Indoor Air Quality, Traffic Pollution Infiltration and Resource Adequacy in School Health Rooms in Bangkok

Jirapat Ratanachotinun[1] and Sattha Phalungsongsathit[2*]

[1]Samsenwittayalai School, Bangkok 10400, Thailand
[2]Faculty of Science, Chandrakasem Rajabhat University, Bangkok 10900, Thailand
**Corresponding Author E-mail: sattha.phalungsongsathit@gmail.com*

ABSTRACT

Environmental safety and resource adequacy within educational settings are pivotal to student healthcare and recovery. This study evaluates environmental factors—specifically particulate matter (PM2.5 and PM10), carbon dioxide (CO_2), and meteorological parameters (temperature, relative humidity, and air velocity)—within school health rooms under the Bangkok Metropolitan Administration. Additionally, it examines the spatial correlation between traffic-related pollutant infiltration and physical setback distances from major roadways, alongside an assessment of physical resource adequacy, focusing on the bed-to-student ratio and emergency medical equipment, such as Automated External Defibrillators (AEDs) and the professional licensing status of healthcare personnel. Using a cross-sectional descriptive design across eleven purposively selected schools, real-time monitoring via calibrated sensors and physical facility surveys were conducted. Polynomial regression analysis revealed a significant non-linear (curvilinear) relationship between setback distance and particulate matter infiltration, demonstrating that increased distance from arterial roads substantially mitigates PM2.5 ($R^2 \approx 0.72$, power function) and PM10 ($R^2 \approx 0.59$, linear function) concentrations. Conversely, indoor CO_2 levels exhibited no spatial correlation with roadways but frequently accumulated inside due to occupancy density and inadequate air exchange. Preliminary compliance and physical resource benchmarking indicated that while meteorological conditions generally aligned with comfort criteria, PM2.5 concentrations frequently breached national safety thresholds. Furthermore, a critical disparity was identified in facility and personnel preparedness: the bed-to-student ratios across most schools fell significantly below optimal recovery standards, and the deployment of life-saving AED units remained critically inconsistent. Crucially, the human resource evaluation revealed that while 60% of the sampled schools employed dedicated health room staff, only half of these personnel (30% of the total sample) possessed official professional licenses, while the remaining half (30% of the total sample) were unlicensed, with 40% of the schools completely lacking designated healthcare staff. These comprehensive findings provide a data-driven framework for policy-makers and architects to establish standardized guidelines that integrate environmental mitigation, spatial site-planning, and emergency resource allocation to secure safe educational recovery environments.

Keywords: School health rooms/ PM2.5/ Polynomial regression/ Resource adequacy/ Healthcare personnel licensing

1. INTRODUCTION

Air pollution in major urban areas, particularly in Bangkok, has intensified significantly over the past decade. Among the most critical pollutants are fine particulate matter with a diameter of less than 2.5 micrometers (PM2.5) and carbon dioxide (CO_2), both of which serve as key indicators of ambient and indoor air quality [1, 2]. These pollutants primarily originate from traffic emissions, fuel combustion, and various anthropogenic activities, posing serious health risks. Numerous studies have demonstrated that exposure to such pollutants is associated with increased incidences of respiratory and cardiovascular diseases, as well as adverse physiological effects [3, 4]. Recent studies in Thailand and Southeast Asia further confirm that PM2.5 levels in urban environments frequently exceed recommended thresholds, particularly in areas with dense traffic and limited air circulation [5, 6].

In Thailand, ambient air quality is regulated under national standards established by the National Environment Board, which define acceptable concentration levels for key pollutants, including PM2.5

and PM10, to protect public health [7]. These standards serve as an essential benchmark for assessing environmental air quality, particularly in urban settings with high emission sources.

Within the context of educational institutions, indoor air quality (IAQ) plays a crucial role in both health and learning performance. Existing research indicates that elevated CO_2 concentrations can impair cognitive function and decision-making ability, while PM2.5 can penetrate deeply into the respiratory system [8, 9]. Studies in air-conditioned classrooms have demonstrated that high occupancy without adequate air exchange leads to CO_2 levels exceeding 1,000 ppm within 45–60 minutes, potentially causing dizziness and lack of concentration [10]. Furthermore, physical factors such as room volume, material leakage, and the presence of exhaust fans significantly influence the stabilization of indoor pollutants [11].

School health rooms represent a particularly sensitive environment, as they are designated for students who are ill or in recovery, necessitating a higher standard of environmental quality than typical classrooms. However, proximity to major roadways increases the likelihood of pollutant infiltration, especially in buildings with inadequate ventilation systems [12, 13]. In Thailand, IAQ in public buildings is regulated through surveillance guidelines issued by the Department of Health, which establish acceptable thresholds for PM2.5, PM10, CO_2, temperature, and relative humidity [14]. Building characteristics and occupancy-related factors—including room size and ventilation conditions—significantly influence the dispersion of indoor air pollutants [15].

Accordingly, this study aims to investigate indoor air quality in school health rooms in Bangkok by examining concentrations of PM2.5, PM10 and CO_2 in relation to indoor environmental parameters. Furthermore, the study analyzes the relationship between the location of health rooms and their distance from major roadways, which serve as primary sources of air pollution. The findings are expected to provide empirical evidence for the design and improvement of school health rooms, contributing to healthier indoor environments and enhancing student well-being and safety in the long term.

2. METHODOLOGY

2.1 Research Objectives

To evaluate the environmental conditions regarding PM2.5, PM10, CO_2, temperature, air velocity, and relative humidity within the health rooms of the sampled schools in the Bangkok study area.

To analyze the environmental impact based on the correlation between the location of school health rooms and their setback distance from the main arterial road.

To perform a comprehensive assessment of indoor air quality and related environmental factors within the sampled school health rooms.

2.2 Scope of the Study

The study focuses on a sample group of ten schools located within the Bangkok Metropolitan Administration.

Surveying baseline institutional data, including educational levels, total school area, student population, health room dimensions, setback distance from the arterial road, and the number of traffic lanes on the road boundary.

Investigating health room specific data, including PM2.5, PM10, CO_2, temperature, relative humidity, air velocity, floor area, dimensions of doors and windows, bed capacity, and the presence of air purifiers, air conditioners, or exhaust fans, as well as the occupancy level during data collection.

Monitoring ambient air quality in the perimeter of the health rooms and at the roadside, focusing on PM2.5, PM10, CO_2, relative humidity, temperature, and air velocity.

2.3 Equipment Preparation

Key instruments utilized for data collection included a laser distance meter for physical setbacks, an anemometer for air velocity, and an air quality monitor for PM2.5, PM10, CO_2, relative humidity, and temperature (as shown in Figures 1, 2, and 3).

Environmental monitoring was conducted using factory-calibrated portable instruments. Particulate matter (PM2.5 and PM10) and CO_2 concentrations, alongside temperature and relative humidity, were continuously monitored using a calibrated multi-parameter air quality monitor (INKBIRD Plus, calibrated via factory NDIR and laser scattering protocols according to ISO/IEC 17025 standards). The detection limits and accuracies were ±10 $\mu g/m^3$ (or ±10%) for PM2.5/PM10, ±50 ppm ±5% for CO_2 (range: 400–5,000 ppm), ±0.5^oC for temperature, and ±3% RH for relative humidity. Air velocity was measured using a calibrated hot-wire thermo-anemometer (KIMO VT 110, measurement range: 0.15–30 m/s, accuracy: ±3% of reading ±0.05 0.05 m/s). Prior to each field deployment, zero-point baseline calibrations for the gaseous and particulate sensors were validated under clean-air baseline conditions.



Figure 1. Laser distance meter.



Figure 2. Air quality monitoring device.



Figure 3. Air movement (air velocity) monitoring device.

2.4 Baseline Institutional Survey

Collecting fundamental school data such as campus area (m^2), educational levels (Kindergarten/Primary/Secondary), and total student population.

2.5 Physical Setback Measurement

Utilizing the laser distance meter to measure the physical setback between the health room and the main arterial road, and documenting roadside characteristics such as the number of traffic lanes.

2.6 Air Quality Monitoring

Measuring PM2.5, PM10, CO_2, temperature, relative humidity, and air velocity within the health rooms, their immediate perimeters, and at the roadside boundary (refer to Figure 5 for the sampling procedure).

2.7 Sampling Protocol

Data collection across the ten schools was conducted asynchronously at various times. Data collection across the sampled schools was carried out between 30 March and 12 May 2026. It should be noted that this operational timeframe corresponds to the late dry and summer transition season in Bangkok. Consequently, the reported concentrations reflect site-specific conditions during this particular seasonal window rather than generalized annual or peak-stagnation winter baselines.

2.8 Data Analysis and Benchmarking

Consolidating all survey data into comparative tables to assess overall air quality and benchmarking the findings against the public building indoor air quality standards set by the Department of Health and the ambient air quality standards set by the Pollution Control Department (as detailed in Table 1).

Table 1 Air quality standards of the Department of Health and the Pollution Control Department.

Parameter	Acceptable Average Threshold	Unit
Temperature	24 to 26 (Not Specified)	Degrees Celsius (°C)
Relative Humidity	50 to 65 (Not Specified)	Percentage (%)
Particulate Matter ≤ 2.5 microns (PM2.5)	Not exceeding 25 (37.5)	Micrograms per cubic meter ($\mu g/m^3$)
Particulate Matter ≤ 10 microns (PM10)	Not exceeding 50 (100)	Micrograms per cubic meter ($\mu g/m^3$)
Carbon Dioxide (CO_2)	Not exceeding 1,000 (Not Specified)	Parts per million (ppm)
Air Movement (Air Velocity)	Less than 0.30 (Not Specified)	Meters per second (m/s)

Note Values in parentheses represent the Ambient Air Quality Standards established by the Pollution Control Department.

2.9 Mathematical Modeling (Regression)

Applying statistical principles to determine the mathematical relationship between the independent variable (setback distance) and dependent variables (percentage change in PM2.5, PM10, and CO_2 concentrations relative to roadside levels).

2.10 Optimization and Conclusion

Analyzing the regression equations to identify the optimal setback distance required to maintain indoor pollutant levels within national safety thresholds, followed by an overall assessment of IAQ influencing factors and research discussion.



Figure 4. Examples of baseline data collection within school health rooms among the sampled schools.

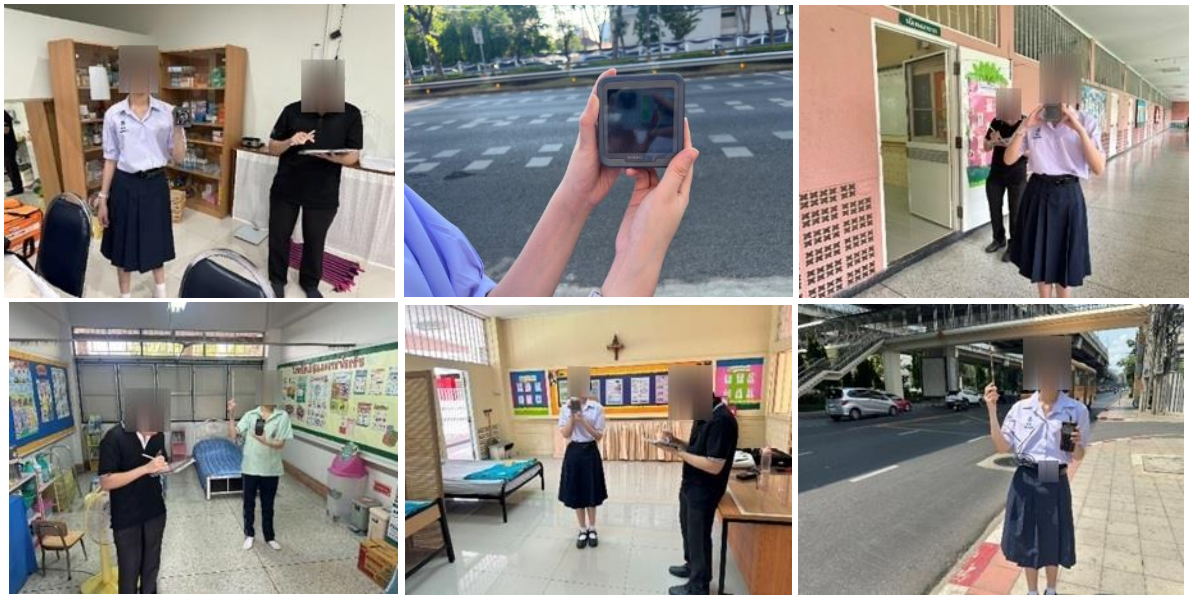

Figure 5. Examples of air quality monitoring both within and around the health rooms of the sampled schools.

The primary objective of this study is to evaluate indoor air quality, specifically focusing on PM2.5 and CO_2 concentrations, within school health rooms in Bangkok. Furthermore, the research aims to analyze the correlation between the distance of these facilities from main traffic arterial roads and

the resulting air quality, providing evidence-based recommendations for optimal architectural positioning and environmental management to ensure the health and safety of students.

2.11 Research Design

This study employs a descriptive-correlational research design using a cross-sectional approach. Field measurements were conducted to capture real-time environmental data across multiple sites. The design facilitates the investigation of how physical proximity to urban emission sources (independent variable) influences indoor pollutant levels (dependent variables).

2.12 Sample and Setting

The study was conducted in ten purposively selected schools under the jurisdiction of the Bangkok Metropolitan Administration. The settings were specifically targeted based on their proximity to high-traffic zones. The "sample units" consisted of the primary health rooms within these schools, representing diverse architectural layouts and varying distances from the main road frontage.

2.13 Ethical Considerations

The research protocol was conducted with strict adherence to ethical standards. Formal permission was obtained from the administration of each participating school prior to data collection. The study ensured non-interference with school operations, and all collected institutional data remained anonymous and was utilized strictly for academic purposes. No sensitive personal information of students or staff was recorded during the environmental monitoring process.

2.14 Data Collection

Data collection involved simultaneous monitoring of indoor and outdoor air quality parameters. Calibrated sensors were utilized to measure PM2.5, PM10, CO_2, temperature, relative humidity, and air velocity.

Synchronous real-time monitoring was conducted simultaneously at three monitoring points per school: (1) indoor breathing height (1.2–1.5 m above floor level in the room center), (2) the immediate outdoor perimeter (1.0 m from the building envelope), and (3) the primary road boundary. At each sampling location, measurements were recorded at a continuous sampling interval of 10 seconds over a steady monitoring period of 45 minutes per site ($N \approx 270$ instantaneous readings per session), from which the arithmetic means were calculated and reported. To reflect real-world operating conditions during schooling hours, the status of physical apertures was strictly standardized: during indoor sampling, all doors and windows were maintained in their routine operational state (closed in air-conditioned facilities and partially opened for cross-ventilation in non-air-conditioned rooms, as detailed in Table 3), while active occupancy was kept constant during each recording period.

2.15 Data Analysis

Statistical analysis was performed using Microsoft Excel 365. The data analysis process was structured as follows:

Descriptive Statistical Analysis: Quantitative data, including pollutant concentrations (PM2.5, PM10 and CO_2) and meteorological parameters (temperature, relative humidity, and air velocity), were summarized using mean, standard deviation (SD), and range (minimum–maximum) to describe the baseline environmental conditions of the health rooms.

Comparative Assessment: The measured indoor air quality parameters were benchmarked against the official indoor air quality standards for public buildings established by the Department of Health, Ministry of Public Health (Thailand), to determine compliance levels.

Infiltration and Efficiency Analysis: The percentage reduction of each pollutant was calculated to evaluate the efficacy of the health room's physical envelope in mitigating ambient air pollution from external sources.

Inferential Analysis (Polynomial Regression): A polynomial regression model was employed to examine the relationship between the setback distance from the arterial road (independent variable) and the percentage change in pollutant concentrations (dependent variable). Initial analysis indicated that a non-linear (curvilinear) relationship provided a significantly higher coefficient of determination (R^2) and a lower residual error compared to a linear model. This regression curve was utilized to determine the critical distance required to maintain indoor PM2.5 levels within the permissible threshold of 25 $\mu g/m^3$.

3. RESULTS AND DISCUSSION

3.1 Baseline Characteristics of the Samples

The physical and operational characteristics of the ten sampled schools, including educational levels, student populations, and campus dimensions, are detailed in Table 2. Detailed architectural layouts of the school health rooms—such as floor area, volume, and ventilation configurations—are provided in Table 3. The setback distances from the primary arterial roads ranged significantly across the samples, providing a robust dataset for spatial correlation analysis.

Table 2 Baseline characteristics of sampled schools.

School No.	Educational Level	Campus Area (m^2)	Student Population	Setback Distance from Main Road (m)	Traffic Lanes on Adjacent Main Road	Survey Date	Weather Conditions
1	Kindergarten–Primary	2,452	260	66	8	30/03/26 15:30	Normal
2	Kindergarten–Primary	4,904	780	14	4	20/04/26 10:00	Normal
3	Secondary	16,800	2,700	150	8	21/04/26 10:00	Normal
4	Kindergarten–Secondary	16,696	830	64	6 (Adjacent to BTS station)	22/04/26 12:00	Normal
5	Kindergarten–Secondary	16,000	600	120	8	23/04/26 10:00	Normal
6	Kindergarten–Primary	12,228	530	66	4	27/04/26 10:00	Normal
7	Secondary	35,776	3,000	42	6	28/04/26 10:00	Normal
8	Kindergarten–Secondary	16,000	1,100	135	6	30/04/26 10:00	Normal
9	Kindergarten–Primary	8,704	60	185	4	08/05/26 10:00	Normal
10	Secondary	37,328	3,600	100	12	12/05/26 10:00	Normal

Note on Environmental Conditions: "Normal" weather conditions during the survey days (30 March – 12 May 2026) were defined as periods characterized by clear to partly cloudy skies, absence of precipitation, and ambient temperatures typical of the late dry/summer season.

The detailed physical configurations of the school health rooms—including room geometry, dimensions of doors and windows, bed capacities, specific building locations, ventilation setups (air conditioning, exhaust fans, air purifiers), and occupancy levels during the survey—are compiled in Table 3.

Table 3 Physical characteristics of school health rooms.

School No.	Physical and Environmental Characteristics of Health Rooms
1	Rectangular room (2.96 × 3.88 × 3.36 m); Door (0.92 × 2.00 m); Window 1 (2.51 × 1.10 m); Window 2 (2.51 × 1.10 m); 2 beds; Located on 1st floor with windows facing the basketball court (approx. campus center); Equipped with air conditioning (infrequently used); No exhaust fan; No air purifier; 2 occupants during survey; AED available; Staffed by a non-professional health teacher.
2	Rectangular room (3.60 × 7.13 × 3.35 m); Doors (0.98 × 2.01 m, 1.06 × 2.00 m); Window 1 (2.95 × 1.47 m); Window 2 (1.16 × 3.84 m); 4 beds; Located on 1st floor with windows facing the school fence adjacent to the main road; Equipped with air conditioning (infrequently used); Equipped with exhaust fan; No air purifier; 2 occupants during survey; No AED; No assigned health teacher.
3	Hexagonal room (7.60 × 9.74 × 14.71 × 3.57 × 5.61 × 6.04 m, Height 2.87 m); Door 1 (2.02 × 2.01 m); Door 2 (1.06 × 2.00 m); Window 1 (1.19 × 0.58 m); Window 2 (2.51 × 1.10 m); 6 beds; Located on 1st floor adjacent to the under-building hall (approx. campus center); Equipped with air conditioning; No exhaust fan; No air purifier; 4 occupants during survey; No AED; Staffed by a professionally licensed school nurse.
4	Rectangular room (6.27 × 8.58 × 3.00 m); Door (0.88 × 1.95 m); Window (0.67 × 1.08 m); 6 beds; Located on 1st floor facing a narrow corridor and basketball court (approx. campus center); No air conditioning; No exhaust fan; No air purifier; 2 occupants during survey; No AED; No assigned health teacher.
5	Rectangular room (6.23 × 3.92 × 3.37 m); Door (0.88 × 2.01 m); 5 sets of windows (0.89 × 1.16 m per set); 2 beds; Located on 1st floor of a building at the rear of the campus; No air conditioning; No exhaust fan; No air purifier; 2 occupants during survey; No AED; Staffed by a non-professional health teacher.
6	Rectangular room (5.89 × 8.02 × 3.22 m); Door (0.88 × 2.00 m); Window (1.12 × 0.90 m); 3 beds; Located on 3rd floor of a building near the rear of the campus; No air conditioning; No exhaust fan; No air purifier; 2 occupants during survey; AED available; No assigned health teacher.
7	Rectangular room (17.38 × 5.86 × 2.67 m); Door (1.81 × 2.41 m); Window (20.51 × 1.21 m); 16 beds; Located on 1st floor of a building near the front of the campus; Equipped with air conditioning; No exhaust fan; No air purifier; 5 occupants during survey; AED available; Staffed by a professionally licensed school nurse.
8	Rectangular room (5.14 × 14.11 × 3.39 m); Door (1.91 × 1.96 m); 11 sets of windows (0.69 × 1.09 m per set); 7 beds; Located on 1st floor of a building near the rear of the campus; No air conditioning; No exhaust fan; No air purifier; 4 occupants during survey; No AED; Staffed by a non-professional health teacher.
9	Rectangular room (7.83 × 7.14 × 3.36 m); Door (0.88 × 2.01 m); 8 window sets (0.89 × 1.15 m per set); 4 beds; Located on the 2nd floor of a building at the front of the campus near the boundary fence; No air conditioning; No exhaust fan; No air purifier; 2 occupants during survey; AED available; Staffed by a non-professional health teacher.
10	Rectangular room (10.60 × 7.00 × 3.34 m); Door (1.26 × 1.98 m); Window set 1 (2.64 × 1.10 m); Window set 2 (1.50 × 1.10 m); 7 beds; Located on the 1st floor of the building; Equipped with air conditioning; Equipped with exhaust fan; Equipped with air purifier (turned off during survey); 4 occupants during survey; No AED; Staffed by a professionally licensed school nurse.

Based on the institutional datasets, key physical parameters—including the bed-to-student ratio, the presence of Automated External Defibrillators (AEDs), and the qualification profiles of health room personnel (categorized into professionally licensed nurses, unlicensed/non-professional staff, or completely unstaffed rooms)—were quantitatively analyzed. These institutional proportions are presented as percentages across the sampled schools in Tables 4 and 5.

Table 4 Bed-to-student ratios across the sampled schools.

School No.	Bed-to-Student Ratio
1	1:130
2	1:195
3	1:450
4	1:138
5	1:300
6	1:177
7	1:188
8	1:157
9	1:15
10	1:514
Average	**1:226**

Table 5 Proportional allocation of AEDs and personnel qualifications.

Resource Parameter / Variables	Percentage (%)
Availability of AED Units	40%
Licensed Professional Nurses	30%
Unlicensed Health Staff	30%
Completely Unstaffed	40%

The data indicates that the average bed-to-student ratio across the sampled facilities stands at approximately 1:226. Reference reviews regarding national legal mandates or international architectural building standards show that there is no officially defined or regulated statutory ratio for school infirmaries. However, based on the empirical observations from this cohort, this ratio is considerably high (averaging over 200 students per bed). In the event of a localized disease outbreak or multiple concurrent student illnesses, the existing bedding capacity would fail to accommodate the surge. Regarding life-saving devices, Automated External Defibrillators (AEDs) are deployed in only 40% of the school health rooms. Legal and international policy screenings confirm that an AED unit is not structurally mandated within a school health clinic. Nonetheless, in practical emergency response scenarios, an AED remains highly vital for reviving students experiencing critical cardiac arrest. For infirmary personnel, the institutional stratification shows that 30% are staffed by licensed professional nurses, 30% are managed by non-professional/unlicensed staff, and 40% are completely unstaffed. Collectively, while 60% of the schools maintain an active presence of health room staff to administer basic first aid and accident management, a lack of specialized professional treatment remains a concern, given that only 30% of the total sample possess formal medical and nursing licenses.

3.2 Indoor Air Quality Data and Compliance

The comprehensive monitoring matrices of PM2.5, PM10, CO_2, temperature, relative humidity, and air velocity—recorded simultaneously inside the health rooms, in the immediate external perimeter, and at the primary roadside boundaries—are organized in Tables 6, 7, and 8, respectively.

Table 6 Indoor air parameters within health rooms and compliance with Department of Health standards.

School No.	PM2.5 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	CO_2 (ppm)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)
1	29 (Fail)	32 (Pass)	450 (Pass)	32 (Fail)	65 (Pass)	0.07 (Pass)
2	34 (Fail)	36 (Pass)	401 (Pass)	32 (Fail)	64 (Pass)	0.34 (Fail)
3	39 (Fail)	49 (Pass)	505 (Pass)	26 (Pass)	55 (Pass)	0.17 (Pass)
4	46 (Fail)	66 (Fail)	632 (Pass)	31 (Fail)	66 (Fail)	0.03 (Pass)
5	38 (Fail)	48 (Pass)	409 (Pass)	34 (Fail)	62 (Pass)	0.25 (Pass)
6	34 (Fail)	40 (Pass)	409 (Pass)	33 (Fail)	61 (Pass)	0.20 (Pass)
7	30 (Fail)	33 (Pass)	450 (Pass)	26 (Pass)	54 (Pass)	0.21 (Pass)
8	41 (Fail)	52 (Fail)	468 (Pass)	31 (Fail)	67 (Fail)	0.15 (Pass)
9	31 (Fail)	37 (Pass)	435 (Pass)	30 (Fail)	75 (Fail)	0.04 (Pass)
10	29 (Fail)	31 (Pass)	489 (Pass)	26 (Pass)	68 (Fail)	0.14 (Pass)

Note: Compliance values in parentheses are benchmarked directly against the indoor environmental surveillance protocols issued by the Department of Health, Thailand.

Table 7 Environmental parameters in the immediate external perimeter of health rooms.

School No.	PM2.5 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	CO_2 (ppm)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)
1	31 (Pass)	34 (Pass)	408	34	58	0.23
2	34 (Pass)	37 (Pass)	404	33	65	0.36
3	41 (Fail)	50 (Pass)	503	27	74	0.11
4	47 (Fail)	68 (Fail)	405	34	60	0.20
5	43 (Fail)	59 (Fail)	404	34	63	0.30
6	35 (Pass)	41 (Pass)	403	34	61	0.27
7	32 (Pass)	36 (Pass)	417	29	54	0.30
8	41 (Fail)	50 (Pass)	409	32	69	1.05
9	34 (Pass)	39 (Pass)	407	31	74	0.30
10	30 (Pass)	33 (Pass)	408	28	80	0.50

Note: Compliance benchmarks inside parenthetical remarks signify evaluations based on the ambient air quality standards enforced by the Pollution Control Department, Thailand.

Table 8 Ambient air parameters at the main roadside boundary of schools.

School No.	PM2.5 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	CO_2 (ppm)	Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)
1	33 (Pass)	36 (Pass)	409	34	62	0.65
2	35 (Pass)	39 (Pass)	409	34	63	0.53
3	50 (Fail)	75 (Pass)	409	33	71	2.50
4	60 (Fail)	98 (Pass)	425	34	60	0.55
5	47 (Fail)	67 (Pass)	402	35	64	0.70
6	36 (Pass)	42 (Pass)	402	34	62	0.80
7	35 (Pass)	39 (Pass)	401	36	69	0.70
8	65 (Fail)	106 (Fail)	446	32	74	1.85
9	43 (Fail)	60 (Pass)	404	31	77	1.07
10	35 (Pass)	41 (Pass)	461	31	74	0.20

Note: Compliance values in parentheses reflect parameters cross-referenced with the ambient air quality thresholds of the Pollution Control Department, Thailand.

3.3 Statistical Correlation and Mathematical Modeling

By utilizing the localized datasets from Tables 6, 7, and 8, regression models were established in Microsoft Excel 365 to analyze the mathematical relationships between physical roadway setbacks (independent variable) and the percentage changes of indoor PM2.5, PM10, and CO_2 concentration values relative to roadside baselines (dependent variables). The aggregated empirical outputs are systematically summarized within Table 9 and visualized through Figures 6, 7, and 8.

Table 9 Percentage changes in indoor pollutants relative to roadside baselines and physical roadway setbacks.

School No.	PM2.5 (±%)	PM10 (±%)	CO_2 (±%)	Roadway Setback Distance (m)
1	-12	-11	+10	66
2	-3	-8	+2	14
3	-22	-35	+23	150
4	-23	-33	+49	64
5	-19	-28	+2	120
6	-6	-5	+2	66
7	-14	-15	+12	42
8	-37	-51	+5	135
9	-28	-38	+8	185
10	-17	-24	+6	100

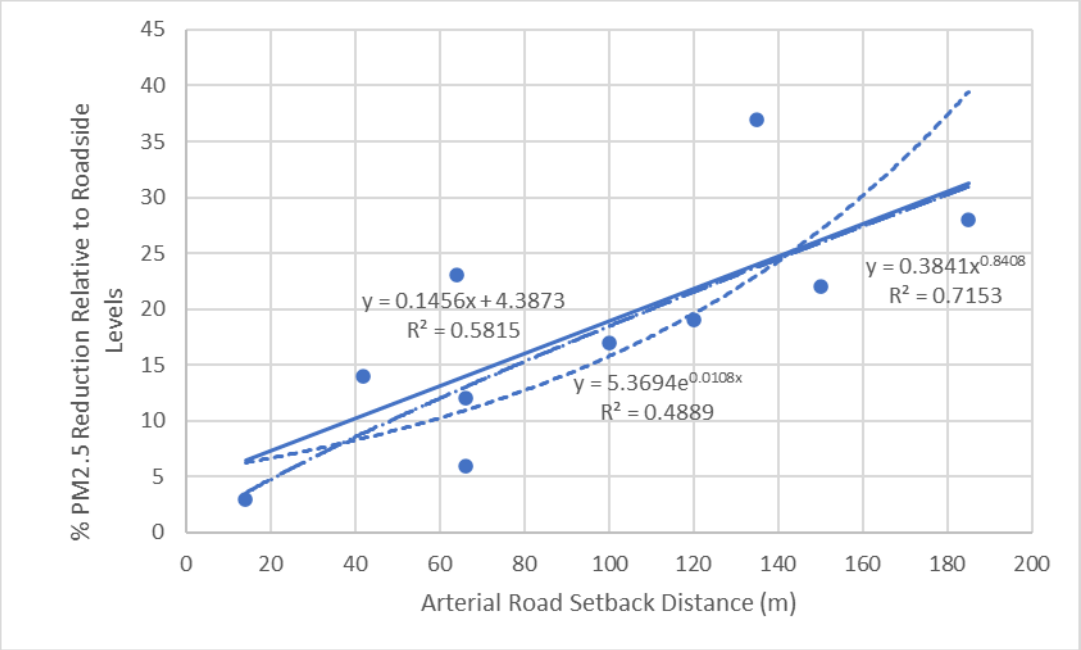

Figure 6. Mathematical regression analysis mapping the relationship between physical main roadway setback distance and the indoor percentage reduction of PM2.5 relative to roadside ambient levels.

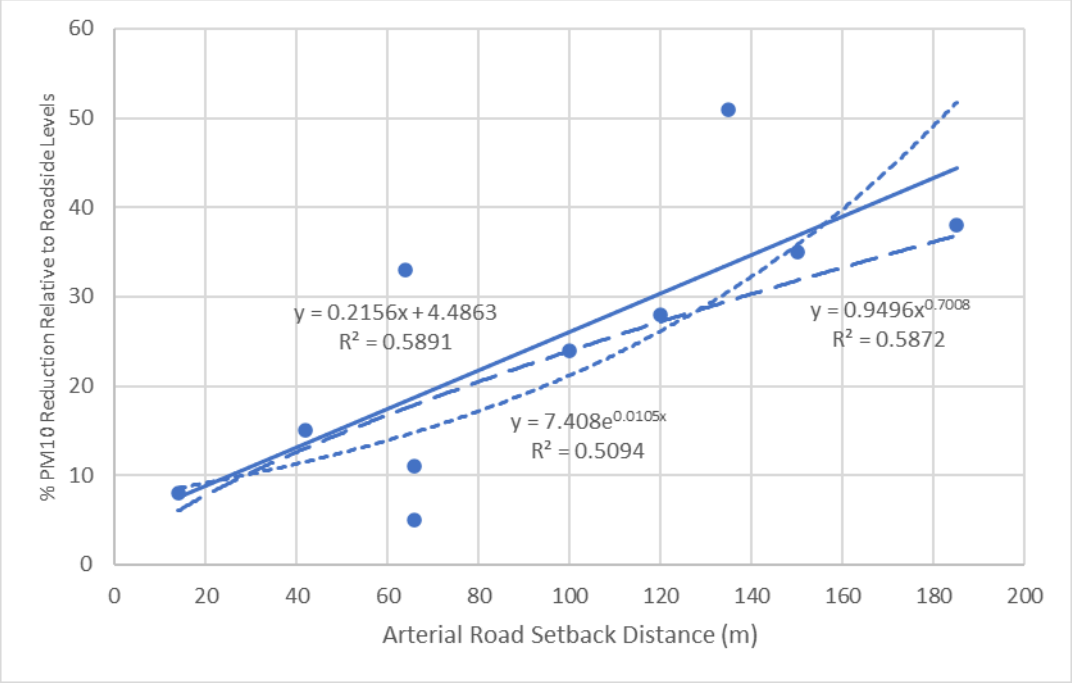

Figure 7. Mathematical regression analysis mapping the relationship between physical main roadway setback distance and the indoor percentage reduction of PM10 relative to roadside ambient levels.

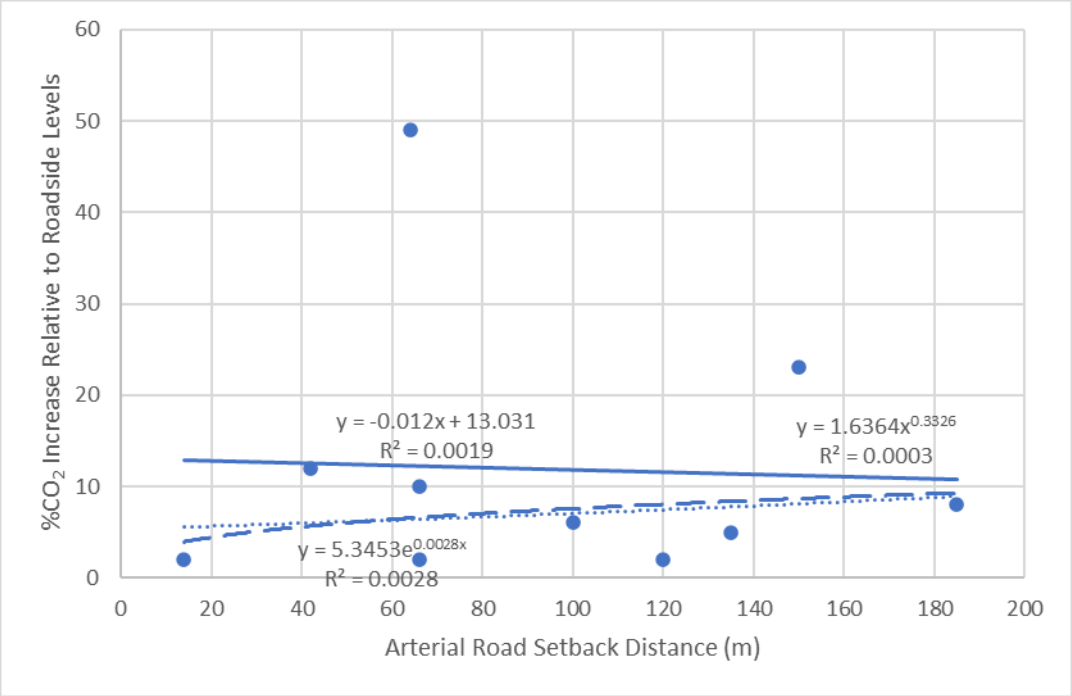

Figure 8. Mathematical regression analysis mapping the relationship between physical main roadway setback distance and the indoor percentage increase of CO_2 relative to roadside ambient baselines.

The statistical modeling results yield the following mathematical correlations: The indoor concentration of fine particulate matter (PM2.5) decreases significantly as the physical setback distance from the main traffic arterial road increases. This decay pattern was fitted to a power function regression model, yielding a coefficient of determination of $R^2 \approx 0.72$. While this R^2 value indicates a relatively strong association within this dataset, model stability and generalizability remain uncertain due to the limited sample size ($n = 10$). Coarse particulate matter (PM10) indoor concentrations also decrease as

the roadway setback expands. The trajectory is best represented via a linear regression model, yielding a moderate-to-strong coefficient of determination of $R^2 \approx 0.59$ (59% predictive accuracy). In sharp contrast, indoor carbon dioxide (CO_2) variations show zero statistical correlation with physical road boundary setbacks. However, indoor CO_2 levels were found to be consistently higher than ambient roadside conditions across the board.

This distinct divergence is driven by the physical properties of the gases versus solid particulate matter. Carbon dioxide is a gaseous phase compound that mixes uniformly and diffuses efficiently with air. In ambient, open-air roadside conditions, CO_2 rapidly dilutes into the higher atmospheric boundary layers. In contrast, heavy solid particulates (PM2.5 and PM10) have a much higher mass and gravitational settling rate, causing them to concentrate closer to ground level in open air. However, inside the enclosed health rooms, human metabolic emissions accumulate gaseous CO_2 over time, creating a building enclosure effect where indoor concentrations outpace roadside ambient baselines.

3.4 Comprehensive Macro Assessment of Infirmaries

When evaluating overall environmental parameters against indoor air thresholds defined by the Department of Health, the compliance rates of the school health rooms are as follows:

PM2.5 Compliance: 0% (All sampled locations failed to meet the safety limit).

PM10 Compliance: 80% of the sampled rooms passed the regulatory limit.

CO_2 Compliance: 100% achieved full compliance under indoor air criteria.

Temperature Compliance: Only 30% of rooms met the targeted comfort threshold.

Relative Humidity Compliance: 60% met the acceptable criteria range.

Air Movement Compliance: 90% successfully complied with the indoor velocity standards.

These macro statistics reveal that PM2.5 constitutes the primary environmental risk factor across all sampled infirmary facilities, consistently violating the Department of Health threshold of 25 $\mu g/m^3$. Coarse particulate matter (PM10) remains largely within acceptable margins under the regulatory safety limit (50 $\mu g/m^3$).

The widespread temperature failures are heavily linked to a lack of operational cooling systems, as a majority of the sampled infirmaries are not actively air-conditioned. Crucially, even within select sample rooms where air conditioning was kept running continuously throughout the day, the indoor system alone was entirely incapable of suppressing PM2.5 infiltration to a safe level. The structural culprit behind this persistent particulate threat is the total absence of specialized mechanical filtration, as none of the schools possessed functional air purifiers or mechanical exhaust systems. Consequently, health rooms without air conditioning suffered massive particulate infiltration, with indoor PM2.5 breaching safe limits even when located at setback distances greater than 100 m from the road boundary.

Mathematical forecasting from the derived regression equations establishes that if a school intends to lower indoor PM2.5 by 20% relative to roadside ambient concentrations through architectural layout alone, it requires a minimal setback distance of 110 m or greater. Furthermore, to achieve a 30% indoor reduction relative to roadside baselines, an architectural setback of at least 180 m is required. Therefore, physical site planning holds a vital role in protecting health rooms from vehicular pollution, which must be augmented with mandatory engineering controls, including split-type air conditioners, high-efficiency particulate air purifiers, and dedicated mechanical exhaust systems across all school infirmaries.

4. CONCLUSIONS

This research executed a comprehensive assessment of physical infrastructure, critical equipment availability, and environmental parameters within school health rooms across the Bangkok Metropolitan area. The empirical parameters tracked focused on structural metrics (student enrollment numbers, bedding availability, AED medical devices, and school nurse qualifications) coupled with extensive multi-zonal air parameter profiles.

The statistical modeling confirms a direct relationship between physical roadway setbacks and fine particulate mitigation. The power function trend for PM2.5 ($R^2 \approx 0.72$) and the linear trend for PM10 ($R^2 \approx 0.59$) suggest an observable empirical association between greater physical setbacks and reduced particulate concentrations in this preliminary cohort; however, these mathematical models should be interpreted with caution given the small sample size ($n = 10$). However, relying solely on architectural distance planning cannot fully resolve indoor air risks, as evidenced by the 0% compliance rate for indoor PM2.5.

The finding that PM2.5 remains hazardous even at setbacks exceeding 100 m underscores the necessity of building mechanical ventilation. The total absence of mechanical exhaust air fans and air filtration units across the sampled institutions allows outdoor fine dust to easily infiltrate building envelopes. Without active filtration, even closed, air-conditioned rooms fail to maintain safe air quality over long periods. This indicates that school building policies must move away from natural or simple mechanical ventilation towards sealed, positive-pressure cleanroom infirmaries equipped with high-efficiency particulate air (HEPA) systems to safely protect recovering students.

The resource assessment reveals critical gaps in institutional preparedness. The average bed-to-student ratio of 1:226, while lacking a formal legal baseline for comparison, is inadequate for handling high-occupancy surges or seasonal outbreaks. This capacity shortage forces ill students to remain in common areas or classrooms, increasing cross-infection risks.

Emergency response capability is also weak, with life-saving AED units available in only 40% of the sampled infirmaries. Furthermore, the personnel evaluation indicates structural vulnerabilities: 40% of schools completely lack designated healthcare staff, and only half of the remaining active staff (30% of the total sample) are professionally licensed nurses. The other 30% are unlicensed personnel who lack formal emergency medical training. This staffing profile indicates that a significant majority (70%) of school infirmary systems are unprepared to handle severe health crises or execute advanced clinical interventions safely.

A major challenge encountered during this research was the bureaucratic and administrative delay in securing institutional access and official survey clearances from individual schools. Document misplacement by school administrators frequently required restarting the approval process, which delayed the data collection schedule. Additionally, a seasonal limitation must be acknowledged: field measurements were recorded between late March and mid-May 2026 under typical dry-summer meteorological conditions. Because ambient particulate pollution in the Bangkok Metropolitan area exhibits pronounced seasonal peaks—frequently driven by winter atmospheric inversions and stagnant winds between December and February—the findings herein represent conditions specific to the observed monitoring window rather than generalized annual exposure profiles. Longitudinal multi-seasonal monitoring is strongly warranted in future extensions.

To build upon these foundational findings, future research should expand the school sample size across a broader range of educational districts to increase statistical reliability. Additionally, the analytical scope should expand to monitor other critical toxic air parameters, including Total Volatile Organic Compounds (TVOCs), Carbon Monoxide (CO), Formaldehyde (HCHO), Ozone (O_3), and total indoor bacterial and fungal colony-forming counts, ensuring a highly comprehensive baseline for school healthcare environments.

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