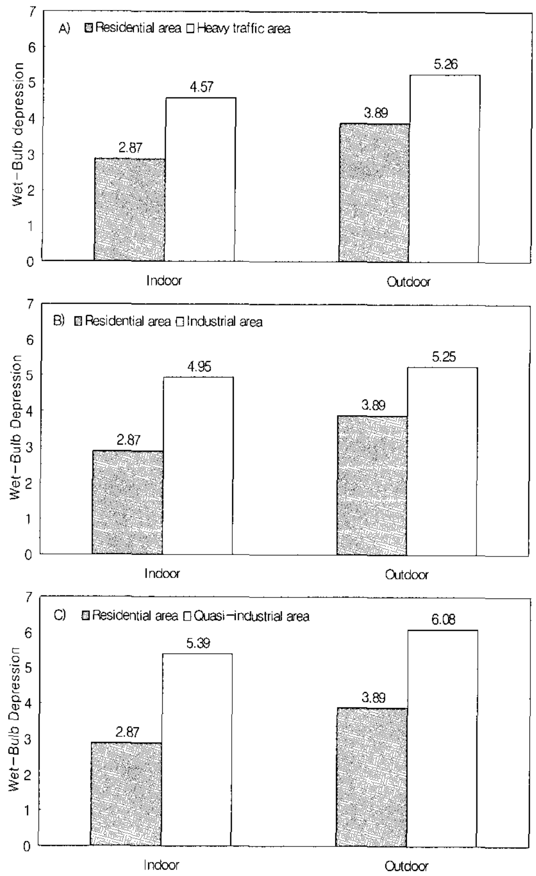


Fig. 7. Comparison of indoor-outdoor wet-bulb depression(T_d-T_w) at A) heavy traffic area(TA), B) industrial areas(IA-I), and C) quasi industrial area(Quasi-IA) with that at residential area(RA).

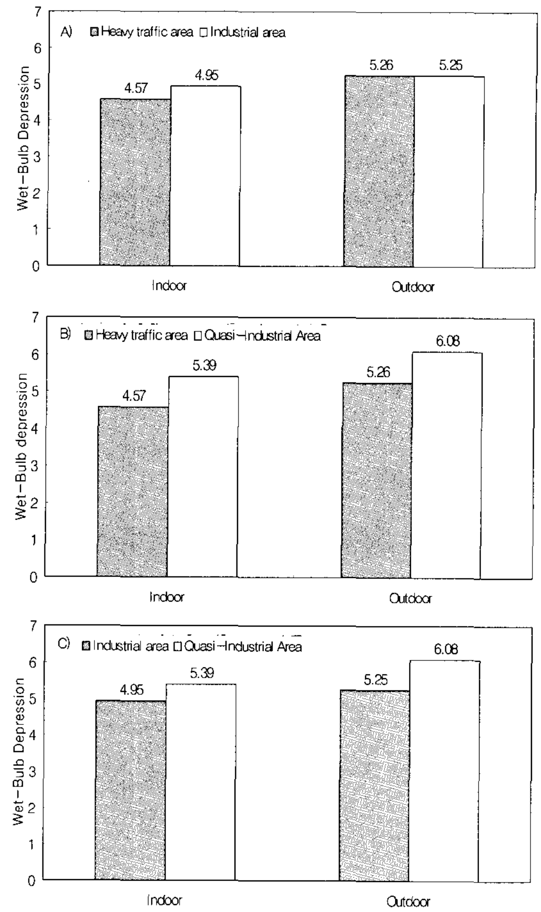


Fig. 8. Comparison of indoor-outdoor wet-bulb depressions(T_d-T_w) at A) industrial area(IA-I) and B) quasi industrial area(Quasi-IA) with that at heavy traffic area(TA), and comparison between C) quasi industrial area(Quasi-IA) and industrial area(IA).

Figure 9 shows the indoor and outdoor distribution of the wet-bulb depression every 10 minutes during the measurement period. At all sites, the outdoor wet-bulb depression was larger than the indoor one. Therefore, the degree of indoor air water vapor saturation was relatively higher than that outdoors. The indoor-outdoor wet-bulb depression at Bakyang Middle School, located in the RA area, was the largest at 1.02 ℃.

Since the indoor wet-bulb depressions were smaller than the outdoor ones, the degree of water vapor saturation was high. The wet-bulb depression, which indicates the water vapor saturation, has an influence on the adsorption of the

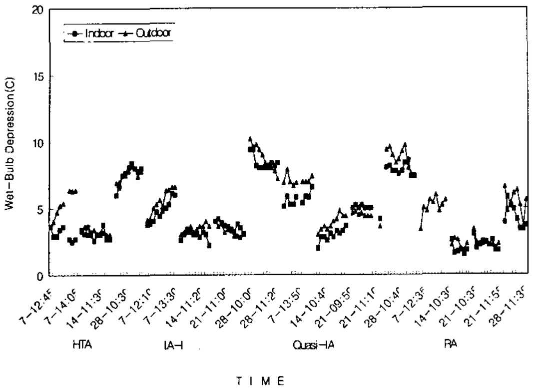


Fig. 9. Comparison of indoor and outdoor wet-bulb depressions(T_d - T_w) relative to time and area. The number 7-12:45 represents 12:45pm on May 7, 1994.

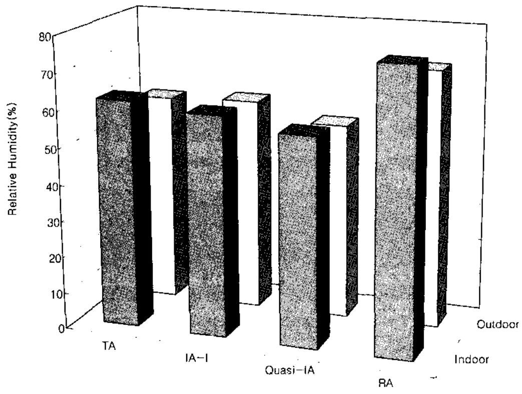


Fig. 10. Comparison of indoor-outdoor average relative humidity at each site.

particulate matter. As such, if the deposition velocities are relatively high, the concentration of particulate matter should decrease. However, the current study found that the particulate matter concentration was higher indoors than outdoors, possibly due to the re-suspension of the particulate matter resulting from the student activity in the classroom.

3.6 Relative humidity and mixing ratio

The relative humidity, an index of the amount of water vapor in the atmosphere, was calculated from the dry- and wet-bulb temperatures. An analysis of the indoor and outdoor relative humidity at all the sites is shown in Figure 10. The highest relative humidity was recorded at the RA site, followed by the TA, IA-I, and Quasi-IA sites in a descending order of magnitude, and found to be associated with a small wet-bulb depression.

Therefore, the concentrations of heavy metals in the school environments were seemingly closely associated with the amount of water vapor in the atmosphere. The higher the relative humidity, the higher the coagulation and adsorption of the particulate matter. As a result, the deposition velocities increase and the amount of particulate matter in the air decreases correspondingly.

In the current study, the relative humidity of the indoor atmospheric environment at the schools was higher than that outdoors, which should predict a lower concentration of heavy metals. However, due to the inflow of air through cracks in the windows and the activity of the students, the particulate matter on the classroom floor may have been re-suspended, thereby increasing the concentration of heavy metals in the indoor atmosphere.

The relative humidity gives an indication of how the air is approaching saturation, rather than the actual quantity of water vapor in the air, as this depends on the air pressure and temperature. Figure 11 shows the mixing ratio, which is expressed as the mass of water vapor in a unit mass of dry air, g kg^{-1}. This shows the amount of water vapor present, regardless of the air pressure and temperature changes in the atmosphere. The highest and lowest mixing ratios were found on May 14 and 28 1994, respectively. The RA site had the highest mixing ratio, followed by the TA and IA-I sites. The Quasi-IA site exhibited the greatest difference in the mixing ratio between the two observation days. However, the mixing ratios at the IA-I and Quasi-IA sites were lower than that at the TA site, similar to the relative humidity.

Therefore, when the mixing ratio is high, the concentration of particulate matter or heavy metals in the air is low. Yet, as the amount of water vapor increases, the coagulation and adsorption of fine and coarse particulate matter also increase, thereby increasing the deposition velocities of the particulate matter and its removal from the atmosphere. In other words, the concentration of heavy metals is closely dependant on the amount of water vapor in the atmosphere, rather than the degree of saturation.

The mixing ratios at the RA and IA-I sites were

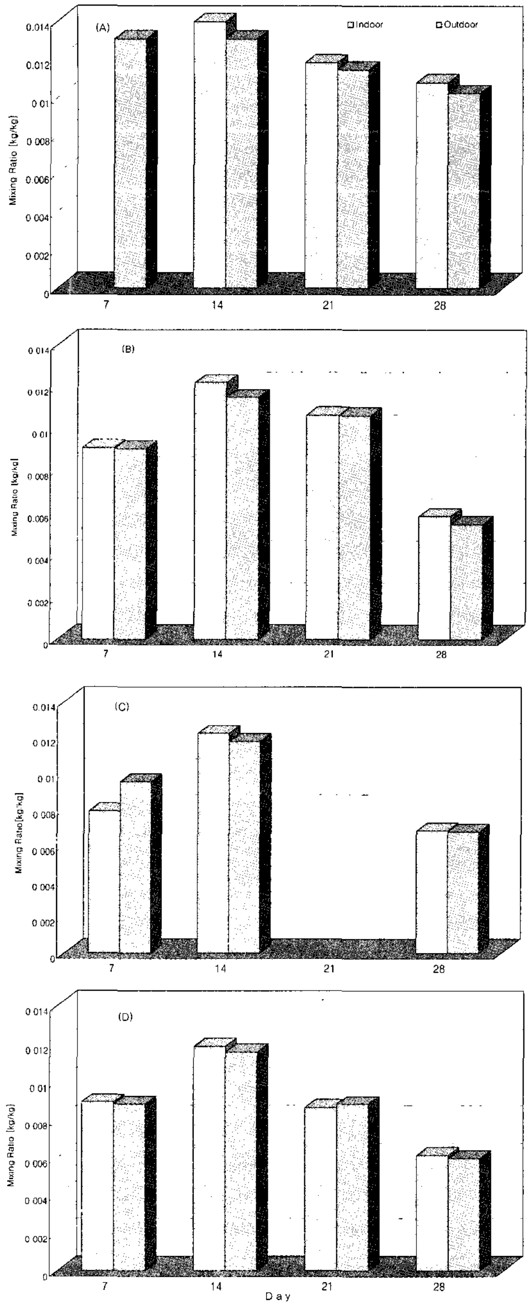


Fig. 11. Comparison of indoor-outdoor mixing ratio at (A) residental area, (B) industrial area, (C) traffic area, and (D) quasi-industrial area relative to observation day.

higher indoors than outdoors, while those at the TA and Quasi-IA sites were either the same indoors and outdoors or higher outdoors. The Average mixing ratios were higher indoors than outdoors, yet the concentrations of heavy metals were higher indoors, because the emission and size of the particulate matter differed at each site, plus the inflow of air from outdoors and student activity also contributed to the high indoor concentrations of heavy metals.

4. Summary

Heavy metal concentrations were investigated in school environments in a heavy traffic area(TA), industrial area(IA), quasi-industrial area(Quasi-IA), and residential area(RA) in the Busan metropolitan area, South Korea.

The site with the highest indoor and outdoor concentrations of heavy metals was the industrial area, followed by the heavy traffic area, residential area, and quasi-industrial area in a descending order of magnitude. The indoor heavy metal concentrations were consistently higher than or equal to the outdoor concentrations.

The heavy metal components with the highest concentrations were Zn, Al, and Ca, all of which were higher indoors than outdoors.

The average total heavy metal concentration or particulate matter concentration in each area was highly dependent on the weather conditions, such as the relative humidity, mixing ratio, and wet-bulb depression. In particular, when the actual amount of water vapor, rather than the degree of saturation, in the air was large, the concentration of suspended particles, including heavy metals, was low, because the degree of absorption and coagulation increased.

Accordingly, the results of the current study indicate the need for special ventilation systems to reduce the air pollution in school environments.

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