

Inhalation Exposure of Particulate Matter Inside and Outside an Air- Conditioned Bus Stop at a Roadside Area in Uthai Thani, Thailand

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Abstract

This study investigates inhalation exposure to particulate matter (PM), particularly PM_{2.5} and PM₁₀, inside and outside an air-conditioned bus stop equipped with designed PM_{2.5} filtration devices located in roadside areas of Uthai Thani, Thailand for the reduction of health impacts on passengers. The research aims to analyze PM concentrations, assess exposure levels, and evaluate associated health risks for bus stop passengers. PM samples were collected using a PMS7003 PM detector every 2 hours from 6:00 a.m. to 6:00 p.m. over three months (June 2022 – August 2022). A total of 60 residents living near the bus station and Central Stadium participated by answering health questionnaires and providing data on exposure time, frequency, duration, and body weight. Exposure assessments were based on calculations of the average daily intake, and the risk levels were determined using hazard quotient (HQ) values. The highest daily PM_{2.5} and PM₁₀ concentrations were found on the main road in front of the Central Stadium, measuring 58.40 and 64.13 $\mu\text{g}/\text{m}^3$, respectively. Inside the air-conditioned bus stop, PM_{2.5} exposure ranged from 0.00 – 1.298 $\mu\text{g}/\text{kg}\text{-day}$, as opposed to 2.047 – 7.026 $\mu\text{g}/\text{kg}\text{-day}$ outside. The HQ for PM_{2.5} inside of the bus stop ranged from 0.00 to 0.26, indicating minimal health impact, whereas it ranged from 0.33 to 1.41 at outside, suggesting potential risks based on exposure factors. Similarly, PM₁₀ exposure inside the bus stop ranged from 0.031 – 1.801 $\mu\text{g}/\text{kg}\text{-day}$, compared with 3.008 – 9.746 $\mu\text{g}/\text{kg}\text{-day}$ outside. HQ values for PM₁₀ ranged from 0.00 to 0.16 inside the bus stop and 0.27 to 0.89 outside, indicating low overall health impacts across all measurement points.

Keywords: PM_{2.5}; PM₁₀; Inhalation exposure assessment; Hazard quotient; Indoor air pollution; Outdoor air pollution; Roadside

1. Introduction

Uthai Thani, Thailand has severe air pollution issues, exceeding Thailand's National Ambient Air Quality Standards within its urban centers. The primary pollutant of concern is airborne particulate matter (PM), predominantly larger than 2.5 μm , with less than 10% of the pollution comprising PM_{2.5}. Nevertheless, PM_{2.5} levels exceed the national limits (Pollution Control Department, 2019). Sources include road dust, construction activities, and incomplete combustion of

agricultural waste and vehicle fuels. High concentrations of PM_{2.5} and PM₁₀, emitted primarily from traffic exhaust and road dust, pose substantial health risks to residents residing in and around these congested areas. In 2020, PM_{2.5} concentrations peaked at 37-97 $\mu\text{g}/\text{m}^3$, surpassing the 50 $\mu\text{g}/\text{m}^3$ standard, adversely impacting public health, particularly those with compromised immune systems (Pollution Control Department, 2022). According to the announcement

by the National Environment Board, new standards for PM_{2.5} in the general atmosphere will be effective from June 1, 2023. The 24-hour average concentration of PM_{2.5} must not exceed 37.5 µg/m³, a reduction from the previous limit at 50 µg/m³ (Pollution Control Department, 2023).

Notably, the bustling Uthai Thani bus interchange serves numerous commuters, who rely heavily on public transport amidst increasing vehicular traffic. Thus, the main sources of PM pollution are concentrated around the central bus station and major roadways, such as road numbers 333 and 3220, which represent densely populated areas where residents face heightened exposure risks. This study aims to investigate PM_{2.5} and PM₁₀ concentrations and assess exposure risks among commuters and residents in Uthai Thani.

Given the health implications associated with prolonged exposure to PM, especially in roadside areas, this research seeks to evaluate the effectiveness of an enclosed, air-conditioned bus stop equipped with PM_{2.5} filtration devices. By assessing the PM concentrations inside and outside the enclosed bus stop, the associated health risks for bus stop passengers are evaluated. In Uthai Thani province, the bus stops have not been previously modified or improved. A prototype air-conditioned bus stop was established through this research.

2. Methodology

2.1 Research Area

This study was conducted in the urban area of Uthai Thani province. The samples were collected along the main road in front of the Uthai Thani provincial stadium (Figure 1).

The average PM_{2.5} and PM₁₀ concentrations were measured to 58.40 and 64.134 µg/m³ during June 2022 and August 2022. These values are relatively high because the main road in front of the Central Stadium is an important route that people constantly use to travel, connecting the city area with other districts and the Nakhon Sawan province, generating heavy traffic every day.

2.2 Research Method

A model bus stop was constructed with dimensions of 1.5 × 6 × 3 m, featuring a steel structure, flooring, ceiling, wall paneling, and lockable sliding glass doors, designed to provide a comfortable environment for commuters. Inside the bus stop, activities that generate PM, such as smoking and tracking in dust from shoes, were strictly prohibited to maintain cleanliness. Interior surfaces were constructed from materials that prevent dust accumulation, ensuring they are smooth and easy to clean. To minimize external air pollution, an advanced air filtration system



Figure 1. The main road in front of the Uthai Thani provincial stadium, showing the location of the air-conditioned bus stop

was installed to effectively reduce the infiltration of polluted air, especially $PM_{2.5}$ and PM_{10} (Figure 2). Specifically, the bus stop is equipped with high-efficiency particulate air (HEPA) filters to eliminate dust particles from the air. These filters operate by inducing an electrostatic charge that attracts ionized particles to the collection surfaces, thereby producing cleaner air.

Overall, the bus stop design adheres to four principles for maintaining a PM-free environment: sealing all potential gaps and leaks in the building structure to prevent external PM ingress, prohibiting PM-generating activities within the bus stop, selecting materials that minimize surface PM accumulation for easy cleaning, and employing advanced air purification technologies like HEPA filters and air purifiers to ensure continuous air quality improvement. This comprehensive design aims to reduce exposure to fine PM, namely $PM_{2.5}$ and PM_{10} , thereby safeguarding the health of commuters in areas with elevated PM concentrations, ensuring compliance with $PM_{2.5}$ ($50 \mu\text{g}/\text{m}^3$) and PM_{10} ($120 \mu\text{g}/\text{m}^3$) standards for 24-hours exposure limits (Ministry of Public Health, 2022).

2.3 Measurement of $PM_{2.5}$ and PM_{10} Outside and Inside the Air-conditioned Bus Stop

2.3.1 Quantitative Research Methods

a) Data collection from questionnaires

The questionnaire used in this study was adapted from a survey conducted in

2015 by the Department of Health in Na Phra Lan Subdistrict, Saraburi Province, with adjustments to suit local conditions (Ministry of Public Health, 2015). The samples consisted of bus stop passengers who commute along the main road in front of the Uthai Thani Provincial Stadium, totaling 60 individuals. The sample size was determined using the Rule of Thumb, which considers a percentage of the population size, following Trikanan approach (2004), to mitigate data collection discrepancies and ensure a sufficient response rate. Anticipating potential issues, such as missing data at a rate of 10%, the sample size was adjusted accordingly. Random sampling was employed to collect data from the participants (Trikanan, 2004). Data collection consisted of two parts. In Part 1, general information was gathered, namely gender, age, residency duration, medical history including congenital diseases, occupation, household smoking habits, housing characteristics, and sources of dust exposure. Part 2 focused on the health effects of air pollution, including acute symptoms, awareness and treatment behaviors during illness, and self-protective measures taken by respondents. This structured approach enabled comprehensive data collection on demographic details, health impacts, and behavioral responses regarding air pollution specific to the study area (Ministry of Public Health, 2015).

b) Data collection of $PM_{2.5}$, PM_{10} , relative humidity, temperature and US AQI



Figure 2. Air-conditioned bus stop

PM_{2.5}, PM₁₀, relative humidity, temperature, and US AQI were collected daily using a PMS7003 PM detector (Figure 3), with measurements taken every 2 hours (i.e., at 6:00 a.m., 8:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 4:00 p.m., and 6:00 p.m.). The data was collected both outside and inside the bus stop model throughout the study period, between June and August 2022, spanning 3 months. The PMS7003 device was created by Department of Physics and Materials Science, Faculty of Science at Chiang Mai University and the Research Team for Energy and Economic Management at the Institute of Science and Technology Research, Chiang Mai University (Chiang Mai University, 2022).

2.3.2 Quantitative Research Methods

A quantitative analysis was conducted to analyze the correlation between the PM_{2.5} and PM₁₀ levels inside and outside the air-conditioned bus stop.

2.4 Assessment of the PM_{2.5} and PM₁₀ Exposure

The exposure time (ET), exposure frequency (EF), exposure duration (ED), and body weight (BW) were analyzed (mean and maximum) to quantify the PM exposure inside and outside the air-conditioned bus stop (U.S. Environmental Protection Agency, 1989; U.S. Environmental Protection Agency, 2016). The assessment method consisted of the following steps:

Step 1 involves gathering the PM_{2.5} and PM₁₀ concentration data at each location, as well as the data from the health questionnaires (U.S. Environmental Protection Agency, 2008).

Step 2 involves assessing the exposure to PM_{2.5} and PM₁₀ through inhalation based on the average daily intake (ADI). Considering exposure from the air, the ADI can be calculated using Equation (1) (World Health Organization, 2018).

$$ADI = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \quad (1)$$

ADI = the average daily intake (mg/kg of body weight per day)

CA = the concentration of PM in the air (mg/m³)

IR = the inhalation rate (m³/hour)

ET = the exposure time (hours/day) (From questionnaire)

EF = the exposure frequency for the sample population (days/year) (From questionnaire)

ED = the average exposure duration (years) for the sample population, calculated based on the average life expectancy of the population and the ages of the participants (From questionnaire)

BW = the average body weight (kg) of population samples (From questionnaire)

AT = the average exposure duration expressed in days, calculated as ED × 365 days/year, which was constant



Figure 3. PM Sensor Wi-Fi Pro by NanoGen (PMS7003)



Figure 4. Participants answering the health questionnaire surveys

2.5 Risk Assessment of the $PM_{2.5}$ and PM_{10} Exposure

The risk level was calculated in terms of the hazard quotient (HQ), according to Equation (2) (Thabethe et al., 2014).

$$HQ = \frac{\text{Exposure (mg/kg/day)}}{\text{RfC (mg/kg/day)}} \quad (2)$$

Exposure = the daily exposure value (mg/kg/day)

RfC = the reference concentration of the pollutant or the amount that enters the body through inhalation without causing a health hazard (mg/kg/day)

3. Results and Discussion

3.1 PM Concentration Inside and Outside the Bus Stop in Uthai Thani

Figures 5 (a-f) show the $PM_{2.5}$ and PM_{10} concentration data collected for each month between June and August 2022, both inside and outside the bus stop. Table 1 and 2 show the values used to calculate exposure. Table 3 and 4 show the HQ values outside and inside the bus stop.

Figure 5 (a) shows the $PM_{2.5}$ concentration inside and outside the air-conditioned bus stop in June. Inside the air-conditioned bus stop, the lowest $PM_{2.5}$ level was $0.56 \mu\text{g}/\text{m}^3$ at 2:00 p.m. and 4:00 p.m., and the highest $PM_{2.5}$ value was

$2.33 \mu\text{g}/\text{m}^3$ at 6:00 a.m., with an average of $1.01 \mu\text{g}/\text{m}^3$. Outside the air-conditioned bus stop, the lowest $PM_{2.5}$ value was $9.33 \mu\text{g}/\text{m}^3$ at 4:00 p.m., and the highest $PM_{2.5}$ value was $18.33 \mu\text{g}/\text{m}^3$ at 8:00 a.m., with an average of $13.40 \mu\text{g}/\text{m}^3$, consistent with previous research (Pimsan, 2020). Most people use the road for commuting during rush hour (7:00–8:00 a.m.), making the traffic congested. The fuel combustion from cars may cause an increase in the amount of $PM_{2.5}$ during this time (Pimsan, 2020).

Figure 5 (b) shows the PM_{10} concentration inside and outside the air-conditioned bus stop in June. Inside the air-conditioned bus stop, the lowest PM_{10} level was $0.56 \mu\text{g}/\text{m}^3$ at 2:00 p.m., and the highest PM_{10} concentration was $2.43 \mu\text{g}/\text{m}^3$ at 6:00 a.m., with an average of $1.08 \mu\text{g}/\text{m}^3$. Outside the air-conditioned bus stop, the lowest value was $10.00 \mu\text{g}/\text{m}^3$ at 4:00 p.m., and the highest value was $21.36 \mu\text{g}/\text{m}^3$ at 8:00 a.m., with an average of $14.87 \mu\text{g}/\text{m}^3$.

Figure 5 (c) shows the $PM_{2.5}$ concentration inside and outside the air-conditioned bus stop in July. Inside the air-conditioned bus stop, the lowest $PM_{2.5}$ value was $0.61 \mu\text{g}/\text{m}^3$ at 4:00 p.m., and the highest $PM_{2.5}$ value was $3.74 \mu\text{g}/\text{m}^3$ at 6:00 a.m., with an average of $1.46 \mu\text{g}/\text{m}^3$. Outside the air-conditioned bus stop, the lowest $PM_{2.5}$ value was $12.48 \mu\text{g}/\text{m}^3$ at 2:00 p.m., and the highest $PM_{2.5}$ value was $20.25 \mu\text{g}/\text{m}^3$ at 8:00 a.m., with an average of $15.02 \mu\text{g}/\text{m}^3$.

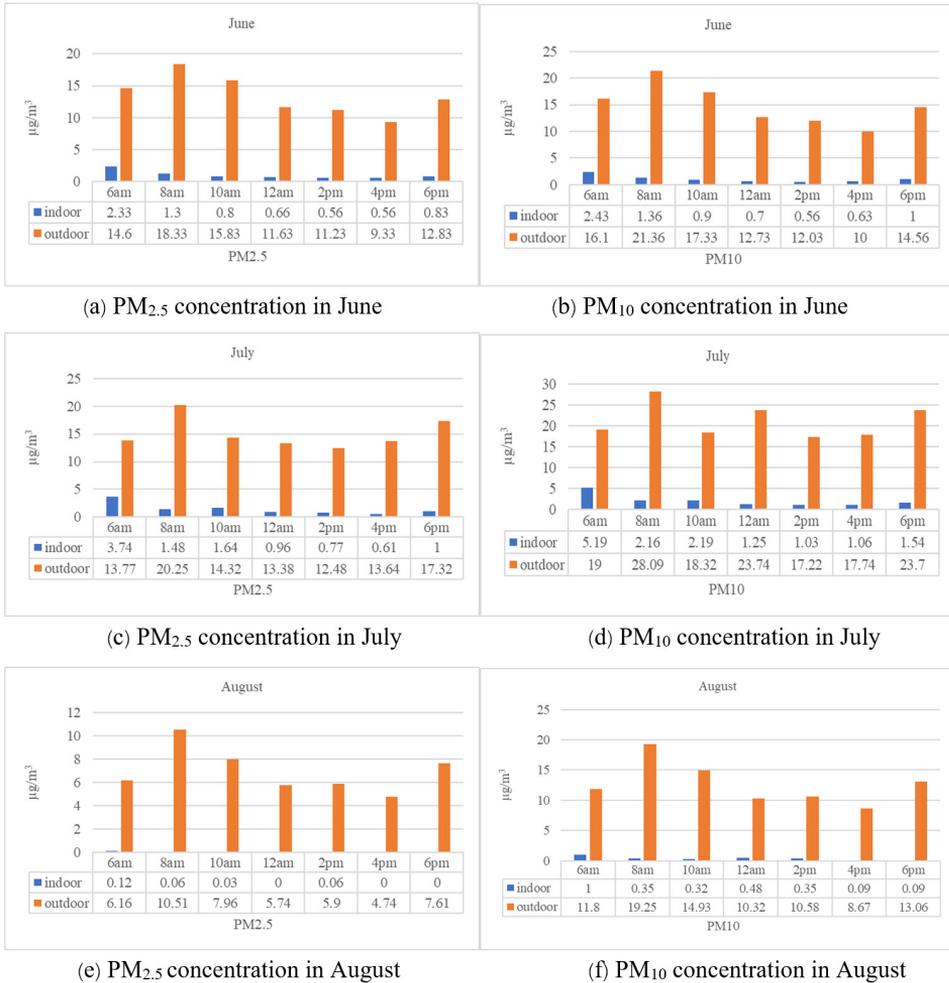


Figure 5. PM concentrations in June, July, and August, measured inside and outside the bus stop

Figure 5 (d) shows the PM₁₀ concentration inside and outside the air-conditioned bus stop in July. Inside the air-conditioned bus stop, the lowest PM₁₀ level was 1.03 µg/m³ at 2:00 p.m., and the highest PM₁₀ value was 5.19 µg/m³ at 6:00 a.m., with an average of 2.06 µg/m³. Outside the air-conditioned bus stop, the lowest PM₁₀ value was 17.22 µg/m³ at 2:00 p.m., and the highest PM₁₀ value was 28.09 µg/m³ at 8:00 a.m., with an average of 21.12 µg/m³.

Figure 5 (e) shows the PM_{2.5} concentration inside and outside the air-conditioned bus stop in August. Inside the air-conditioned bus stop, the lowest PM_{2.5} level was 0.00 µg/m³ at 12:00 a.m., 4:00 p.m., and 6:00 p.m., and the highest PM_{2.5} value was 0.12 µg/m³ at 6:00 a.m., with an average of 0.04 µg/m³. Outside the air-conditioned bus stop, the lowest PM_{2.5} value

was 4.74 µg/m³ at 4:00 p.m., and the highest PM_{2.5} value was 10.51 µg/m³ at 8:00 a.m., with an average of 6.95 µg/m³.

Figure 5 (f) shows the PM₁₀ concentration inside and outside the air-conditioned bus stop in August. Inside the air-conditioned bus stop, the lowest PM₁₀ level was 0.09 µg/m³ at 4:00 p.m. and 6:00 p.m., and the highest PM₁₀ value was 1.00 µg/m³ at 6:00 a.m., with an average of 0.38 µg/m³. Outside the air-conditioned bus stop, the lowest PM₁₀ value was 8.67 µg/m³ at 4:00 p.m., and the highest PM₁₀ value was 19.25 µg/m³ at 8:00 a.m., with an average of 12.66 µg/m³.

The amount of PM was not measured in 2021, but there is data for the amount of PM at the City Hall of the Pollution Control Department in 2022. It was found that the average PM_{2.5} and PM₁₀ concentrations were

18.17 and 32.83 $\mu\text{g}/\text{m}^3$, respectively (Pollution Control Department, 2023). PM measurement data from the Pollution Control Department in Nakhon Sawan (a nearby province) in 2021 shows that the average $\text{PM}_{2.5}$ and PM_{10} concentrations were 20.33 and 40.55 $\mu\text{g}/\text{m}^3$, respectively (Pollution Control Department, 2022). In 2022, the average $\text{PM}_{2.5}$ and PM_{10} concentrations were 23.58 and 45.50 $\mu\text{g}/\text{m}^3$, respectively (Pollution Control Department, 2023).

The PM concentration in air-conditioned bus stops is controlled not to exceed 20 $\mu\text{g}/\text{m}^3$. The maximum $\text{PM}_{2.5}$ concentration was 19 $\mu\text{g}/\text{m}^3$, and the maximum PM_{10} concentration was 20 $\mu\text{g}/\text{m}^3$. The $\text{PM}_{2.5}$ and PM_{10} concentrations were both higher outside the bus stop than those inside the bus stop at all intervals. Overall, this prototype bus stop reduced the amount of $\text{PM}_{2.5}$ by 91.95%, 92.66%, and 99.49% in July, June, and August, and reduced the amount of PM_{10} by 89.09%, 92.66%, and 96.88% in July, June, and August, respectively. Thus, the prototype air-conditioned bus stop was highly effective for reducing exposure to $\text{PM}_{2.5}$ and PM_{10} (Pukklin and Thongsanit, 2023).

3.2 Inhalation Exposure to PM Inside and Outside the Bus Stop in Uthai Thani

This study examined the levels of PM exposure inside and outside the bus stop area in Uthai Thani Province.

a) The $\text{PM}_{2.5}$ exposure in June 2022

The enclosed bus stops effectively lowered the PM levels to a range of 0.194 – 0.808 $\mu\text{g}/\text{kg}$ day. The highest of $\text{PM}_{2.5}$ exposure occurred in the early morning (6:00 a.m.), reaching 8.08 $\mu\text{g}/\text{kg}$ -day, and the lowest levels were recorded in the afternoon (2:00 p.m. and 4:00 p.m.), around 0.194 $\mu\text{g}/\text{kg}$ -day. Outside the bus stop, air conditioning reduced the $\text{PM}_{2.5}$ to within a range of 3.237 – 6.360 $\mu\text{g}/\text{kg}$ -day. The highest exposure to $\text{PM}_{2.5}$ was observed during working hours (8:00 a.m.), which was 6.360 $\mu\text{g}/\text{kg}$ -day, and the lowest value was observed in the afternoon (4:00 p.m.), 3.237 $\mu\text{g}/\text{kg}$ -day.

b) The $\text{PM}_{2.5}$ exposure in July 2022

Inside the bus stop, the $\text{PM}_{2.5}$ concentration was reduced to within a range of 0.212 – 1.298 $\mu\text{g}/\text{kg}$ -day. The highest exposure value

Table 1. Exposure to $\text{PM}_{2.5}$ between June and August 2022 ($\mu\text{g}/\text{kg}/\text{day}$)

month	period	outdoor	indoor
June	06.00 a.m.	5.066	0.808
	08.00 a.m.	6.360	0.451
	10.00 a.m.	5.493	0.278
	12.00 p.m.	4.035	0.229
	2.00 p.m.	3.896	0.194
	4.00 p.m.	3.237	0.194
	6.00 p.m.	4.452	0.288
July	06.00 a.m.	4.778	1.298
	08.00 a.m.	7.026	0.514
	10.00 a.m.	4.969	0.569
	12.00 p.m.	4.642	0.333
	2.00 p.m.	4.330	0.267
	4.00 p.m.	4.733	0.212
	6.00 p.m.	6.010	0.347
August	06.00 a.m.	2.137	0.042
	08.00 a.m.	3.647	0.021
	10.00 a.m.	2.762	0.010
	12.00 p.m.	1.992	0.000
	2.00 p.m.	2.047	0.021
	4.00 p.m.	1.645	0.000
	6.00 p.m.	2.640	0.000

of PM_{2.5} was observed during the time before work (6:00 a.m.), which was 1.298 µg/kg-day, and the lowest value was observed in the afternoon (4:00 p.m.), 0.212 µg/kg-day. Outside the bus stop, the PM_{2.5} concentration was reduced to within a range of 4.330 – 7.026 µg/kg-day. The highest exposure to PM_{2.5} was observed during working hours (8:00 a.m.), which was 7.026 µg/kg-day, and the lowest value was observed in the afternoon (2:00 p.m.), 4.330 µg/kg-day.

c) The PM_{2.5} exposure in August 2022

Inside the bus stop, the PM_{2.5} concentration was reduced to within a range of 0.000 – 0.042 µg/kg-day. The highest exposure value of PM_{2.5} was observed during the time before work (6:00 a.m.), which was 0.042 µg/kg-day, and the lowest value was observed in the afternoon (12:00 p.m., 4:00 p.m., and 6:00 p.m.), 0.00 mg/kg-day. Outside the bus stop, the PM_{2.5} concentration was reduced to within a range of 1.645 – 3.647 µg/kg-day. The highest exposure to PM_{2.5} was observed during working hours (08.00 am), which was 3.647 µg/kg-day, and the lowest value was observed in the afternoon (4:00 p.m.), 1.645 µg/kg-day.

Overall, PM exposure decreased during August owing to the rainy season in Uthai Thani province.

Researchers conducted studies similar to those in Rayong, Chiang Mai, and Phitsanulok. One study was; Health Risk Assessment of PM_{2.5} Exposure in the Initiative of the Eastern Economic Corridor Area Project During the Dry Season in 2022: Case Study of Rayong City, which assessed the health risks of PM_{2.5} exposure. The study evaluated individual lifetime cancer risk (Ric), finding average Ric values for children, teenagers, and adults ranging from 10⁻⁶ to 10⁻⁴ during the dry season (Bootdee *et al.*, 2023).

Another study; ‘Health Impact Related to Ambient Particulate Matter Exposure: A Spatial Health Risk Map Case Study in Chiang Mai, Thailand, which examined the correlation between PM_{2.5} concentrations and various health conditions. The study found that PM_{2.5} levels were highly correlated with the incidence of dermatitis (R = 0.84), conjunctivitis (R = 0.81), stroke (R = 0.74), and lung cancer (R = 0.73) (Jarernwong *et al.*, 2023).

Table 2. Exposure to PM₁₀ between June and August 2022 (µg/kg/day)

month	period	outdoor	indoor
June	06.00 a.m.	5.586	0.843
	08.00 a.m.	7.411	0.472
	10.00 a.m.	6.013	0.312
	12.00 p.m.	4.417	0.243
	2.00 p.m.	4.174	0.194
	4.00 p.m.	3.470	0.219
	6.00 p.m.	5.052	0.347
July	06.00 a.m.	6.592	1.801
	08.00 a.m.	9.746	0.750
	10.00 a.m.	6.357	0.760
	12.00 p.m.	8.237	0.434
	2.00 p.m.	5.975	0.357
	4.00 p.m.	6.155	0.368
	6.00 p.m.	8.223	0.534
August	06.00 a.m.	4.094	0.347
	08.00 a.m.	6.679	0.121
	10.00 a.m.	5.180	0.111
	12.00 p.m.	3.581	0.167
	2.00 p.m.	3.671	0.121
	4.00 p.m.	3.008	0.031
	6.00 p.m.	4.531	0.31

The third study was The Inhalation Exposure of PM_{2.5} at Bus Stops in Phitsanulok Municipality, assessed the health risks of PM_{2.5} exposure at three bus stops: Phitsanulok Municipal Market 6, Chalermkwansatree School, and Buddhachinaraj Phitsanulok Hospital. This study found PM_{2.5} exposure levels ranging from 0.387 to 1.708 µg/kg-day (Muensin and Thongsanit, 2022).

d) The PM₁₀ exposure in June 2022

Inside the bus stop, the PM₁₀ concentration was reduced to within a range of 0.194 – 0.843 µg/kg-day. The highest exposure value of PM₁₀ was observed during the time before work (6:00 a.m.), which was 0.843 µg/kg-day, and the lowest PM₁₀ value was observed in the afternoon (2.00 p.m.), 0.194 µg/kg-day. Outside the bus stop, the PM₁₀ concentration was reduced to within a range of 3.470 – 7.411 µg/kg-day. The highest exposure to PM₁₀ was observed during working hours (8:00 a.m.), which was 7.411 µg/kg-day, and the lowest value was observed in the afternoon (4:00 p.m.), 3.470 µg/kg-day.

e) The PM₁₀ exposure in July 2022

Inside the bus stop, the PM₁₀ concentration was reduced to within a range of 0.357 – 1.801 µg/kg-day. The highest exposure value for PM₁₀ was observed during the time before work (6:00 a.m.), which was 1.801 µg/kg-day, and the lowest value was observed in the afternoon (2:00 p.m.), 0.357 µg/kg-day. Outside the bus stop, the PM₁₀ concentration was reduced to within a range of 5.975 – 9.746 µg/kg-day. The highest exposure to PM₁₀ was observed during working hours (8:00 a.m.), which was 9.746 µg/kg-day, and the lowest value was observed in the afternoon (2:00 p.m.), 5.975 µg/kg-day.

f) The PM₁₀ exposure in August 2022

Inside the bus stop, the PM₁₀ concentration was reduced to within a range of 0.031 – 0.347 µg/kg-day. The highest exposure value of PM₁₀ was observed during the time before work (6:00 a.m.), which was 0.347 µg/kg-day, and the lowest value was observed in the afternoon (4:00 p.m. and 6:00 p.m.), 0.031 µg/kg-day. Outside the bus stop, the PM₁₀ concentration was reduced to

Table 3. HQ values for PM_{2.5} between June and August 2022

month	period	outdoor	indoor
June	06.00 a.m.	1.01	0.16
	08.00 a.m.	1.27	0.09
	10.00 a.m.	1.10	0.06
	12.00 p.m.	0.81	0.05
	2.00 p.m.	0.78	0.04
	4.00 p.m.	0.65	0.04
July	6.00 p.m.	0.89	0.06
	06.00 a.m.	0.96	0.26
	08.00 a.m.	1.41	0.10
	10.00 a.m.	0.99	0.11
	12.00 p.m.	0.93	0.07
	2.00 p.m.	0.87	0.05
August	4.00 p.m.	0.95	0.04
	6.00 p.m.	1.20	0.07
	06.00 a.m.	0.43	0.01
	08.00 a.m.	0.73	0.00
	10.00 a.m.	0.55	0.00
	12.00 p.m.	0.40	0.00
August	2.00 p.m.	0.41	0.00
	4.00 p.m.	0.33	0.00
	6.00 p.m.	0.53	0.00

within a range of 3.008 – 6.679 µg/kg-day. The highest exposure to PM₁₀ was observed during working hours (8:00 a.m.), which was 6.679 µg/kg-day, and the lowest value was observed in the afternoon (4:00 p.m.), 3.008 µg/kg-day.

Overall, PM exposure decreased during August owing to the rainy season in Uthai Thani province.

3.3 Risk Assessment of PM Exposure

Table 3 shows that the HQ values for PM_{2.5} inside the bus stop range from 0.00 to 0.26, which is less than 1, meaning that the health of people using the bus stop was not impacted at any interval. Outside the air-conditioned bus stop, the HQ ranges from 0.33 to 1.41, indicating that some values are above 1, which signifies potential health impacts. Symptoms and severity levels vary based on exposure duration, pollution concentration, user age, and individual resistance.

According to an HQ valuation previously performed in Phitsanulok, the passengers who use the bus service at all bus stops were

safe from the impacts of PM_{2.5} exposure (Muensin and Thongsanit, 2022). People of all age groups are at risk of health impacts from long-term exposure to PM_{2.5} (HQ ≥ 1). Children aged 1 – 5 years are at the highest risk (HQ of males was 3.38; HQ of females was 3.33). Furthermore, males are at greater health risk from exposure to PM_{2.5} than females in all age groups (Busarangsi *et al.*, 2019). Considering HQ < 0.1 means no danger, 0.1 ≥ HQ ≤ 1.0 means there is a low level of danger, 1.1 ≥ HQ ≤ 10 means there is a moderate level of danger, and HQ > 10 means there is a high level of danger, the HQ values within the air-conditioned bus stop indicate no danger (U.S. Environmental Protection Agency, 1989).

Table 4 shows that the HQ values for PM₁₀ inside the air-conditioned bus stop are in the range of 0.00 – 0.16 and those outside the air-conditioned bus stop are in the range of 0.27 – 0.89, which all remain below 1, meaning that those who use the bus stop do not experience an impact on their health due to inhalation exposure during any measurement interval.

Table 4. HQ values for PM₁₀ between June and August 2022

month	period	outdoor	indoor
June	06.00 a.m.	0.51	0.08
	08.00 a.m.	0.67	0.04
	10.00 a.m.	0.55	0.03
	12.00 p.m.	0.40	0.02
	2.00 p.m.	0.38	0.02
	4.00 p.m.	0.32	0.02
	6.00 p.m.	0.46	0.03
July	06.00 a.m.	0.60	0.16
	08.00 a.m.	0.89	0.07
	10.00 a.m.	0.58	0.07
	12.00 p.m.	0.75	0.04
	2.00 p.m.	0.54	0.03
	4.00 p.m.	0.56	0.03
	6.00 p.m.	0.75	0.05
August	06.00 a.m.	0.37	0.03
	08.00 a.m.	0.61	0.01
	10.00 a.m.	0.47	0.01
	12.00 p.m.	0.33	0.02
	2.00 p.m.	0.33	0.01
	4.00 p.m.	0.27	0.00
	6.00 p.m.	0.41	0.00

4. Conclusion

In this study, the inhalation exposure of PM was investigated inside and outside an air-conditioned bus stop model at a roadside area in Uthai Thani, Thailand. While standing on the side of a road, the level of PM in the atmosphere can often be at a level that is detrimental to human health. The enclosed air-conditioned bus stop equipped with a PM filter effectively reduced the PM_{2.5} and PM₁₀ exposure and maintained the concentrations at safe levels, lower than those outside the bus stop.

The results showed that from June to August 2022, the PM_{2.5} level was highest outside the bus stop, between 33 and 55 µg/m³, where as the level inside the bus station was between 3 and 19 µg/m³. The amount of PM₁₀ outside the bus stop had a maximum value in the range of 55 – 69 µg/m³, but inside the bus stop, a maximum value of 8 – 20 µg/m³ was observed. Outside the air-conditioned bus stop, the PM_{2.5} exposure was within the range of 2.047 – 7.026 µg/kg-day, and inside the bus stop, it was reduced to the range of 0.000 – 1.298 µg/kg-day. The HQ values for PM_{2.5} inside the air-conditioned bus stop were 0.00 – 0.26, indicating a low level of impact. Outside the air-conditioned bus stop, HQ values for PM_{2.5} were in the range of 0.33 – 1.41, which includes values greater than 1, meaning that the health of people outside the bus stop may be impacted during the measurement intervals. Exposure to PM₁₀ inside the air-conditioned bus stop was reduced to a range of 0.031 – 1.801 µg/kg-day, compared with 3.008 to 9.746 µg/kg-day outside. The HQ values for PM₁₀ inside the air-conditioned bus stop were in the range of 0.00 – 0.16, and outside the air-conditioned bus stop, it was in the range of 0.27 – 0.89, indicating the users inside and outside the bus stop did not experience health impacts due to inhalation exposure from PM₁₀.

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