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Ambient Levels of CO and PM10 at Low- and High-floor Apartments in Industrial Complexes

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Since low-floor apartments are vertically closer to parking lots and roadways, it is hypothesized that residents in low-floor apartments may be exposed to elevated ambient levels of motor vehicle emissions compared to residents in high-floor apartments. The present study examined this hypothesis by measuring two motor vehicle source-related pollutants(CO and PM10) in ambient air of high-rise apartment buildings within the boundary of industrial complexes according to atmospheric stability. The ambient air concentrations of CO and PM10 were higher for low-floor apartments than for high-floor apartments, regardless of atmospheric stability. The median concentration ratio of the low-floor air to high-floor air ranged from 1.3 to 2.0, depending upon atmospheric stabilities, seasons and compounds. Moreover, the CO and PM10 concentrations were significantly higher in the winter and in the summer, regardless of the floor height. Atmospheric stability also was suggested to be important for the residents' exposure of high-rise apartment buildings to both CO and PM10. The median ratios of surface inversion air to non-surface inversion air ranged from 1.2 to 1.7 and from 1.0 to 1.6 for PM10 and CO, respectively, depending upon seasons. Conclusively, these parameters(apartment floor height, season, and atmospheric stability) should be considered when evaluating the exposure of residents, living in high-rise apartment buildings, to CO and PM10. Meanwhile, the median PM_{10} outdoor concentrations were close to or higher than the Korean annual standards for PM10, and the maximum PM10 concentrations substantially exceeded the Korean PM10 standard, thus suggesting the need for a management strategy for ambient PM10. Neither the median nor the maximum outdoor CO concentrations, however, were higher than the Korean CO standard.

Key Words : Atmospheric stability, High-rise apartment, Floor height, Season, Exposure level

1. Introduction

Like many other cities, Daegu includes several industrial complexes, which borders on certain residential areas. Seongseo and Dalseong industrial complexes are known as two representative ones in Daegu. For nearby residents, odor caused by air pollutants emitted from these complexes has been a common nuisance and cause of complaints. Moreover, nearby residents have also complained that the odor-causing air pollution increases their health risk. Yet the evaluation of the air pollution in this residential area has, in most cases, been left to local authorities and generally based on personal observations and judgment. Accordingly, since the results are open to error, subjective, and possibly biased, they are regarded as unsatisfactory by the residents, authorities, and owners/operators of the sources. Consequently, the need for an adequate evaluation of the residential air pollution near the complexes became obvious in order to establish air pollution abatement programs.

The distance from a residence to urban pollution sources has already been associated with high residential exposure to ambient air pollutants[1~4]. Nakai et al.[5] reported that residential ambient air concentrations of NO_2 in Tokyo were higher close to the roadside than further away from it. They also found that indoor air levels were consistent with ambient air levels when no indoor heating was used. Jo and Moon[3] confirmed that residents in neighborhoods near a service station were exposed to elevated ambient VOC levels compared to residents living further away from such a source, even though the elevated outdoor levels nearby

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the service stations were not identified as a major contributor to the exposure of the residents living in close proximity. Moreover, recent epidemiological studies have reported that residents living near major roads experience more chronic respiratory symptoms, lung function decrements, and more hospital admissions for asthma[6~8]. In these studies, exposure to air pollution was characterized as the distance to major roads.

Many proximity studies, however, have been focused on horizontal proximity to pollution sources. Yet in Korea, many city residents live in high-rise apartment buildings. According to the Korean National Statistics Office, about 22 million people live in Korea's eight largest cities and about 10 million of these live in high-rise apartments (defined as 10 or more stories). As such, it can be expected that apartment residents are exposed to motor vehicle emissions from vehicles in the apartment parking lots and nearby roadways. Yet, since low-floor apartments are vertically closer to parking lots and roadways, it is hypothesized that residents in low-floor apartments may be exposed to elevated ambient levels of motor vehicle emissions compared to residents in high-floor apartments. Vehicle emissions are the largest source for both PM10 and CO in Korean urban areas[9]. During recent decades, the two target compounds have been considered as representative urban air pollutants in many countries. Accordingly, the current study evaluated above theory based on measuring two motor vehicle source-related pollutants (CO and PM10 [particulate matter = 10 μm in aerodynamic diameter]) in ambient air of high-rise apartment buildings within the boundary of two industrial complexes(Seongseo and Dalseong industrial complexes). In particular, this study was done in the early morning, when surface inversion can potentially occur, as surface inversion is an important meteorological factor in the vertical distribution of urban air pollution. About 1.1 million Daegu residents live in high-rise apartments.

2. Experimental Methods

2.1. Study Design

The present study measured the concentrations of CO and PM10 in the ambient air of high-rise apartment buildings located in two industrial complexes during winter, 2004 and during summer, 2005. Two industrial complexes areas included Seongseo and Dalseong industrial complexes (Table 1). The former complex has currently 2,446 establishments and 51,463 workers, while the latter complex has 296 establishments and 14,771 workers. 30 apartment buildings where satisfied the experimental criterion and the residents granted permission to measure the indoor and outdoor air concentrations were selected from each industrial complex. The criterion was as follows: the apartment buildings should be high-rise apartment buildings with 10 or more stories. One low-floor apartment (first or second floor) and one high-floor apartment (between 10^{th} - 15^{th} floor) were concurrently surveyed from each building. The same apartments participated in both the summer and winter studies. The ambient concentrations of CO and PM10 were measured from outside the apartments, and recorded as 30-min averages. These measurements were conducted between 6:00 a.m. and 7:00 pm, when surface inversion can potentially occur. If there was any sample loss due to sampling or analytical problems, all samples for that sampling day were discarded and the whole experimental procedure was re-conducted on another sampling day. Ambient air temperatures were measured concurrently prior to and right after the measurements of CO and PM10 concentrations, using thermo recorders with a resolution of 0.1°C (Model TR-72S, T & D Co.). Simultaneously, wind speeds were measured using air velocity meters with a resolution of 0.1 m s^{-1} (VelociCheck Model 8330, TSI Inc.). Meanwhile, all surveyed apartments were constructed with concrete and iron frames. The apartments used liquid petroleum gas (LPG) as their primary heating system and for cooking. The exhaust gas generated from heating or cooking was mechanically vented out of the apartments. The outdoor air sampling was performed in such a way as to avoid any potential influence from the exhaust gas.

2.2. Measurements of CO and PM10 Concentrations

The CO concentrations were measured using CO dosimeters (CMCD-10P, GASTEC Co., Kanagawa, Japan). The CO measurement concentration of the dosimeter ranges from 0.1 to 50 ppm, with a sensitivity of 0.1 ppm. In the current study, the CO monitor was calibrated by checking the zero and span gases before each use and at specific intervals during the analysis runs. The monitor was equipped with an activated

Table 1. Information on Seongseo and Dalseong industrial complexes[a]

Industrial Classification	Industrial zone	Establishment (number)	Workers (persons)
Food	Dal-seong	10	1,376
	Seong-seo	33	1,069
Textile/Clothes	Dal-seong	83	1,366
	Seong-seo	672	11,736
Wood/Paper	Dal-seong	16	296
	Seong-seo	73	2,403
Petrochemistry	Dal-seong	31	2,308
	Seong-seo	118	1,248
Nonmetal	Dal-seong	14	283
	Seong-seo	138	3,009
Primary Metalworking Industry	Dal-seong	21	1,110
	Seong-seo	94	1,886
Assembly Metal	Dal-seong	100	8,032
	Seong-seo	769	12,227
Transport Equipment	Dal-seong	NA	NA
	Seong-seo	330	10,692
Electricity · Electron	Dal-seong	NA	NA
	Seong-seo	149	5,995
etc.	Dal-seong	21	NA
	Seong-seo	70	1,198

[a]Source : Report on the census on basic characteristics of establishments (Daegu Metropolitan City, 2003); NA, not available.

charcoal-Purafil prefilter to remove any potentially interfering compounds[10].

The CO dosimeter also included an auto-zeroing function. For the auto-zeroing function, zero gas was generated by passing ambient air through a CO removal filter. The calibration procedure was performed using monitors powered by fully charged batteries instead of a primary electrical outlet, to prevent differences in the monitor performance when operated by a source of power not used in some fields.

The PM10 concentrations were measured using real-time light scattering PM10 monitors (HAZ-DUST Model EPAM-500, Environmental Devices Inc., Plaistow, New Hampshire). The PM10 measurement concentration of the monitor ranges from 1 to 2000 g m^{-3}, with a sensitivity of 1 g m^{-3}. The monitor was calibrated by checking the zero and span gases and flow rates before each use and at specific intervals during the analysis runs. Similar to the CO monitor, the calibration procedure was performed using monitors powered by fully charged batteries.

2.3. Statistical analyses

Using the SAS program (Version 8) on a personal computer, the Shapiro-Wilk statistical test was employed to evaluate the normality of the data. The data were compared using a paired t-test or a non-parametric test (Wilcoxon Rank-Sum Test). Median values were used to characterize the log-normally distributed data, when this was indicated by the Shapiro-Wilk statistical test. The criterion for significance in the procedures was $p<0.05$.

3. Results and Discussion

3.1. Ambient Concentrations for Low- and High-Floor Apartments

Table 2 summarizes the outdoor concentrations of CO and PM10 measured at the high-rise apartment buildings located in two industrial complexes, during

Table 2. Summery of PM10 (μg/m³) and CO (ppm) concentrations measured for low and high floors in high-rise apartment buildings according to atmospheric stability and season[a]

Comp/Temp/RH/WS	Season	Inversion									Non-inversion								
		Low floor				High floor				*L/H*[b]	Low floor				High floor				*L/H*[b]
		Mean	S.D.	Med	Max	Mean	S.D.	Med	Max		Mean	S.D.	Med	Max	Mean	S.D.	Med	Max	
PM10	win	0.09	0.03	0.09	0.19	0.06	0.03	0.07	0.11	**1.4**	0.08	0.02	0.08	0.12	0.05	0.02	0.05	0.10	**1.6**
	sum	0.08	0.03	0.07	0.171	0.05	0.03	0.04	0.131	**1.8**	0.05	0.021	0.04	0.11	0.03	0.02	0.03	0.07	**1.8**
CO	win	1.5	0.6	1.3	3.4	0.8	0.2	0.8	1.1	**1.6**	1.2	0.4	1	2.3	0.7	0.2	0.8	1.0	**1.3**
	sum	0.8	0.3	0.8	1.5	0.5	0.2	0.4	0.9	**2.0**	0.5	0.1	0.5	0.7	0.3	0.1	0.3	0.6	**1.7**
Temp(℃)[c]	win	1.6	3.9	3.2	6.8	2.5	3.9	4.2	7.8	0.8	1.4	3.6	2.2	7.6	1.0	3.6	1.5	7.3	1.5
	sum	24.2	1.6	24.3	27.3	25.1	1.5	25.2	27.5	1.0	25.8	2.0	26.3	30.2	25.4	2.1	25.8	29.6	1.0
RH(%)[c]	win	54	11	50	76	53	11	48	77	1.0	48	11	44	77	47	11	45	75	1.0
	sum	68	9	69	83	66	9	65	86	1.1	68	10	68	83	67	9	67	82	1.0
WS(m/s)[d]	win	0.91	0.75	0.55	2.47	0.68	0.59	0.53	2.13	1.1	0.78	0.59	0.56	2.14	0.80	0.72	0.52	3.12	1.1
	sum	0.54	0.39	0.42	1.32	0.43	0.31	0.32	1.21	1.3	0.49	0.60	0.32	2.59	0.59	0.72	0.31	2.98	1.0

[a]Number of samples: N = 18 for winter-inversion-low, N = 18 for winter-inversion-high, N = 48 for winter-non-inversion-low, N = 48 for winter-non-inversion-high, N = 24 for summer-inversion-low, N = 24 for summer-inversion-high, N = 36 for summer-non-inversion-low, N = 36 for summer-non-inversion-high.

[b]Median concentration ratios of low-floor to high-floor; boldface indicates that the two data sets were significantly different at p<0.05 or close to 0.05.

[c]Average ambient temperature or relative humidity of two readings observed during 30-min ambient air measurement period.

[d]Average ambient wind speed(WS) of two readings to outdoor observed during 30-min ambient air measurement period.

surface inversion and non-surface inversion for two seasons(winter and summer). A statistical test of normality(Shapiro-Wilk statistics) showed that the data were log-normally distributed. Paired sample means of low-floor and high-floor apartments were analyzed using a paired t-test. The present study classified the atmospheric stability into two cases: presence and absence of surface inversion. Surface inversion is typically defined as the period when the temperature at the surface increases with height. As such, this study defined a surface-inversion period as when the average temperature measured during each sampling period was higher for the high floor than for the low floor. Regardless of the atmospheric stability, the ambient concentrations of CO and PM10 were significantly higher for the low floors than for the high floors in both winter and summer. The median concentration ratio of the low-floor air to high-floor air ranged from 1.3 to 2.0, depending upon atmospheric stabilities, seasons and compounds. This difference in the ambient air concentrations between low and high floors is consistent with the findings of Ilgen et al.[9] and Jo et al.[10], who reported that ambient air levels revealed a decrease in the concentration of aromatic hydrocarbons, which are known as other markers for vehicle emissions, with an increase in the height above street level. In the current study, CO and PM10 appeared to have similar outdoor sources and sinks, since the correlation of the two compounds for the outdoor air concentrations was significant, regardless of floor levels (Table 3). As described in an earlier section, vehicle emissions are the largest source for both PM10

Table 3. Spearman correlations of CO and PM10 concentrations measured in two industrial complexes(Seongseo and Dalseong) according to apartment floor height[a]

Seongseo				Dalseong			
Low floor		High floor		Low floor		High floor	
r_s	*P*	r_s	*P*	r_s	*P*	r_s	*P*
0.51	<0.0001	0.48	<0.0001	0.63	<0.0001	0.55	<0.0001

[a]Number of samples: N = 60 for each data set.

and CO in Korean urban areas[11]. As such, with no other significant sources around the surveyed areas, it is assumed that the differences in the outdoor air levels of PM10 and CO between the low and high floors were mainly due to the vertical concentration gradient of the vehicle emission pollutants emitted from the vehicles in the apartment parking lots and nearby roadways. Meanwhile, the median CO were lower than the Korean 8-hr standard for CO (9 ppm). However, the median PM10 concentrations were close to or higher than and the Korean annual standard for PM10 (70 μg/m^3), the American annual standard for PM10 (50 μg/m^3) and the maximum PM10 concentrations substantially exceeded the Korean PM10 standard, thus suggesting the need for a management strategy for ambient PM10.

3.2. Surface Inversion Period vs. Non-Surface Inversion Period

Table 4 allows comparing the ambient concentration measured during the inversion perod and non-surface inversion period. The median ratios of surface inversion air to non-surface inversion air ranged from 1.2 to 1,7 and from 1.0 to 1.6 for PM10 and CO, respectively, depending upon seasons. As such, most ambient concentrations of the target compounds for the low and high floors were significantly higher during inversion periods compared to non-inversion periods. This is supported by Wallace et al.[12], who found that overnight inversions produce elevated outdoor VOC concentrations in Los Angeles. Under the stable atmospheric condition, there is a restricted vertical motion of ambient pollutants from roadway motor vehicle emissions[7,9,13~14]. Ambient air pollutants can penetrate into indoor environments and then, they can elevate indoor pollution[15]. Accordingly, it is suggested that surface inversion is another important parameter for the residents' exposure of high-rise apartment buildings to CO and PM10.

3.3. Seasonal Variation of Ambient Concentrations

Table 5 allows comparing ambient air concentrations between the two seasons for the low- and high-floor apartments. The ratios of winter air to summer air ranged from 1.2 to 2.0 for PM10 concentrations, while they ranged from 1.5 to 2.7 for CO concentrations, depending upon atmospheric stabilities. The wind speed was significantly higher for the winter than for the summer, regardless of the floor height. As such, strong wind speed would more effectively dilute the air pollutant levels around emission sources during winter, thereby decreasing the urban air pollution. Nevertheless, the ambient concentrations of both CO and PM10 were significantly higher for the winter. One possible parameter is the lower combustion efficiency of gasoline in winter, thereby causing higher

Table 4. Median ratios of surface inversion air to non-surface inversion air according to apartment floor height and season

Comp/Temp/ RH/WS	Winter		Summer	
	Low floor	High floor	Low floor	High floor
PM10(μg/m^3)	1.2	1.4	1.7	1.6
CO(ppm)	1.3	1.0	1.6	1.3
Temp(°C)	1.5	2.5	0.9	1.0
RH(%)	1.2	1.1	1.0	1.0
WS(m/s)	1.0	1.0	1.3	1.0

Table 5. Median ratios of winter air to summer air in industrial complexes according to apartment floor height and atmospheric stability

Comp/Temp/ RH/WS	Surface inversion		Non-surface inversion	
	Low floor	High floor	Low floor	High floor
PM10(μg/m^3)	1.2	1.7	1.8	2.0
CO(ppm)	1.6	2.0	2.0	2.7

concentrations in the ambient air. This is also supported by Bruetsch's study[16], which found that high tailpipe emissions from motor vehicles are associated with a cold ambient temperature. Furthermore, in cold temperatures engines take longer to warm up. Other possible parameters for the seasonal difference include the wind speed, inversion, mixing height, and traffic intensity.

4. Conclusions

The current study evaluated the hypothesis that residents in low-floor apartments may be exposed to elevated ambient levels of motor vehicle emissions compared to residents in high-floor apartments. This was established based on measuring two motor vehicle source-related pollutants (CO and PM10) in ambient air of high-rise apartment buildings within the boundary of industrial complexes. This study found that the ambient air concentrations of CO and PM10 were higher for low-floor apartments than for high-floor apartments, regardless of atmospheric stability. Moreover, the CO and PM10 concentrations were significantly higher in the winter and in the summer, regardless of the floor height. Atmospheric stability also was suggested to be important for the residents' exposure of high-rise apartment buildings to both CO and PM10. Conclusively, these parameters should be considered when evaluating the exposure of residents, living in high-rise apartment buildings, to CO and PM10. Meanwhile, the median PM10 ambient concentrations were close to or higher than the American and the Korean annual standards for PM10, and the maximum PM10 concentrations substantially exceeded the Korean PM10 standard, whereas neither the median nor the maximum outdoor CO concentrations were higher than the Korean CO standard. These findings suggest the need for a management strategy for ambient PM10, since the elevated ambient PM10 levels can influence the exposure levels of residents inside high-rise apartment buildings, by penetration into the apartments.

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