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Assessment of Urban Area CO_2 Concentrations using the Atmospheric Dispersion Model for Micro Areas

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ABSTRACT

In this study, we would like to predict and analyze contributions of carbon dioxide emissions from urban traffic mass through the two type resolution CALPUFF modeling (1 km x 1 km and 0.1 km x 0.1 km), focusing on the potentials of the carbon dioxide that can accelerate health risks and urban heat contaminations. After modeling and analyzing, we got the results that follow like these; even if same emissions enter into the modeling, differences cannot occur between concentrations of high traffic volume sites and low traffic volume sites in the 1 km x 1 km resolution modeling case, but we can see differences cannot occur between concentrations of high traffic volume sites and low traffic volume sites in the 0.1 km x 0.1 km resolution modeling case. To put it concretely, we got the over 700 ppm CO_2 data in high traffic volume sites and about 400 ppm CO_2 data in low traffic volume sites by modeling and sensor monitoring. So, micro area modeling may be essential to calculate more accurate modeling data. Moreover, when we applying to the indoor ventilation estimating, we assumed the outside CO_2 concentration as 300 - 400 ppm, but we got the over 700 ppm CO_2 data in this study. Therefore, in the estimating of ventilation, we have to use the monitored or modeled CO_2 data in the road side sites.

1. Introduction

With an increase in carbon dioxide concentration of roadside, it could cause the Heat Island Effect. For the Heat Island Effect is the representative phenomenon of climate change, the phenomenon that the urban temperature is presented remarkably higher than the one of surrounding areas under the influences of an increase in population, all sorts of artificial establishments, concrete cover, and vehicle traffic, the release of artificial heat, and the greenhouse effects, etc., the air pollution deepens if the heat island effect accelerates.

Thus, in this study, we used the atmospheric diffusion model (CALPUFF) to evaluate the distribution of carbon dioxide concentration in city where the Heat Island Effect, the reason for the health risk and the climate change, accelerates.

Also, In case of stores located at the place where the carbon dioxide concentration is high, the indoor carbon dioxide concentration can be measured higher than 700 ppm due to the outdoor air. Therefore, this study result could be practically used as the preliminary data that is useful for coming up with measures of Indoor Air Quality management in future.

1.1 Existing Research Trend

As it is observed that urbanization cause the rise in temperature and an increase of carbon dioxide concentration by IPCC [1-3], it can be to say that the current city climate is the sign of an upcoming climate change. There can be various reasons to increase the carbon dioxide concentration in the city, however, the carbon dioxide emission that is emitted due to the growth in vehicle traffic.

In this context, the carbon dioxide concentration was measured at the roadside of busy vehicle traffic and in residential area of comparably low traffic by Korea Federation for Environment Movement in 2013.

As a result of measurement, 3,088.40 ppm on Yonsei Street, Shin-Chon, which was the highest, was measured in carbon dioxide concentration. On average, it was measured 794.80 ppm at the roadside, 667.70 ppm at nearby school, and 632, 80 ppm for residential area in the carbon dioxide concentration [4].

As an index that is a measure of Indoor Air Quality or ventilation, it is being treated as one of important indoor air pollutants with carbon monoxide, being lack of the amount of oxygen that is essential for breath once the carbon dioxide concentration rises in the interior spaces.

At the roadside located stores that has a high level of carbon dioxide concentration, the indoor carbon dioxide concentration could increase due to the open air, and for the modern people mostly living indoor, their health could be harmed by carbon dioxide. Though the general hygienic allowable value is 0.1%, when it becomes 3% while breathing, the breath is extended, and for 4%, the amount of carbon dioxide within the pulmonary goes into a rise, then causes the symptoms such as a difficulty in breathing, headache [5].

There are more study examples using the carbon dioxide emission [6-8]. The researcher Noorollahi [6] assessed and predicted the concentration of H_2S, carbon dioxide using the diffusion model (ISC3View) at the industrial complex where the Nesfavellir local power plant is located in, and Lac et al [7] investigated the ability of a high-resolution model to simulate meteorological and carbon dioxide fields around Paris agglomeration during the March field campaign of the carbon dioxide - MEGAPARIS project. Also, Heydenrych et al [8] verified New Zealand with the condition of industrial emission such as smokestacks and domestic-heating emission through the Calpuff modeling.

2. Experimental Methods

For the reality reflected result of concentration, we have performed atmospheric diffusion modeling targeting April, 2014.

2.1 Wide Area Modeling

The modeling area was set to 120 km×120 km (1 km x 1 km resolution) for the capital area to be included. For the emission quantity, we analysed degree of contribution to the capital area depending on the emission source, performing modeling for each CAPSS emission source (Fig. 1).

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2.2 Micro Space Modeling

For the measuring to be included, the modeling area has been set to 3 km × 3 km (0.1 km x 0.1 km resolution), the micro space modeling was performed using the carbon dioxide emissions at the measuring point (Fig. 2).

Fig. 1 Metropolitan modeling area

Fig. 2 Micro space modeling area

We examined the suitability of the model after comparing the atmospheric diffusion modeling result of the capital are and micro spaces, with the measured value of the carbon dioxide concentration. The carbon dioxide was measured at the roadside and in residential area to verify the comparative analyzing data for the atmospheric diffusion of the capital area and micro spaces. We selected the roadside of three lane in digital complex five-way intersection as a measuring point for roadside, and comparably trafficless D apartment which was 670 m apart from the roadside as the one for the residential area (Fig. 4).

Also, after three days of measurement using the carbon dioxide measuring detector that the measuring method is NDIR (Non-Dispersive Infrared Absorption) type (Fig.3), we studied the suitability of the model through the comparative analysis with the atmospheric diffusion in capital area.

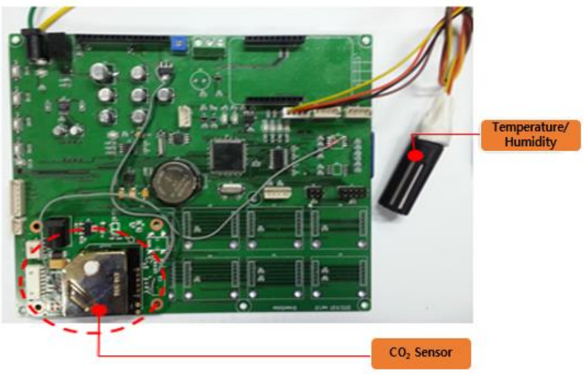

Fig. 3 CO_2 Measuring Instrument

Fig. 4 CO_2 measuring points

3. Results and Discussion

3.1 Influence of Stationary Sources Emission

During the period of measurement, the carbon dioxide concentration was compared and analyzed time-based depending on the traffic with the result in modeling of 18th, roadside measuring period, and 22nd, residential area measuring period. For the morning rush hour of 9 AM, the evening rush hour of 6 PM, and relatively low traffic time of 1 PM, we analyzed the equivalent concentration curves.

As a result of the atmospheric diffusion modeling in Seoul area, around 9 AM, It appeared that the carbon dioxide concentration was 0.1 ppm - 0.2 ppm which was a little high at near the center of the emission source in Seoul, and the further being from the emission source, the lower the carbon dioxide concentration turned up, around 0.04 ppm - 0.05 ppm.

It was presented that the carbon dioxide concentration was higher in morning, which was 0.2 ppm in Seoul central, than the one of nearby area at 1 PM with the continuous emission of area sources. The concentration value was 0.12 ppm, which was also high. From 1 PM on 22nd, it showed the tendency that the concentration range of 0.01 ppm - 0.015 ppm, which was wide- spread in Seoul, is reduced.

As a result of modeling in Gyeong-gi area, the carbon dioxide concentration distribution appeared near Gyeong-gi and Incheon as the emission source was concentrated in Gyeong-gi province, it appeared 0.01 ppm - 0.4 ppm at 9 PM, which was high, and 0.2 ppm - 0.1 ppm near Seoul that is apart from Gyeong-gi area.

Around 1 PM, the carbon dioxide concentration was 0.2 ppm - 1.5 ppm near the central Gyeong-gi, and 0.05 ppm - 0.5 ppm in Seoul. The concentration measured at 6 PM seemed similar to the one at 1 PM.

3.2 Influence of Energy Industrial Combustion Emission

We performed the modeling using the point pollution source emission depending on the classification of the emission quantity by CAPSS 1 km x 1 km grid to study the effect that the carbon dioxide emitted from thermal power plants affects to the capital area as there are many large-sized thermal power plant in Incheon.

As a result of the modeling performance, on 18th of April, the carbon dioxide concentration appeared 0.1 ppm at emission source and the nearby, and 0.05 ppm in Seoul which is comparably apart from the emission source. In addition, while lasting of the thermal power plant operation, the carbon dioxide concentration of 1 PM, 6 PM was 4 ppm - 6 ppm at near the center of emission source, and 0.1 ppm - 0.25 ppm in Seoul.

On 22nd of April, at 9 AM, the carbon dioxide concentration in the Gyeong-gi area close to In-cheon was 0.2 ppm. Also, at around 6 PM, the concentration of In-cheon city where the thermal power plant is located in appeared as 4 ppm.

3.3 Influence of Energy Industrial Combustion Emission

The result of the atmospheric diffusion modeling performance depending on the mobile emission sources in Seoul, Gyeong-gi, In-cheon is as follows.

In the case of Seoul, the carbon dioxide concentration was as high as 40 ppm - 45 ppm at near the city central at around 9 AM, and at 1 PM, as the traffic was quite low compared to rush hour, the concentration appeared 20 ppm near the center of emission source. Also, it appeared 40 ppm - 50 ppm, which was quite high, during the evening rush hour.

In Gyeong-gi, during the rush hour of high traffic, the carbon dioxide concentration appeared high, 30 ppm - 50 ppm near the center of emission source, but in Seoul that is apart from the emission source, the concentration was around 10 ppm - 40 ppm.

For Incheon, as the carbon dioxide emission was low following mobile emission compared to Seoul, Gyeong-gi, the carbon dioxide emission appeared 1 ppm - 3 ppm near the center of emission source during the rush hour, whereas the concentration was 0.125 ppm - 1 ppm, which is a little low, near Seoul being apart from emission source.

3.4 Influence of Energy Industrial Combustion Emission

As a result of the carbon dioxide atmospheric diffusion modeling in capital areas according to the area sources emission and mobile emission, it appeared that the area sources emission does not affect to the carbon dioxide concentration (Table 1).

Table 1 Contribution of the roadside measuring point (the atmospheric diffusion modeling result of metropolitan wide area)

Date	Concerntion(ppm)					
	Seoul (Area Sources)	Seoul (Mobile Sources)	Gyeong-Gi (Area Sources)	Gyeong-Gi (Mobile Sources)	In-Cheon (Energy)	In-Cheon (Mobile Sources)
18th, 9 AM	0.19	38.26	0.006	30	0.70	1.20
18th, 1 PM	0.13	12.90	0.30	15	0.10	0.34
18th, 6 PM	0.01	43.67	0.22	20	2.10	0.98
19th, 9 AM	0.18	35.31	0.01	21.04	0.54	1.52
19th, 1 PM	0.26	19.80	0.20	15.1	0.48	0.82
19th, 6 PM	0.20	41.67	0.13	22.1	0.53	1.12
20th, 9 AM	0.11	40.26	0.02	29.5	0.98	0.77
20th,1 PM	0.17	22.30	0.16	10.4	0.86	0.38
20th, 6 PM	0.20	43.23	0.15	19.45	0.93	2.14
21th, 9 AM	0.06	45.79	0.02	33.12	1.41	2.20
21th, 1 PM	0.17	14.35	0.31	16.90	1.49	1.87
21th, 6 PM	0.24	45.12	0.19	29.88	1.63	2.40

On the other hand, although it appeared that the mobile emission has a little influences on the carbon dioxide concentration of capital areas, the carbon dioxide concentration was presented law at the estimation point as the carbon dioxide concentration is diffused well in the wide modeling area. Therefore, the carbon dioxide concentration was appeared lower than the measurement of the roadside or the residential area (Table 2).

Table 2 Contribution of the residential area measuring point(the atmospheric diffusion modeling result of metropolitan wide area)

Date	Concerntion (ppm)					
	Seoul (Area Sources)	Seoul (Mobile Sources)	Gyeong-Gi (Area Sources)	Gyeong-Gi (Mobile Sources)	In-Cheon (Energy)	In-Cheon (Mobile Sources)
22th, 9 AM	0.09	20	0.30	21	0.10	2.10
22th, 1 PM	0.03	2.3	0.05	5.42	1.50	0.27
22th, 6 PM	0.02	40	0.10	20.70	2.40	1.11
23th, 9 AM	0.08	16.90	0.43	15.20	0.14	1.97
23th, 1 PM	0.02	10.85	0.09	9.32	1.08	0.67
23th, 6 PM	0.04	26.20	0.32	19.54	1.85	2.54
24th, 9 AM	0.01	35.58	0.39	22.17	0.64	2.17
24th, 1 PM	0.02	26.89	0.12	18.03	0.97	1.22
24th, 6 PM	0.04	49.70	0.45	31.80	1.09	2.44
25th, 9 AM	0.02	21.80	0.52	19.50	0.84	2.01
25th, 1 PM	0.03	17.20	0.15	12.40	0.97	1.37
25th, 6 PM	0.04	20.01	0.48	17.90	1.69	2.42

As a wide area modeling targeting a whole capital areas has a limit of reflecting the regional characteristics that should be predicted, it was identified that there is a difficulty in a precise prediction.

3.5 Micro-Space Modeling Result

For the result of the carbon dioxide modeling performance of each emission source in capital areas, It has been appeared that the contribution rate affecting micro-space was low (Fig. 5).

Therefore, for this study, the micro-space modeling about the area above has been performed, and the result was as in the following. The A and B on the equipotent curve is a roadside measuring point and the one of residential area respectively.

On 18th, around 6 PM, the carbon dioxide concentration for the roadside measuring point was appeared higher than 150 ppm, and for the upper part of the measuring point that has loads of traffic as it is a 10 lane road, the carbon dioxide concentration was 1,000 ppm - 2,000 ppm.

At the measuring point on 22nd of April, the time for measurement, the carbon dioxide concentration is as follows. At 9 O'clock, which is rush hour, 100 ppm - 300 ppm of the carbon dioxide concentration was taken at the roadside measuring point, and the carbon dioxide concentration of residential area was shown as less than 10 ppm.

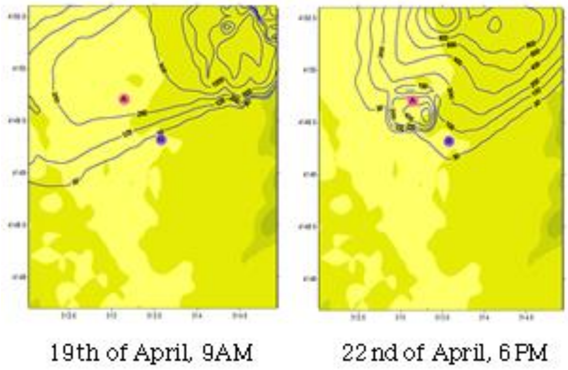

Fig. 5 The result in micro-space

To figure out the contribution of the concentration to capital city, the measured value was compared to combine one of the carbon dioxide average ambient concentration of An-Myoen Do in 2012, 402.23 ppm, with the result in micro-space modeling performance.

As Figs. 6 - 9 are the graph of comparative analysis between the measured value of roadside, residential area and the result value, it seemed that there is a difference in the concentration of the roadside for each time period compared to the one of residential area. Thus, to compare the tendency of modeling result value with roadside measured value, Figs. 6 - 9 was subdivided.

As Fig. 6 is a result that is comparing the modeling result value with the carbon dioxide measured value for 3 days, from 18th of April 1 PM to 21st of April 5 PM, the tendency of modeling result value and measured value was shown comparably similar.

Especially, the graph of 18th, weekday, shows the concentration pattern of carbon dioxide which was measured in rush hour well, it was shown that the carbon dioxide concentration of 400 ppm - 500 ppm from 2 to 4 PM rose up to 700 ppm from 6 to 7 PM. This is estimated that there is an influence on the carbon dioxide concentration from the rapid growth in traffics of rush hour.

The tendency of carbon dioxide concentration curve of 19th and 20th during the weekend, appeared a little different than one of 18th. Compared to the one that the carbon dioxide concentration of the closing time was higher than any other time on 18th, the concentration tended to remain steady relatively, irrespective of commuting time during the weekend. Particularly, it is identified that the carbon dioxide concentration of roadside measuring point would have appeared relatively high because of heavy traffic more than other places as there is a huge shopping center around them despite during the weekend.

On the graph of 3rd day after measurement, the carbon dioxide concentration was maintained at the point of 600 ppm from 20th 6 PM to 21st 6 AM, weekend, it turned out 900 ppm on 21st 8 AM, the morning rush hour, which was the most high.

Thus, as a result of the comparative analysis between carbon dioxide measured value and the modeling result value, it appeared for patterns of the measured value and the modeling result value to be comparably similar. Also, it helped for us to figure out the characteristic of the carbon dioxide concentration for the rush hour.

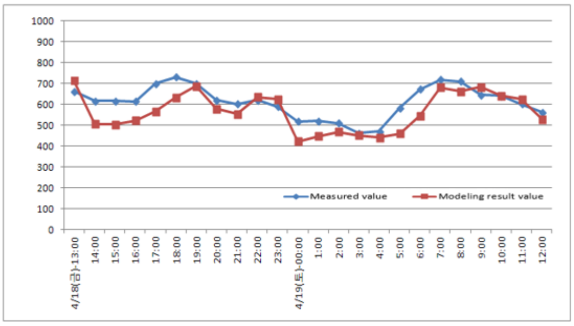

Fig. 6 The measured value of carbon dioxide on the roadside and the modeling result value (ppm)

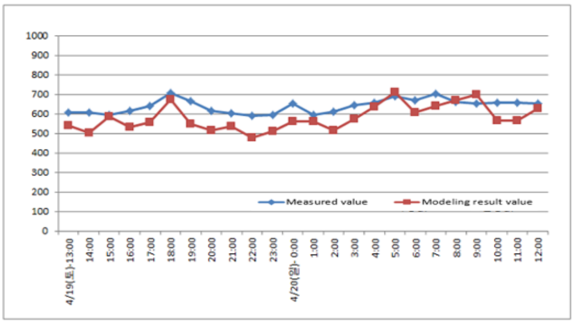

Fig. 7 The carbon dioxide measured value on the roadside and the modeling result value (ppm)

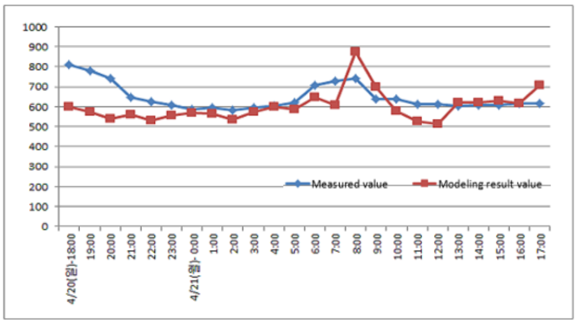

Fig. 8 The carbon dioxide measured value on the roadside and the modeling result value (ppm)

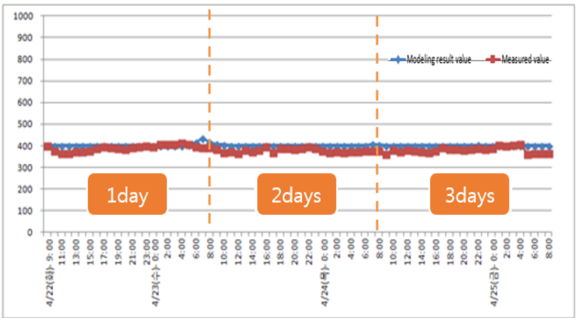

Fig. 9 The carbon dioxide measured value in residential areas and the modeling result value (ppm)

Fig. 9 is a graph that compares the carbon dioxide measured value for 3 days from 22nd of April 9 AM to 25th 8 AM and the modeling result.

Although it was during the weekday from 22nd to 25th, it was suggested that the carbon dioxide concentration in residential area remained steady around 400 ppm which was different than the concentration of roadside in each time during the period of measurement.

Also, compared to 402.23 ppm, the average ambient concentration of carbon dioxide in An-myoen Do, it has been shown that the residential areas are not influenced by the carbon dioxide concentration

Through the comparative analysis between the measured value of roadside as well as residential areas and the result value, the carbon dioxide concentration distribution appeared in different pattern. In the case of roadside, the characteristic of carbon dioxide concentration distribution was reflected in modeling depending on the commuting time during the weekdays. For the residential areas, the carbon dioxide concentration was marked on the average ambient concentration level which is different than the one of roadside despite during the weekdays, and from that we were informed that the residential area does not almost affected by the concentration.

Thus, for the result of this micro-space modeling performance, the emission source that directly affects the carbon dioxide concentration is the mobile emission.

Thus, in this study, the modeling result of micro-space and relationship with the measurement showed in a relation and an explanation through the regression analysis on the (Fig. 10). The result in the regression analysis of the result value and measurement for the micro-space modeling was presented that there is a correlation as having the R^2 of 0.605.

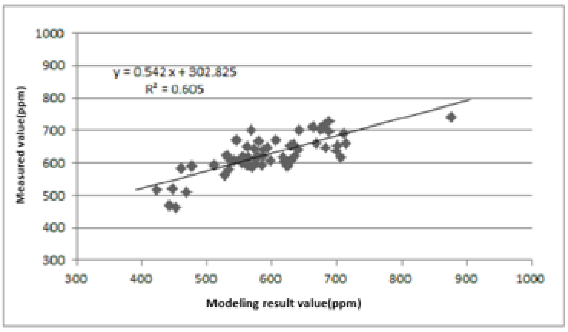

Fig. 10 A comparison between the result value and the measurement of the micro-space modeling

According to the result of this study, there is a possibility that the carbon dioxide concentration could be underestimated in the area to estimate more than the actual one as the modeling of large grid has limits in the simulation for the high-concentration in micro space.

Thus, for an accurate estimation of the area to estimate, it seemed that the micro-space modeling would be needed. Also, viewing the existing indoor ventilation calculation (Eq. 1), 330 ppm was applied for the carbon dioxide concentration [9, 10].

$$Q = \frac{G}{C_i - C_o} \quad (1)$$

In the expression above,

Q : ventilation requirement (m^3/hr)

G : CO_2 emission for person per hour, 21/hr

C_i : permissible level for indoor CO_2, usually 0.1%

C_o : CO_2 concentration in the air, 0.033%

However, according to the result of this study, as the carbon dioxide concentration of the roadside appeared up to 700 ppm, the natural ventilation in roadside could be meaningless any longer in accordance with the carbon dioxide concentration which is being applied on the existing indoor ventilation calculation. Thus, it was considered that the multi-modal studies from the perspectives of policy such as relevant regulations for indoor air quality management would be needed.

4. Conclusion

In this study, to estimate an influence of the carbon dioxide emission on capital area, after using the micro-space modeling reflecting the local characteristic of wide area modeling about the entire metropolitan area and micro area through the CALPUFF model, with a comparative analysis for the predicted concentration, we have gained the following conclusions.

The result in micro-space modeling performance of the entire metropolitan area according to the carbon dioxide emission by category of CAPSS 1 km x 1 km emission source is as follow. It appeared that the area source emission does not effect on the carbon dioxide concentration almost, and the mobile emission does a little as it was 30 ppm - 50 ppm. However, as the modeling of large grid has a limit for the high concentration simulation of micro area, the carbon dioxide concentration has a possibility to be underestimated more than actual one, and it actually estimated lower than the roadside. Based on this, the wide area modeling targeting the entire metropolitan area is limited to reflecting the characteristic of high concentration area which is micro, so it was identified that there is a difficulty in an accurate prediction.

To complement the limits for the wide area modeling of large grid, the micro-space modeling performance result is as follows.

The carbon dioxide concentration at the measuring point of roadside on 18th, 6 PM when the traffic is high appeared more than 150 ppm, especially at the upper part of measuring point the traffic is high with 10 lanes, and the carbon dioxide concentration appeared 1,000 ppm - 2,000 ppm.

To figure out how much the carbon dioxide concentration contribute to the metropolitan area, as a result of comparison with the measured value after adding the carbon dioxide average background concentration [10], 402.23 ppm, with the outcome of micro-space modeling performance, it was analyzed that there is a correlation partly as the result of regression analysis for the outcome of micro-space modeling performance and the measured showed R^2 of 0.605.

Also, whereas the carbon dioxide concentration applied to the existing indoor ventilation calculation, as a result of this study, the carbon dioxide concentration of the roadside appeared up to average 700 ppm, so to analyze with the carbon dioxide concentration applied to the current indoor ventilation calculation, the outcome that the utility of natural ventilation at roadside of city central where the traffic is high could be low was obtained. Thus, for the indoor air quality management, it seemed to be needed the diversified review from the political perspective such as relevant regulations.

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