Indoor Nitrogen Dioxide Investigation and Health Risk Assessment in Primary Schools at Rayong City, Thailand

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Received: 25 April 2019, Revised: 29 June 2019, Accepted: 31 July 2019

Abstract

Indoor air pollution in schools adversely affects children's health due to the inhalation of nitrogen dioxide (NO_2), which is a toxin released by motor vehicles. This research aims to measure NO_2 levels around schools in an attempt to evaluate indoor air quality within the framework of a health risk assessment. Air samples were collected in schools from indoor and outdoor locations. The results for indoor NO_2 concentrations in urban, industrial and rural areas ranged between 12.8 - 32.9, 11.7 - 36.6 and 7.0 - 17.5 μg/m^3, while the values for outdoor areas ranged between 13.0 - 43.7, 15.5 - 37.6 and 10.1 - 32.6 μg/m^3, respectively. The indoor NO_2 concentrations measured in urban and industrial areas were significantly higher than those in rural areas ($p<0.05$), while the values for urban and industrial areas were not significantly different ($p>0.05$). The mean of indoor and outdoor NO_2 concentrations were not significantly different ($p>0.05$) and these values were more significantly correlated ($r = 0.526$). Moreover, the values of NO_2 concentrations and meteorological factors were not significantly correlated, thereby rejecting the hypothesis that meteorological factors might have affected indoor NO_2 concentrations. These findings clearly stress the relationship that exists between NO_2 concentrations and the level of local activity, for example traffic intensity. Hazard quotient (HQ) values indicated that human health risks linked to NO_2 inhalation were of the low hazard type. It can be concluded that local activities played a significant role in the emission of NO_2 and the level of indoor air quality in classrooms.

Keywords: indoor air pollution, nitrogen dioxide, passive sampling, hazard quotient (HQ)
DOI 10.14456/cast.2019.21

1. Introduction

Indoor air pollution in schools represents one of the most serious environmental and public health concerns in the world. Indoor pollutants such as particulate matter (PM), volatile organic compounds

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(VOCs), formaldehyde, carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and polycyclic aromatic hydrocarbons (PAHs)have often been measured in schools [1-3]. Major sources of pollutants in schools can originate from outdoor pollution sources like motor vehicle traffic, industry and combustion, while other sources are related to indoor human activities including painting, cleaning, equipment building and furnishings [4, 5].

The measured level of nitrogen dioxide commonly is often a major indicator of traffic air pollution [1, 6]. It is the most toxic form of nitrogen oxides (NO_X). Boulter *et al.* [7] reported that the proportion of NO_2 within the total NO_X for diesel burning (20-70%) in an engine was 7-10 times higher than for petrol burning (2-10%). Relations between NO_2 levels inside primary schools and urban areas of Italy were studied by Cibella *et al*. [6], who established that the mean of indoor NO_2 concentrations during winter and spring seasons were 32.2±16.3 μg/m^3 and 31.9±14.9 μg/m^3, respectively. Moreover, during 25.2 % of the time in winter and 24.5% of the time in spring, indoor NO_2 concentrations in primary schools exceeded the World Health Organization indoor limit of 40 μg/m^3. An investigation into indoor NO_2 levels inside primary schools located in the centre of cities and in the suburban area of Aveiro in Portugal was undertaken. The researchers revealed that indoor NO_2 concentrations during a one-week time-frame ranged from 12.81±0.59 to 16.46±0.98 μg/m^3 and from 12.92±0.59 to 16.57±0.99 μg/m^3 in city centre and sub-urban areas, respectively. The researchers further concluded that the levels of NO_2 observed were related to vehicular exhaust emissions from nearby intense traffic [1]. Rivas *et al* [8] revealed the presence of NO_2 concentrations in classrooms and playgrounds in 39 schools in Barcelona, Spain. It was found that the levels of NO_2 concentrations in classrooms (5-69 μg/m^3) were lower than those in playgrounds (14-98 μg/m^3). The intensity of road traffic was identified as the main cause of pollution.

Each day, children spend most of their time in schools, where they are primarily exposed to indoor pollution rather than outdoor pollution. Children while still growing up have an immune system that is not yet fully developed. Therefore, they are more vulnerable to various indoor environmental pollutants than are adults [1, 9, 10]. Previous studies reported that a relationship existed between exposure to NO_2 and health effects in schoolchildren such as respiratory illnesses, impaired lung function, and asthma [6, 11-13]. Furthermore, Norbäck *et al*. [3] revealed that indoor NO_2 concentrations in schools were associated with ocular symptoms and fatigue. Giffin *et al*. [13] reported that 10 ppb increase in NO_2 levels was associated with a 5% decrease in pulmonary function. An increment of 21.9 μg/m^3 in the 7-day-average concentrations of NO_2 was associated with a 6.1 % increase in pneumonia hospitalizations [14]. Ayuni and Juliana [12] found that exposure to indoor NO_2 concentrations might increase the risk of respiratory problems among schoolchildren living near petrochemical industries. Furthermore, girls may be more susceptible to indoor NO_2 than boys [11].

Indoor air quality in schools is regarded as a serious issue because air pollutants can be the cause of adverse health effect in students. Consequently, the main objective of this research is to accurately determine indoor NO_2 concentrations in various primary schools located within the vicinities of intense traffic areas so as to assess the level of quality of indoor air and its possible risks to health.

2. Materials and Methods

2.1 Sampling sites

Rayong province is located in the eastern part of Thailand. It is famous for its natural resources, which include various kinds of tropical fruit and seafood. Moreover, an industrial estate is also situated there. Sampling sites were surveyed and randomly selected within three areas of the Rayong province. There are 12 primary schools (Figure 1 and Table 1) included in the study and they can be divided into urban areas (4 sites), industrial areas (4 sites) and rural areas (4 sites). Air-quality samples were randomly collected inside three primary school classrooms surrounded by communal ambient air. The selection of locations for the sampling sites was based on criteria like school roadside infrastructure, traffic intensity, population density, and human activities. The sampling sites as seen in Figure 1 are defined as follows :

Urban area (UB) : This urban area is identified as the Rayong municipality. It is a community area which includes residential and business buildings, a transportation network and high traffic intensity.

Industrial area (ID) : This is the Map ta phut industrial estate in Map ta phut municipality. Most of the area is occupied by industrial plants and included are petroleum plants, a coal-fired power plant, petrochemical and plastics facilities, community areas and various transportation networks.

Rural area (RR) : This is the Wong Chan district. Most of the area is used for agricultural purposes such as rubber trees and pineapples fields. There is a low level of vehicle traffic.

The samples were subjected to continual exposure over a week from September 2017 to February 2018 (except for the entire month of October 2017, which was the primary school semester break).

2.2 NO_2 sampling and analysis

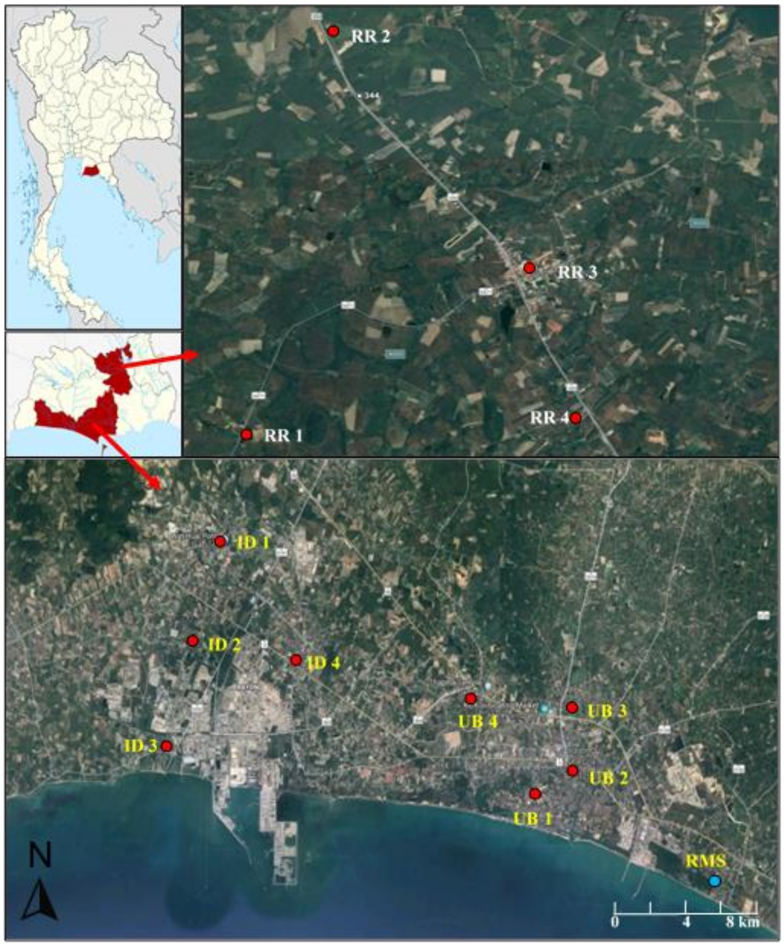
The indoor and outdoor NO_2 concentrations were collected using lab made passive samplers sourced from the Environmental Chemistry Research Laboratory (ECRL), Chemistry Department, Faculty of Science, Chiang Mai University. The polypropylene (PP) passive sampler (7.70 cm length and 1.50 cm inner diameter) containing 50 µl of 20% triethanolamine (TEA) was directly added onto the Whatman GF/A filter paper. A sample set consisted of 5 sampling tubes and 3 blank tubes, which were attached to a shelter and hung at 1.5 – 2.0 m above ground level for 1 week. After sampling, the NO_2 concentration was determined colorimetrically as nitrite (NO_2^-). For extraction, the NO_2 samplers were extracted with 2 ml of deionized water, shaken and held for 15 min. One ml of the extracted sample solution was filtered through a 0.45 µm cellulose acetate membrane. Then, the solution was mixed with 2 ml of Saltzmann reagent and allowed to stand for 10 min until color development was completed. After extraction, the absorbance was measured by spectrophotometer (Shimadzu UV 2600, Japan) at 540 nm [15].

2.3 Statistical analysis

The data were statistically analyzed by T-test to determine the difference between indoor and outdoor nitrogen dioxide levels. One-way ANOVA was used to analyze the mean difference between the spatial variations. The NO_2 concentrations were log–transformed to achieve normal distribution. Pearson correlation analysis was used to assess the relationship between the meteorological data and the NO_2 concentrations. The meteorological data were received from Rayong Meteorological Station (RMS) and from the Thai Meteorological Department (TMD) (Figure 1).

2.4 Health risk assessment

Health risk assessment is a process estimating the exposure risk linked to pollutant inhalation on the basis of the hazard quotient (HQ). The hazard quotient (HQ) is widely used to assess the effects of non-carcinogenic risk exposure to a known pollutant. It reflects the probability of an adverse health outcome occurring among healthy or sensitive individuals [16-18]. Human exposure was explained in terms of the average daily dose (ADD). ADD was quantified as described in equation 1 :



Note: Applied from Google map

Figure 1. Map of NO_2 sampling sites; (A) Wang Chan district and (B) Maung district of Rayong province.

Table 1. Sampling sites and land-use patterns of primary schools in Rayong province

Site	Code	Classrooms characteristics	GPS position Lat-Long
Urban area	UB 1	The school is located along a road of approximately 8 m in width. A high level of traffic intensity occurs during rush hours. It is surrounded by many government offices. Its buildings have 3 floors and are constructed from concrete.	12° 40' 29.73" 101°16' 44.79"
	UB 2	The school is located in a temple area, ~200 m distant from a road of 8 m in width with a high level of traffic intensity. Its buildings are of 3-4 floors and are constructed from concrete.	12° 40' 47.88" 101° 16' 59.94"

Table 1. (cont.)

	UB 3	The school is located behind a temple area. The buildings are of 2 floors and are constructed from concrete. The school is near the local market and department store. It is approximately 1 km away from a highway road.	12° 42' 1.278" 101° 16' 29.44"
	UB 4	The school is located close to a highway intersection or interchange road that has a high level of traffic intensity during rush hours. Its buildings are of 2-3 floors and are constructed from concrete.	12° 42' 16.938" 101° 14' 24.69"
Industrial area	ID 1	The sampling site is near an intersection and a temple. Its buildings have 2-4 floors and are constructed from concrete. It is located close to a tapioca flour manufactory.	12° 45' 15.96" 101° 8' 11.76"
	ID 2	The school is located on the premises of a temple near a petrochemical plant. It is built from wooden and concrete materials and consist of 2 floors. It is near an intersection and approximately 100 meters away from a road where a high level of traffic intensity occurs especially during rush hours.	12° 41' 6.6768" 101° 6' 58.88"
	ID 3	The school is located at the back of the Maptaphut municipality. It is built from wooden materials and has 2 floors. This site is surrounded by governmental offices.	12° 43' 23.37" 101° 7' 35.58"
	ID 4	The school is located on a highway road. There are 4-6 floor buildings that are constructed from concrete. It is surrounded by commercial buildings and a local market. This site is a residential area close to an intersection with a high level of traffic intensity.	12° 42' 55.63" 101° 10' 0.45"
Rural area	RR 1	The school is located on a local road in a small residential area surrounded by rubber tree fields and orchards. The school has 2 floors and it is built of wooden and concrete materials.	12° 54' 38.28" 101° 28' 47.61"
	RR 2	The sampling site is located on a highway. Its buildings are constructed with wooden materials and have 2 floors. It is surrounded by rubber tree fields.	12° 58' 50.63" 101° 29' 32.88"
	RR 3	The school is located near a hospital. It is surrounded by commercial buildings and a local market. Its buildings have 2 floors and are constructed from concrete and wooden materials.	12° 56' 23.874" 101° 31' 38.82"
	RR 4	The school is located in a temple area. It has 2 floors and its buildings are constructed from concrete and wooden materials. The sampling site is surrounded by rubber tree fields.	12° 54' 47.264" 101° 31' 54.42"

$$\mathrm{ADD} = \frac{\mathrm{C} \times \mathrm{Inh\ R} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

where ADD is the ADD of pollutants; C is the concentration of NO_2 (μg/m^3); ED is the exposure duration (days); BW is the body weight of the exposed group (Kg); AT is the average time (days); InhR is the inhalation rate (m^3/day) and EF is the exposure frequency (days/year). The values of these parameters were reported [16-18] as shown in Table 2.

Table 2. Parameters of the average daily dose (ADD) for NO_2

Parameters	**Exposed group**	
	Child (6-12 years)	**Adult (19-75 years)**
Exposure frequency (EF)	350 days/year	350 days/year
Exposure duration (ED)	12 years	30 years
Averaging time (AT) AT = ED ×365 days	4,380 days	10, 950 days
Body weight (BW)	45.3 Kg	71.8 Kg
Inhalation rate (InhR)	16.6 m^3/day [19]	21.4 m^3/day

The HQ was calculated from the ratio of ADD and the reference dose (RfD) of each pollutant using the following equation 2.

$$\mathrm{HQ} = \frac{\mathrm{ADD}}{\mathrm{RfD}} \quad (2)$$

The reference concentrations (RfD) allowable for human exposure are shown in Table 3. When the HQ < 0.1, there is no hazard or only negligible risk. When the HQ values are situated between 0.1-1.0, there are low hazard risks. When the HQ values are situated between 1.1-10.0, there are moderate risks. When the HQ values are situated above the threshold of 10, there are high hazard risks [16].

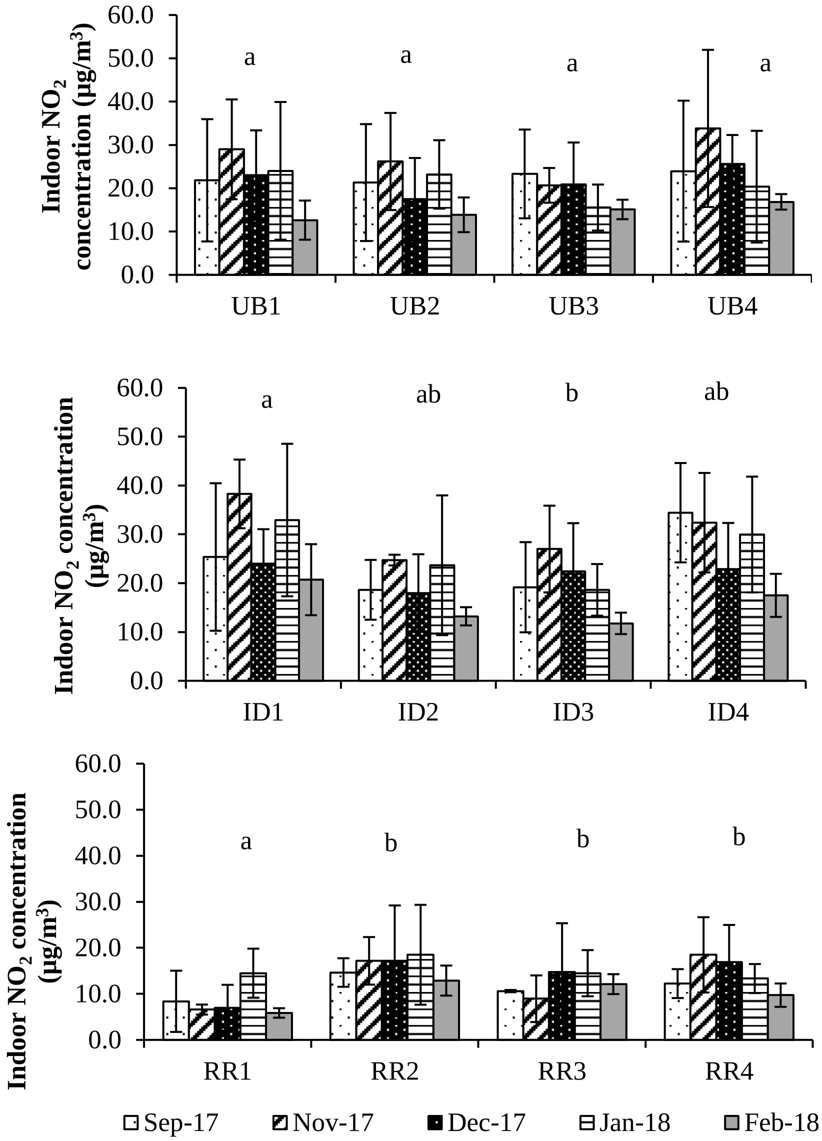
Table 3. The indoor air quality standard of nitrogen dioxide (NO_2)

Organization or country	**Indoor air quality standards for NO_2 (μg/m^3)**		
	1 h	**8 h**	**Annual mean**
NAAQ-US-EPA[20]	200	-	40
WHO[21]	200	-	40
Thailand[22]	-	150	-
Hong Kong[23]	200	150	40

3. Results and Discussion

3.1 NO_2 concentrations in primary schools

The mean concentrations of NO_2 were measured inside classrooms at primary schools in Rayong city as shown in Figure 2. The highest indoor NO_2 concentrations were found in the urban area at the UB4 site (15.1-52.0 μg/m^3). It is located close to a highway intersection with high traffic intensity. However, the indoor NO_2 concentrations were not significantly different ($p>0.05$) from one site to another. The highest indoor NO_2 concentration in the industrial area was found at the ID1 site (20.7±7.3 to 32.9±15.6 μg/m^3), while that in the rural area was found at the RR2 site (12.9±3.3 to 18.5±10.8 μg/m^3).



Note: a, b = Significant differences ($p < 0.05$) among groups of primary school within the same period

Figure 2. Indoor NO_2 concentrations in school at urban area (UB), industrial area (ID) and rural area (RR)

The cause of NO_2 concentrations in the industrial area may well be related to traffic and industrial plants, while the values in the rural area are likely due to traffic and open burning. Moreover, One-Way ANOVA was used to determine the differences in indoor NO_2 concentrations between each primary school. It was found that the indoor NO_2 concentrations in the primary schools of the urban area were not significantly different ($p>0.05$), and the values of the rural area from RR2 to RR4 were not significantly different ($p>0.05$). In the industrial area, the indoor NO_2 concentrations in the ID1 site were significantly different from the ID3 site ($p>0.05$). The values at the ID3 site were the lowest of indoor NO_2 concentrations in the industrial area despite the fact that this site was surrounded by government offices (Table 1). The buildings were made from wooden materials and an advantage of using them as building materials is that they cause a lower input of contaminants [4]. Therefore, the schools located within the vicinities of high traffic intensity are exposed to pollutants that may adversely affect the health of students and teachers.

The mean concentrations of NO_2 that were measured both indoors and outdoors at primary schools in Rayong province in the urban area, industrial area and rural area are shown in Table 4. The ranges of indoor NO_2 concentrations in the urban area, industrial area and rural area were 12.8-32.9 (mean: 21.4±4.6), 11.7-36.6 (mean: 23.8±5.5) and 7.0 - 17.5 μg/m^3 (mean: 12.7±2.0), while the values of outdoor were 13.0-43.7 (mean: 26.8±5.7), 15.5-37.6 (mean: 23.9±4.2) and 10.1-32.6 μg/m^3 (mean: 21.4±2.1), respectively. Further, the indoor NO_2 concentrations in the urban area, industrial area and rural area found in this study were higher than those found inside primary schools in Spain [24]. They reported that the indoor NO_2 concentrations in the urban area, industrial area and rural area ranged between 7.5-23.1, 9.8-15.8 and 1.4-29.3 μg/m^3, while the outdoor NO_2 concentrations were between 1.0-16.8, 3.7 0-9.2 and 1.0-2.2 μg/m^3, respectively. Guerriero *et al.* [25] reported indoor NO_2 concentrations in the suburban area (9.1-22.5 μg/m^3) and in the urban area (25.5-41.2 μg/m^3) of London, UK. It was found that the levels of indoor NO_2 were higher than those in this study. Moreover, the indoor and outdoor NO_2 values in this study were also lower than the levels of indoor (2.9-47.0 μg/m^3) and outdoor (1.7-50.9 μg/m^3) values in six schools in Stockholm, Sweden that were exposed to traffic [26]. Blaszczyk *et al.* [27] investigated the indoor and outdoor NO_2 concentrations of urban and rural kindergartens in Silesia, Poland. They found that the values from the urban area were 6.8-9.8 μg/m^3 (indoor) and 19.0-55.0 μg/m^3 (outdoor), whereas the values in the rural area were 4.2-13.5 μg/m^3 (indoor) and 8.0-17.0 μg/m^3 (outdoor), which were lower values than those in this study. It appears that the wooden materials used to construct primary schools in the rural area of Rayong allowed ventilation and in turn NO_2 contamination inside classrooms [4]. Significantly, the mean values of NO_2 concentrations collected from both indoor and outdoor areas were lower than the National Ambient Air Quality Standard (NAAQS) in the USA per annum, which is 40 μg/m^3[20]. The mean indoor NO_2 concentrations in the urban area, industrial area and rural area from September 2017 to February 2018 were 21.4±4.6, 23.8±5.5 and 12.7±2.0 μg/m^3, while the mean values of outdoor areas were 26.8±5.7, 23.9±4.2 and 21.4±2.1 μg/m^3, respectively.

For our statistical analyses, differences in the means of NO_2 concentrations between indoor and outdoor areas were calculated using paired T-tests. It was found that the concentrations of NO_2 measured indoors were not significantly different from outdoor concentrations in urban and industrial areas ($p>0.05$), whereas the values in the rural area were significantly different ($p<0.05$). However, the outdoor NO_2 concentrations in urban, industrial and rural areas were higher than those in indoor ones. One-Way ANOVA was used to differentiate the average NO_2 concentrations between the different sampling areas for each month. The indoor NO_2 concentrations measured in urban and industrial areas were significantly higher than those in the rural area ($p<0.05$), while the values of urban and industrial areas were not significantly different ($p>0.05$). The outdoor NO_2 concentrations in the urban area were significantly higher than those in the rural area ($p<0.05$). However, the outdoor NO_2 values in the industrial areas and the rural areas were not significantly different.

Table 4. Indoor and outdoor NO_2 concentrations (µg/m^3) and metrological data from sampling sites between September 2017 - February 2018

Study site			Concentrations of NO_2 (µg/m^3)					
			Sep. 2017 (n=4)	Nov. 2017 (n=3)	Dec. 2017 (n=4)	Jan. 2018 (n=4)	Feb. 2018 (n=4)	Sep. 2017 -Feb. 2018
Indoor	Urban area^A (N=4)	Max	23.9	33.8	25.6	24.0	16.9	27.4
		Min	21.3	20.7	17.4	15.5	12.6	14.6
		Mean	22.6^{ab}	27.4^a	21.7^{ab}	20.8^{ab}	14.6^b	21.4
		SD	1.2	5.5	3.4	3.8	1.8	4.6
	Industrial area^A (N=4)	Max	34.4	38.3	24.0	32.9	20.7	30.6
		Min	18.6	24.7	18.0	18.6	11.8	15.8
		Mean	24.4^{ab}	30.6^a	21.8^{ab}	26.3^a	15.8^b	23.8
		SD	7.4	6.0	2.6	6.4	4.1	5.5
	Rural area^B (N=4)	Max	14.6	18.5	17.2	18.5	12.9	15.2
		Min	8.4	6.6	7.0	13.3	5.8	10.1
		Mean	11.5^a	12.8^a	14.0^a	15.2^a	10.1^a	12.7
		SD	2.6	5.9	4.8	2.3	3.2	2.0
Outdoor	Urban area^A (N=4)	Max	35.6	54.0	32.1	42.6	37.2	33.7
		Min	15.2	24.4	13.0	19.3	15.0	21.0
		Mean	23.1^a	32.0^a	21.0^a	33.7^a	24.1^a	26.8
		SD	8.7	14.7	8.0	10.0	9.4	5.7
	Industrial area^{AB} (N=4)	Max	27.7	40.8	25.6	38.4	28.8	30.6
		Min	13.4	25.8	15.3	15.7	13.2	19.8
		Mean	22.1^a	30.6^a	19.8^a	25.3^a	21.8^a	23.9
		SD	7.0	7.0	4.3	9.7	7.2	4.2
	Rural area^B (N=4)	Max	27.9	38.2	38.2	32.7	30.3	23.4
		Min	9.7	14.5	12.6	14.8	14.7	18.2
		Mean	18.2^a	22.9^a	21.0^a	23.4^a	21.4^a	21.4
		SD	8.1	10.7	11.6	9.2	7.0	2.1
Ratio I/O	Urban area		0.98	0.86	1.03	0.62	0.61	0.80
	Industrial area		1.10	1.00	1.10	1.04	0.72	0.99
	Rural area		0.63	0.55	0.66	0.65	0.47	0.59
Total precipitation (mm)* (precipitation date)			276.9 (17)	100.7 (10)	11.6 (3)	1.4 (3)	16.6 (4)	411.4 (37)
Relative humidity (%)*			82.1 ±3.3	80.1 ±11.7	69.3 ±5.1	78.9 ±7.0	78.2 ±5.3	77.6 ±7.4
Wind speed (Knot)*			2.8±1.4	2.3±1.7	2.9±0.8	2.0±0.8	2.4±0.4	2.5±1.0
Ambient temperature (ºC)*			28.2 ±0.7	26.9 ±0.4	25.7 ±1.3	26.6 ±1.4	26.9 ±1.0	26.9 ±1.3

Notes; N = Number of school days
n = Number of weeks
A, B = Range of significant discrepancy ($p < 0.05$) among clusters of sampling areas (vertical direction)
a, b = Range of significant discrepancy ($p < 0.05$) among clusters of sampling months (horizontal direction)
* Thai Meteorological Department, 2017-2018

Table 4 shows that the indoor NO_2 concentrations in urban and industrial areas in November 2017 were significantly different from those in February 2018 ($p<0.05$), whereas the values in the rural area from September 2017 to February 2018 were not significantly different. The outdoor NO_2 concentrations in all areas from September 2017 to February 2018 were not significantly different ($p>0.05$).

The indoor/outdoor (I/O) ratio of NO_2 concentrations is specifically defined to be greater than 1, which shows that the exposure of NO_2 values can be higher indoors when compared to the extended outdoor area. Table 4 presents the I/O ratio means for NO_2 concentrations in the urban area, industrial area and rural area of primary schools in the Rayong province. It was found that the I/O ratios of NO_2 concentrations in descending order were: urban area (0.61-1.03 and mean: 0.80) > industrial area (0.72-1.10 and mean: 0.99) > rural area (0.47-0.66 and mean: 0.59). Guerriero *et al*. [25] reported that the I/O ratios of NO_2 levels in primary schools of London in the urban area were (0.6-0.8; mean 0.7±0.1) and in the sub-urban area were (0.3-0.7, means 0.5±0.2), results that were very similar to the values obtained in this study. Moreover, the I/O ratios of NO_2 concentrations in this study were lower than those in the primary schools of Stockholm, Sweden (0.44-2.17 and mean: 0.96±0.36) [26]. Bruno *et al.* [28] and Poupard *et al.* [29] revealed that the I/O values vary within a narrow range, from 0.88 to 1, as shown by the positive relationship that exists between indoor and outdoor NO_2 concentrations. On the whole, indoor concentrations reflect the outdoor concentrations irrespectively of the level of airtightness of the building.

3.2 Effects of meteorological factors on NO_2 concentrations

The climate in Thailand is under the influence of monsoon winds of seasonal character, such as the southwest monsoon (SW) and the northeast monsoon (NW). When the SW monsoon prevails over Thailand, the rainy season occurs, and abundant rain falls over the country. This happens from mid-May to mid-October. Winter, which starts in mid-October and ends in mid-February, is influenced by the NE monsoon. The NE monsoon brings cold and dry air from the anticyclone in mainland China over the Northern and Northeastern parts of Thailand [30]. Figure 3 presents the different wind directions and levels of wind speed in the Rayong province during the sampling periods. The major SW-NE wind direction dominated throughout September 2017 and January to February 2018, whereas in November and December 2017 the N-S (north to south) wind prevailed. The wind speed range from September to December 2017 was 2-10 knots whereas it was about 2-9.9 knots in January and February 2018. The calmness index was averaging a level nearing 50% and above. Overall wind speed was poor.

Pearson's correlations of NO_2 concentrations and meteorological factors including total precipitation (total-P), relative humidity (RH), wind speed (WS) and ambient temperature (Temp.) are shown in Table 5. The results suggested significantly strong correlations between indoor and outdoor NO_2 concentrations as r = 0.526 (P<0.001). These results were similar to those of Bozkurt *et al.* [31] and Blaszczyk *et al.* [27], who studied the correlation values of NO_2 in schools in industrial cities in Turkey (r = 0.9-1.0) and rural kindergartens in Silesia, Poland (r = 0.430) observed. Moreover, the positive correlations of relative humidity with total precipitation and ambient temperature were significant (r = 0.512 and 0.654), while wind speed levels and relative humidity were negatively correlated with any level of significance (r = -0.576). On the other hand, the indoor NO_2 concentrations were weak and hence negatively related to wind speed and ambient temperature. The relationships between outdoor NO_2 concentrations and wind speed or ambient temperature were weak, and hence negative. Nevertheless, previously published studies demonstrated that NO_2 concentrations were negatively related to rainfall, temperature and wind speed (r = -0.929, -0.819 and -0.950, respectively) with any level of significance [32]. Ahmad and Aziz [33] revealed that outdoor NO_2 concentrations were significantly related to temperature (r = -0.839) and rainfall (r = -0.928). In general, increasing levels of wind speed facilitate the dilution of air pollutants at the ground level and a reaction of the indoor level as well. Decreasing atmospheric temperature supports low mixing height, which prevents the dispersion of pollutants. Consequently, indoor values were found to rise to such a high level. The increase in total precipitation is linked to relative humidity, as rain cleanses and eliminates pollutants from the atmosphere [34]. Moreover, low wind speed together with calm conditions constitute important factors that condition the accumulation of air pollutants [35]. It seems that meteorological factors might not have affected NO_2 concentrations since the correlation of NO_2 concentrations with different meteorological factors did not identify any significant relationships. Importantly, however, the obtained results indicated that indoor NO_2 concentrations and outdoor NO_2 ones are primarily dependent upon the level of local activity i.e. traffic intensity and industrial plant operations. According to Wichman *et al.* [26], the main source (64-71%) of indoor NO_2 at schools and pre-schools was outdoor NO_2 that had infiltrated indoors.

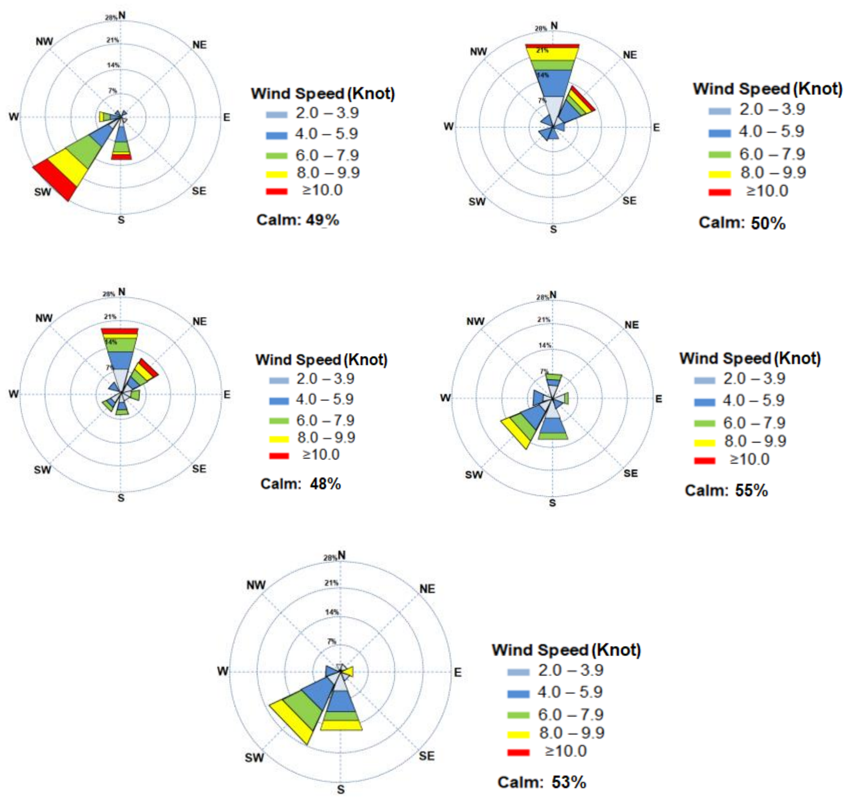


Figure 3. Wind Speed in Rayong province during sampling in each month: A. September 2017, B. November 2017, C. December 2017, D. January 2018 and E. February 2018

Table 5. Pearson correlations of meteorological factors and NO_2 concentrations in primary schools

N = 57	**Indoor NO_2**	**Outdoor NO_2**	**Total-P**	**RH**	**WS**	**Temp.**
Indoor NO_2	1.000					
Outdoor NO_2	**0.526****	1.000				
Total-P	0.241	-0.021	1.000			
RH	0.062	-0.004	**0.512****	1.000		
WS	-0.132	-0.165	0.002	**-0.576****	1.000	
Temp.	-0.190	-0.291*	**0.392****	**0.654****	-0.048	1.000

*Correlation is significant at the 0.05 level (2- tailed)
**Correlation is significant at the 0.01 level (2- tailed)

3.3 Human health risk of indoor NO_2 concentration

The hazard quotient (HQ) is used for the estimation of non-carcinogenic risks to human health that derive from NO_2. The HQ of NO_2 is calculated by equations 1 and 2. Students spend most of their time indoors, in the classroom. They are more exposed to pollutants when they are inside than when they are outside in playgrounds. Therefore, human health risk was assessed according to the level of inhalation of NO_2 in indoor environments only. Table 6 presents the HQ of short-term (1- 8 hours) and long-term (annual mean) non-carcinogenic health risks for indoor NO_2 exposure in urban, industrial and rural areas. The results for all HQ values deriving from exposure to indoor NO_2 over a period of 5 months via the inhalation pathway were less than 1.0, which indicates the existence of a low hazard. In the same way, Olufemi *et al.* [18] studied HQ values pertaining to exposure to NO_2 indoors among students in schools located within the vicinities of coal mines in Emalahleni, South Africa. They found that HQ values deriving from exposure to NO_2 were less than 1.0. The HQ values per annum in relation to children and adults in the industrial area of Rayong city were higher than those for individuals in urban and rural areas of Rayong city. However, many health risk studies have established that exposure to low concentrations of NO_2 may increase the risks of pneumonia, hospitalization, asthma problems, respiratory problems and decreased lung function in children [6, 14, 36, 37]. Zhang *et al.* [38] revealed that an increase of 10 $\mu g/m^3$ in NO_2 concentration contributed towards an increase of 2.0 % in associated chronic obstructive pulmonary disease (COPD) in adults, an increase of 1.3 % in hospital admissions and an increase of 2.6 % in mortality.

Table 6. ADD and HQ values for indoor NO_2 at primary schools in each area of Rayong city

Sampling site	**ADD (μg/Kg)**		**HQ**					
			Child			**Adult**		
	Child	**Adult**	**1 h**	**8 h**	**Annual**	**1 h**	**8 h**	**Annual**
Urban area	7.5±1.6	6.1±1.3	0.04	0.05	0.19	0.03	0.04	0.15
Industrial area	8.4±1.9	6.8±1.6	0.04	0.06	0.21	0.03	0.04	0.17
Rural area	4.5±0.7	3.6±0.6	0.02	0.03	0.11	0.02	0.02	0.09

4. Conclusions

The concentrations of indoor NO_2 in primary schools at Rayong city were found to be directly associated with outdoor pollution caused by road traffic intensity. It was clearly seen that the values of NO_2 in urban and industrial areas were significantly higher than those in the rural area. Moreover, a positive correlation for NO_2 concentrations between indoor and outdoor premises in primary schools was identified within the relevant range of significance. Meteorological factors might not have affected indoor NO_2 concentrations. The obtained results indicate that indoor NO_2 concentrations levels are much more dependent upon local activities such as traffic intensity than upon meteorological factors. Students sitting in classrooms in proximity to zones of high traffic intensity may be exposed to NO_2. However, the HQ values in relation to a non-carcinogenic risk to human health deriving from NO_2 exposure have indicated the existence of a low hazard.

5. Acknowledgements

Financial supports from King Mongkut's University of Technology North Bangkok (Contract no. KMUTNB-61-NEW-019) are gratefully acknowledged. The authors are grateful to the Thai Meteorological Department for Meteorological data in the Rayong province, Thailand.

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