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Article

Prediction of $PM_{2.5}$ Dispersion in Bangkok Pathumwan District) Using CFD Modeling

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Abstract. City configuration, meteorological conditions and emission source are the important factors affecting the dispersion and concentration of pollutants within urban street canyon. The dispersion of $PM_{2.5}$ emitted from traffic in Pathumwan district, Bangkok which has the characteristics of street canyon was predicted using a Computational Fluid Dynamics (CFD) model with the RANS standard k-ε turbulence model. The studied area covers the area with high aspect ratio such as the shopping center area with the skytrain structure. The Discrete Phase Model (DPM) was used for simulating the $PM_{2.5}$ injection and dispersion. The concentrations of $PM_{2.5}$ were investigated under different conditions to demonstrate the effects of skytrain structure in the street canyon, meteorological conditions, and city lockdown due to the COVID-19 pandemic on $PM_{2.5}$ concentration. The numerical model was validated with the measured data from the air quality monitoring station of the Environment Bureau, Bangkok. The reduction of emission rate during the city lockdown causes the $PM_{2.5}$ concentration to decrease by 1.35 times from the normal time. In addition, the city configuration with the skytrain structure located between the tall buildings results in higher $PM_{2.5}$ concentration than the case without the skytrain structure in Pathumwan district by around 1.2 times. Moreover, the meteorological conditions must be considered, especially wind speed and direction. Finally, the results obtained from the simulation will be used for proposing the guidelines to reduce the concentration of $PM_{2.5}$.

Keywords: $PM_{2.5}$, CFD, street canyon, Bangkok.

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1. Introduction

Nowadays, Bangkok is facing the air pollution problems that are getting more severe, especially particulate matter (PM) problem. Fine particulate matter or $PM_{2.5}$ (PM with an aerodynamic diameter of equal to or less than 2.5 microns) has an impact on the respiratory system since it can pass through the respiratory tract and deep into the lungs [1]. Therefore, this particulate matter problem is realized as an important issue and need to be solved because it can cause the adverse health effects to human.

Particulate matter can be emitted from two types of sources which are natural sources and human-made sources. Emissions from natural sources consist of regional wind-blown dust, biogenic emissions and sea salt, while human-made sources consist of industry, power generation, mining, construction and motor vehicles [2]. Since Bangkok is an urban area and also the capital city of Thailand, rapid urban growth causes a fast increase in vehicle population which continues to increase every year leading to traffic congestion [3]. Overcrowded traffic and incomplete combustion of fuel result in the emission of a lot of $PM_{2.5}$. Ha Chi et al. [4] reported that the on-road mobile is the main contributor to $PM_{2.5}$ in the Bangkok Metropolitan Region (BMR), accounting for 59% of the total $PM_{2.5}$ emissions, followed by biomass open burning (20%) and industry (19%). Wimolwattanapun et al. [5] also reported that the major sources for $PM_{2.5}$ in Bangkok are traffic, followed by aged sea salt and biomass burning. Thus, traffic emission is considered as a major source of particulate air pollution in Bangkok [6]. In addition, the dispersion of pollutants emitted from vehicles is also influenced by the structure of the buildings [7] and wind direction [8]. Most city configurations in an urban area consist of a relatively narrow street with buildings lined up continuously along both sides called street canyon [9], causing poor ventilation leads to the accumulation of $PM_{2.5}$ within the city.

Pathumwan, one of the districts of Bangkok, is a street canyon since it is a central business district that consists of large shopping malls along both sides of the road which is quite narrow. Besides, there are also high-rise buildings in the university area and skytrain passing by the shopping area that is full of tall buildings. For the traffic in Pathumwan district, there are a lot of cars pass by all day. The number of vehicles is related to $PM_{2.5}$ in ambient. Thus, a large number of vehicles in Pathumwan district result in a high $PM_{2.5}$ concentration [10]. Annual average concentrations of $PM_{2.5}$ in Pathumwan were 28.25, 27.58 and 25.17 $\mu g/m^3$ in the year 2018, 2019, and 2020, respectively [11] which exceeded Thailand's national air quality standard annual limit of 25 $\mu g/m^3$ [12].

To control or reduce the concentration of $PM_{2.5}$ effectively, knowledge and understanding about $PM_{2.5}$ dispersion which is influenced by the emission source, wind direction, meteorological characteristics and city configuration that are specific to the area are necessary.

For the prediction of $PM_{2.5}$ dispersion, there are numerous methods and tools including field measurement, physical modeling in wind tunnel and using computational calculations such as computational fluid dynamics (CFD) modeling. Since field measurement is time-consuming and difficult to keep the parameters the same when the measurement needs to be repeated and the wind tunnel experiment generally takes quite a lot of time and resources compared to computational simulation, the CFD model is preferred as an effective method for predicting the pollutant dispersion [13, 14] and it has been applied in this research as well.

2. Methodology

2.1. Physical Model Configuration

The studied area in Pathumwan district has an area of around 1.95 square kilometers, covering the area with Bangkok's air quality monitoring station, the university area, and the area with high aspect ratio such as the shopping center area with the skytrain structure. The university area and shopping center area consist of many tall buildings which obstruct the flow of air. The skytrain structure is located on Rama I road, which is only 21 meters wide and surrounded by tall buildings along the road. There are two stations and track in the studied area, one station is located between the high-rise buildings of shopping malls blocking the flow of air. The track located along the entire length of the road also obstructs the airflow. These stations and track cause poor ventilation, leading to the accumulation of $PM_{2.5}$ within the street canyon. In addition, there is a large number of vehicles passing the studied area each day, especially at Pathumwan intersection, where traffic congestion results in a large amount of $PM_{2.5}$ emissions. In 2019, the traffic volumes in Pathumwan district on Rama I, Phayathai and Henri Dunant roads are 28,280, 38,966 and 11,100 vehicles/day, respectively [15]. Yeemadarlee [10] reported that the traffic volume is significantly related to the $PM_{2.5}$ concentration at Pathumwan intersection and 84% of the $PM_{2.5}$ in ambient can be explained by the number of vehicles. Thus, traffic emission is considered as a major source of $PM_{2.5}$ in Pathumwan district. The scope of focused area in yellow frame and the direction are shown in Fig. 1.

2.2. Governing Equations

The governing equations are based on the conservation of mass, momentum and energy. The conservation equations are related to the rate of change in the amount of that property within an arbitrary control volume to the rate of transport across the control volume surface and the rate of the production within that volume [16].

Fig. 1. The scope of focused area in Pathumwan district.

2.2.1. Mass conservation equation

The equation for conservation of mass, or continuity equation, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \tag{1}$$

where ϱ is the fluid density, $\vec{v}$ is the flow velocity and ∇ is the gradient operator.

2.2.2. Momentum conservation equation

The momentum conservation (Navier-Stokes) equation or Newton's second law can be written as follows:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\mu[(\nabla \vec{v} + \nabla \vec{v}^T)]) + \rho \vec{g} \tag{2}$$

where p is the static pressure, μ is the molecular viscosity and $\rho \vec{g}$ is the gravitational body force.

Most flows in nature and engineering application are turbulent which introduces additional terms in the governing equations. These terms need to be modeled to solve the 'closure problem' and to include the turbulence effects [16]. Reynolds averaged Navier-Stokes (RANS) equations are the mathematical models for solving turbulent flows. Due to the high Reynolds number (Re = 4.33e+07) and the city configuration resulting in fully turbulent flow in the studied system, thus the RANS equations are employed for the mean flow field in the street canyon. The RANS equations are modeled by various two-equation turbulence models such as k-ε models and k-ω models, or by seven-equation turbulence model such as Reynolds Stress Model (RSM) [17].

Common models for the simulation of turbulent flows and pollutant dispersion in street canyons are the k-ε models due to their robustness and efficiency [7, 17]. The assumption in the derivation of the Standard k-ε model is that the flow is fully turbulent which is consistent with the flow in the system. Since the RNG k-ε model provides an analytically derived differential formula for effective viscosity that accounts for low-Reynolds number effects while the Standard k-ε model is a high-Reynolds number model [18], the Standard k-ε model is more suitable for the simulation of turbulent flow and pollutant dispersion in this study. In addition, the validation between the numerical results and measurement results of Yassin [19] and Wang et al. [20] that use the Standard k-ε model also show good agreement. Xie et al. [21] reported that the Standard k-ε model is the most optimum turbulence model among the k-ε model variants (e.g., Standard, RNG and Chen-Kim) for calculating the pollutant dispersion in street canyons. Therefore, the Standard k-ε model was selected for this study and its equation can be written as follows:

Turbulent kinetic energy (k) transport equation:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k \overrightarrow{v_i}) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho \varepsilon \tag{3}$$

Turbulent dissipation rate (ε) transport equation:

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon\overrightarrow{v_i}) = \frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{4}$$

where k is the turbulent kinetic energy, ε is the turbulent dissipation rate, G_k represents the generation of turbulent kinetic energy due to the mean velocity gradients. G_b is the generation of turbulent kinetic energy due to buoyancy. $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are constants which equal to 1.44 1.92 and $tanh\left|\frac{v}{u}\right|$, respectively, where v is the component of the flow velocity parallel to the gravitational vector and u is the component of the flow velocity perpendicular to the gravitational vector. σ_k and σ_ε are the turbulent Prandtl numbers for k and ε which equal to 1.0 and 1.3, respectively [18]. The turbulent (or eddy) viscosity, μ_t, is computed by combining k and ε as follows:

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon} \tag{5}$$

where C_μ is a constant and equal to 0.09 [18].

2.2.3. Energy conservation equation

$$\frac{\partial\rho e}{\partial t}+\nabla\cdot(\rho\vec{v}e)+\frac{\partial\rho \mathrm{K}}{\partial t}+\nabla\cdot(\rho\vec{v}\mathrm{K})+\nabla\cdot(\vec{v}p) = \nabla\cdot\left(\alpha_{eff}\nabla e\right)+\rho g\cdot\vec{v} \tag{6}$$

where e is the thermal energy, K is the kinetic energy, g is the gravitational acceleration and α_{eff} is the effective thermal diffusivity which is defined as the sum of laminar and turbulent thermal diffusivities.

2.2.4. Discrete phase model

The trajectories of particles in the discrete phase are predicted by integrating the force balance on the particles.

$$m_p\frac{d\overrightarrow{v_p}}{dt}=m_p\frac{\vec{v}-\overrightarrow{v_p}}{\tau_r}+m_p\frac{\vec{g}\left(\rho_p-\rho\right)}{\rho_p}+\vec{F} \tag{7}$$

where m_p is the particle mass, $\vec{v}$ is the fluid phase velocity, $\overrightarrow{v_p}$ is the particle velocity, ρ is the fluid density, ρ_p is the particle density which will be considered as the density of carbon that equals 2000 kg/m^3 since carbon is the major element of $PM_{2.5}$ in Bangkok [22]. $\vec{F}$ is an additional force term, $m_p\frac{\vec{v}-\overrightarrow{v_p}}{\tau_r}$ is the drag force, and τ_r is the particle relaxation time.

2.3. Computational Domain

The lateral and upper boundaries of the domain were placed about 1.25 times Hmax far from the focused area, where Hmax is the height of the tallest building on each side. At a distance of 1.25 times Hmax, the velocity profile is not affected by the buildings since it is the reattachment length [23].

2.4. Mesh

The mesh was made of about 4.8 million tetrahedral elements, with an element size of 10 m. For the edge sizing, element size along the roadside was set to 2.5 m which equals the shortest distance between the road and the building, while element size at the corner of enclosure was set to 3.5 m which equals the height of the lowest building. The average value of skewness, which is directly related to the quality of mesh structure is 0.23.

2.5. Boundary Conditions

Steady-state simulations were performed using ANSYS 19.2 with the RANS standard k-ε turbulence model. The boundary used as an inlet boundary was based on the wind direction measured from the air quality monitoring station. At the inlet boundary, the temperature, wind velocity and direction were specified using the data from the Bangkok's air quality monitoring station during the study period. The wind was uniform over the inlet face and normal to boundary. The outlet boundary was set as the pressure outlet which equals the atmospheric pressure. Symmetry conditions were applied for the upper and lateral boundaries. Since the flow at the upper and lateral boundaries are not affected by the buildings, thus flow patterns on both sides of the boundary are symmetry. Stationary wall and no-slip condition were applied to the ground surfaces and building walls, over which the temperatures were specified. The maximum temperature difference at midday between the air and the ground surface can reach 12-14 °C for the road surface made from asphalt [24]. Then, the temperature of road and ground surface were set 13°C above the air temperature. For the traffic exhaust which is considered as the only source of $PM_{2.5}$ in this study, the Discrete Phase Model (DPM) was used for simulating the $PM_{2.5}$ injection and dispersion. The DPM is based on the Eulerian approach for the continuous phase and the Lagrangian approach for the discrete phase [25]. The interaction between discrete and continuous phases was not taken into account. Since the discrete phase or particle in the study area is present at a fairly low volume fraction, thus the effect of particle on the flow is negligible [26, 27]. Carbon which is the major element of $PM_{2.5}$ in Bangkok [22] was set to be emitted from the road surfaces in the direction normal to the road. The injection of the carbon discrete phase was set at the upper face of each road with a particulate mass flow rate and a particle diameter of 2.5e-06 m using the DPM. The injection type was surface. Buoyancy was turned on since it was included by default when gravity was enabled. The mass flow rate of $PM_{2.5}$ emitted from the sources was calculated by the following equation [20].

$$Emission\ rate\ (\frac{kg}{s}) = \frac{\sum Q_i \cdot f_i \cdot l}{3600} \tag{8}$$

where Q_i is the traffic volume of type i motor vehicle (veh/h), f_i is the emission factor of type i motor vehicle (kg/(km·veh)) and l is the length of the road (km).

The emission factors of each vehicle type are shown in Table 1 [10].

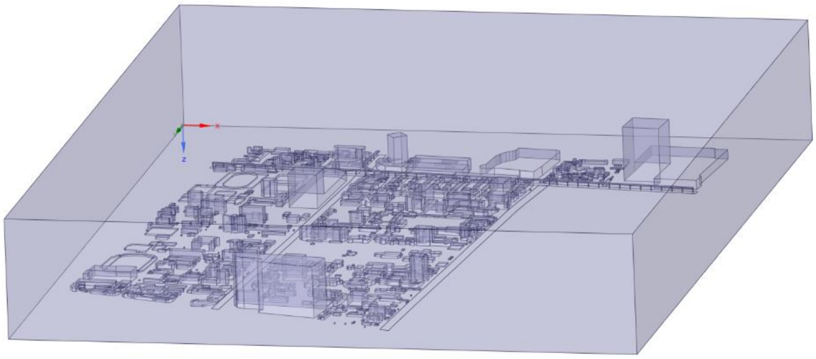

Fig. 2. Computational domain for the CFD simulation.

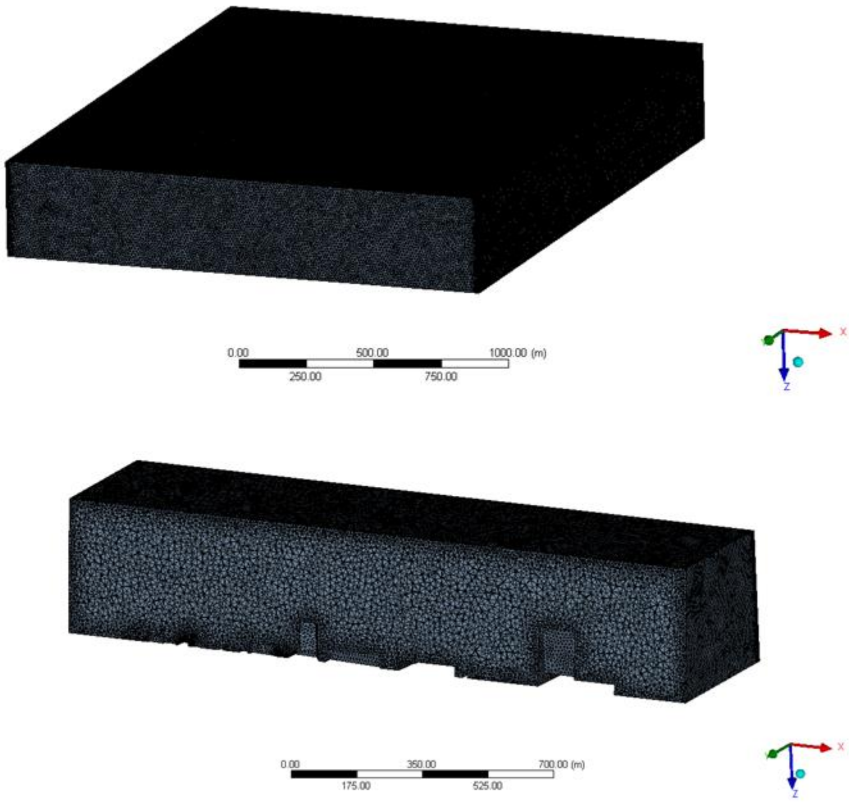

Fig. 3. Detail of the mesh.

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Table 1. $PM_{2.5}$ emission factors for mobile sources.

Vehicle type	Emission factor (g/km)
Two wheeler	0.0035
Three wheeler	0.0114
Passenger car	0.0011
Heavy commercial vehicles	0.0783

2.6. Investigation of the Effect of City Configuration and Other Variables on $PM_{2.5}$ Dispersion

The investigation of the effect of city configuration and other variables on $PM_{2.5}$ dispersion was divided into 2 main cases. These include the effect of skytrain structure in the focused area and the effect of city lockdown due to COVID-19 pandemic. In addition, the effect of meteorological conditions was analyzed. These cases were considered at different city configurations, meteorological conditions, and different number of vehicles within the focused area. They are important factors that affect the air flow and $PM_{2.5}$ dispersion in the street canyon. Moreover, the change in $PM_{2.5}$ concentration during the morning, noon and evening was also investigated to determine the influences of different meteorological conditions and emission rates during the day on $PM_{2.5}$ concentration. From the investigation of these effects on $PM_{2.5}$ dispersion, the guidelines to reduce the concentration of $PM_{2.5}$ in the focused area to not exceed the daily standard of 50 μg/m³ were developed.

3. Results and Discussion

3.1. Model Validation

The numerical model is validated with the measured data from the air quality monitoring station of the Environment Bureau, Bangkok which is in front of Samyan Mitrtown Building (corner of Phayathai and Rama IV roads intersection). The results from the simulation are compared with the measured data at a height of 2.5 m based on the principle of installing an air sampling station [28].

The validation results of $PM_{2.5}$ concentration and temperature profiles in Fig. 4 and 5, respectively, show good agreement. The simulated $PM_{2.5}$ concentrations in Fig. 4 are the concentrations around the air quality monitoring station, thus the values may quite different from the values measured directly at the station. However, the trend of concentrations obtained from simulation are consistent with concentrations obtained from measurement. Thus, the numerical model can predict the changes of $PM_{2.5}$ concentration and air temperature well.

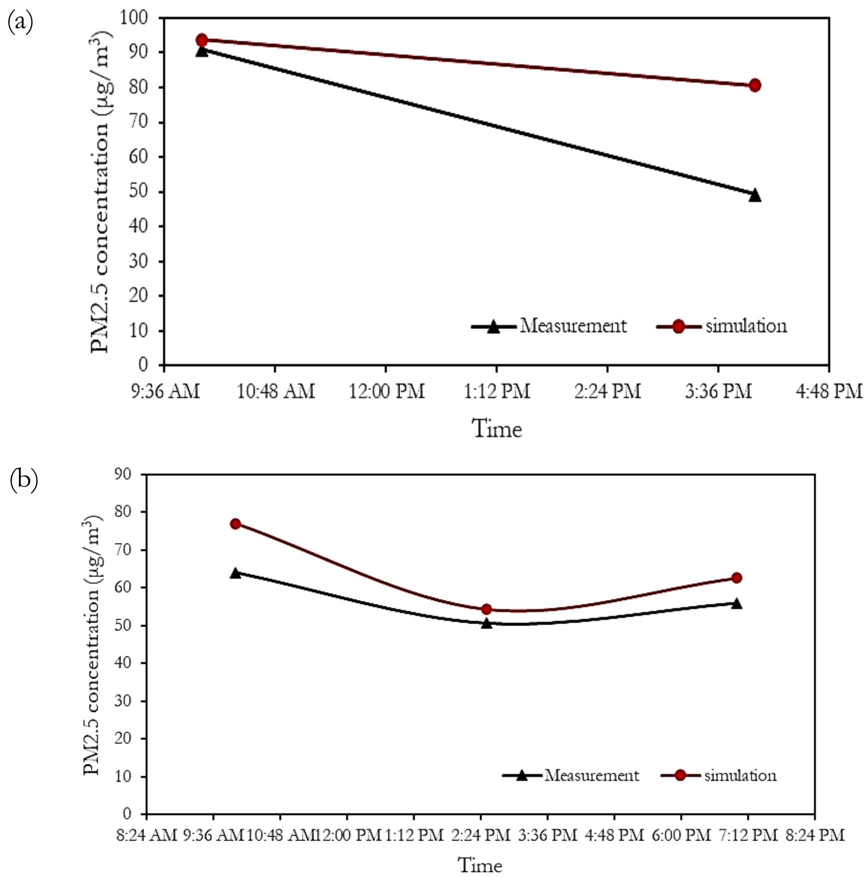

Fig. 4. Validation results of $PM_{2.5}$ concentration on (a) 14 Jan 2019 (normal time), (b) 21 Jan 2021 (lockdown).

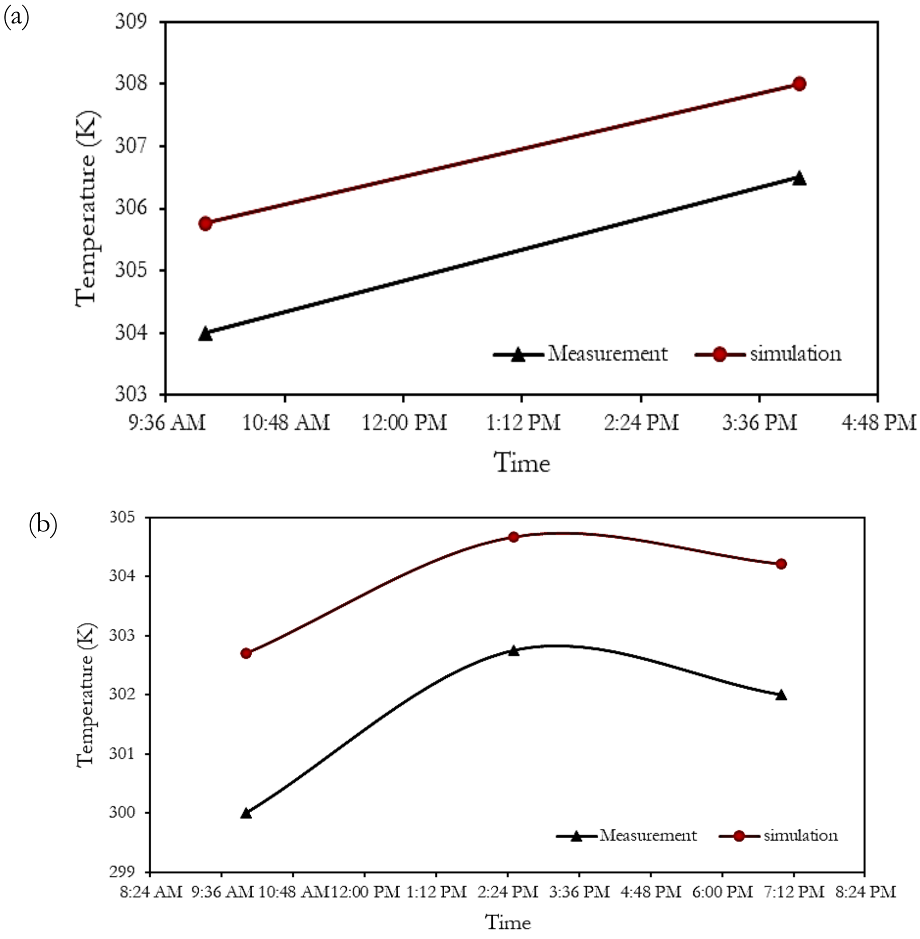

Fig. 5. Validation results of temperature on (a) 14 Jan 2019 (normal time), (b) 21 Jan 2021 (lockdown).

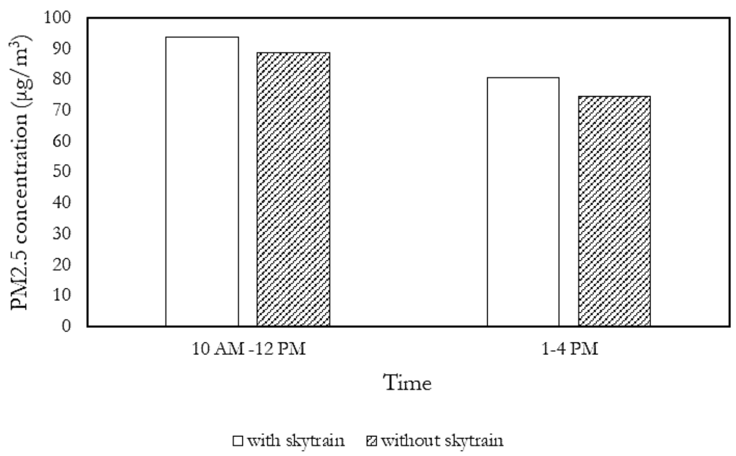

Fig. 6. Effect of skytrain structure in Pathumwan district on $PM_{2.5}$ concentration at the air quality monitoring station area (simulated based on the traffic volume and meteorological data on 14 Jan 2019).

Table 2. Emission rate and meteorological data around the air quality monitoring station, Phayathai road on 14 Jan 2019.

Time	Wind speed (m/s)	Wind direction	Temperature (K)	Emission rate (kg/s)
10 AM – 12 PM	0.2	E ➞ W	305.8	9.89e-06
1 – 4 PM	0.31	E ➞ W	308.0	1.48e-05

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3.2. The Effect of Skytrain Structure in Pathumwan District on $PM_{2.5}$ Concentration

The skytrain structure in Pathumwan district is surrounded by high-rise buildings, leading to poor ventilation and accumulation of pollutants. The effect of the skytrain structure on $PM_{2.5}$ concentrations at the air quality monitoring station away from the skytrain structure and in the vicinity of the skytrain structure is investigated.

3.2.1. The effect of skytrain structure on $PM_{2.5}$ concentration at the air quality monitoring station area

Figure 6 shows the comparison of $PM_{2.5}$ concentration at the air quality monitoring station area with and without skytrain structure in Pathumwan district. It is found that the presence of the skytrain structure in Pathumwan district increases $PM_{2.5}$ concentration at the air quality monitoring station area, which is away and in the south direction from the skytrain structure, by about 1.07 times. Although the emission rate is higher in the afternoon (1-4pm), $PM_{2.5}$ concentrations in both cases are lower compared with the morning results. This might be due to the higher wind speed which increases the air ventilation. In addition, the higher temperature in the afternoon heats up the air and makes it rise vertically. This enhances $PM_{2.5}$ dispersion and helps reduce the pollutant [29].

3.2.2. The effect of skytrain structure on PM2.5 concentration at the area under the skytrain

The effect of skytrain structure in Pathumwan district on $PM_{2.5}$ concentrations at the area under the skytrain is demonstrated in Fig. 7. The presence of the skytrain structure increases $PM_{2.5}$ concentration at the area under the skytrain by about 1.2 times. The skytrain structure in Pathumwan district is surrounded by tall buildings of shopping malls (i.e., street canyon characteristic). These can obstruct the airflow, leading to poor ventilation. The highest concentration of $PM_{2.5}$ occurs at 1-4 pm when the emission rate is high. Despite the higher wind speed and air temperature during 1-4 pm, the wind flow along the street canyon (as shown in Fig. 8(c)). Thus, the pollutant is trapped and not being able to disperse out of the area, causing high $PM_{2.5}$ concentration. In addition, $PM_{2.5}$ concentration is the second highest in the morning during 7-9 am. Although the emission rate is the lowest at that time, the wind speed and air temperature are also the lowest. Furthermore, the wind flows from the south toward the skytrain and high-rise building area. Thus, the pollutant is accumulated and resulting in the high concentration in the area. The low air temperature in the morning also reduces the influence of thermal effect causing the pollutant to sink in the street canyon.

3.3. The Effect of the City Lockdown due to the COVID-19 Pandemic on $PM_{2.5}$ Concentration

The city lockdown due to the COVID-19 pandemic [30] directly affects the traffic volume which is the main emission source of $PM_{2.5}$ in the urban area. During the lockdown period, the traffic volumes during 10 AM – 12 PM and 1 – 4 PM are 9,855 and 14,783 vehicles respectively, while the traffic volumes during normal time are 12,904 and 19,356 vehicles [15]. The effect of the city lockdown is demonstrated by comparing $PM_{2.5}$ concentration during the normal time (14 Jan 2019) and the city lockdown period (21 Jan 2021). The reference dates were chosen for the similar meteorological conditions, so that the effect of the city lockdown, hence the traffic volume, would be more apparent. From Table 4, the emission rate is reduced by about 20.25% during the city lockdown period. In addition, Fig. 11 shows that $PM_{2.5}$ concentration around the air quality monitoring station is also reduced by about 25.24% during the city lockdown period. In other words, the reduction of traffic volume can significantly reduce $PM_{2.5}$ concentration in Pathumwan district.

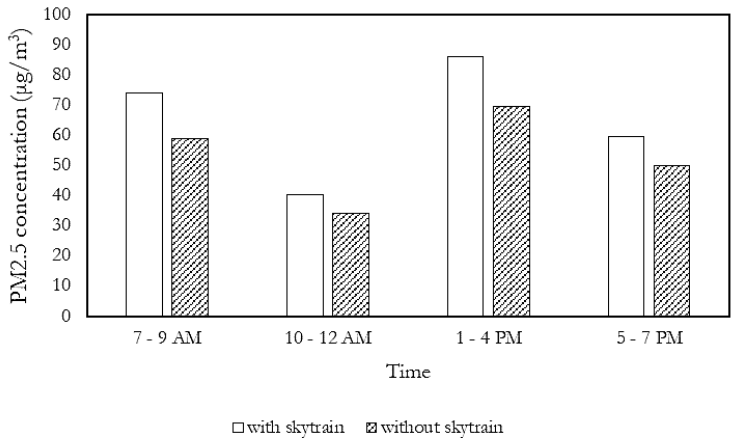

Fig. 7. Effect of skytrain structure in Pathumwan district on $PM_{2.5}$ concentration at the area under skytrain (simulated based on the traffic volume and meteorological data on 14 Jan 2019).

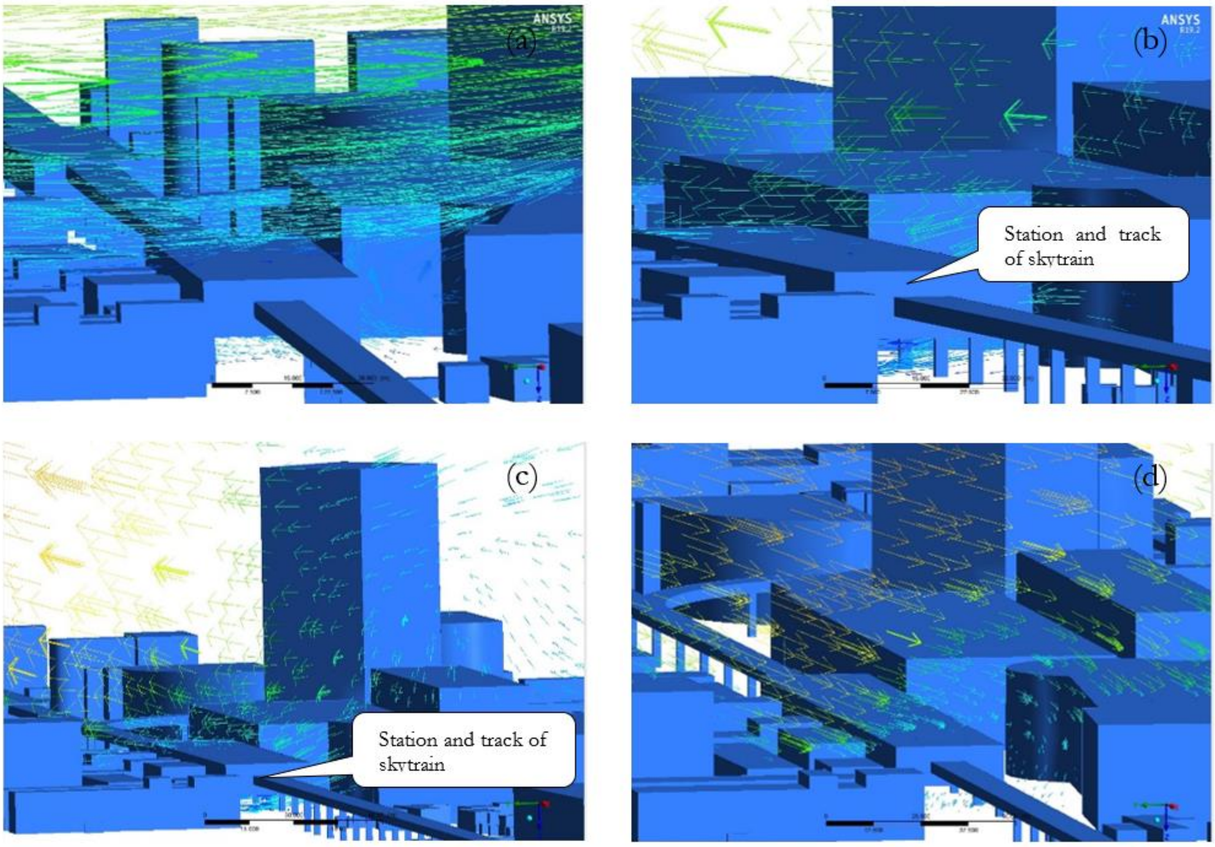

Fig. 8. Airflow fields around the skytrain structure on Rama I road during (a) 7-9 AM, (b) 10AM – 12PM, (c) 1-4 PM and (d) 5-7 PM.

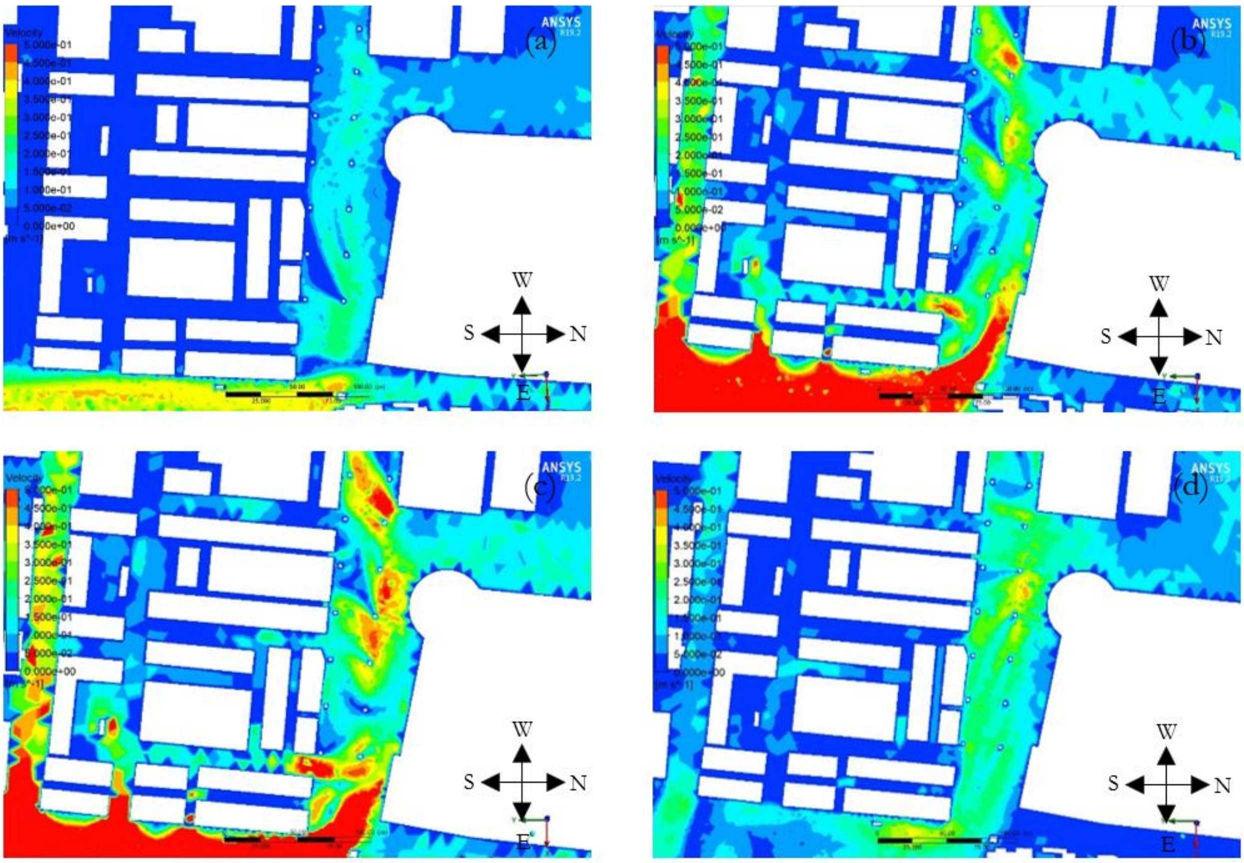

Fig. 9. Velocity contours at the area under the skytrain on Rama I road during (a) 7-9 AM, (b) 10AM – 12PM, (c) 1-4 PM and (d) 5-7 PM.

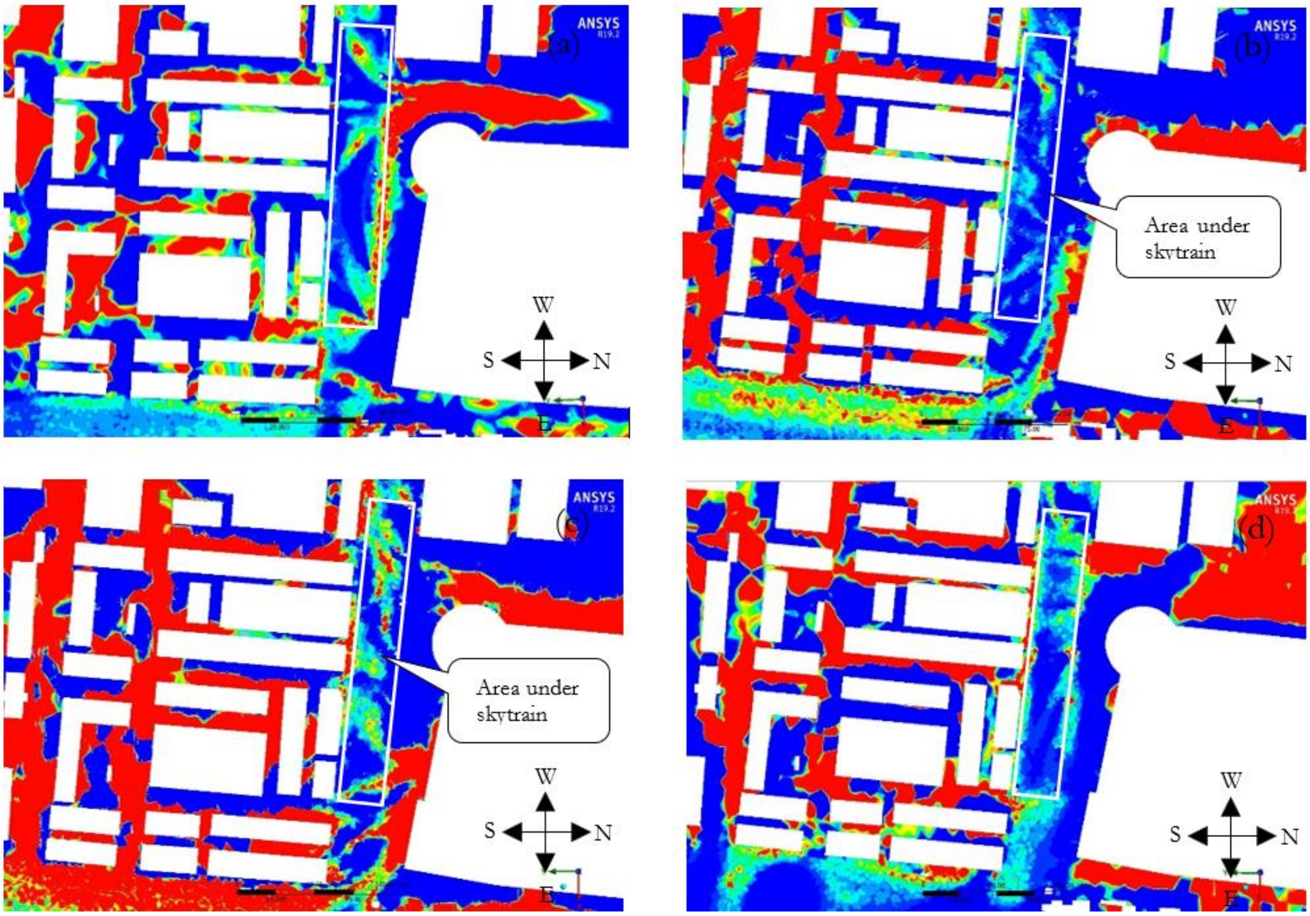

Fig. 10. $PM_{2.5}$ concentration contours at the area under the skytrain on Rama I road during (a) 7-9 AM, (b) 10AM – 12PM, (c) 1-4 PM and (d) 5-7 PM.

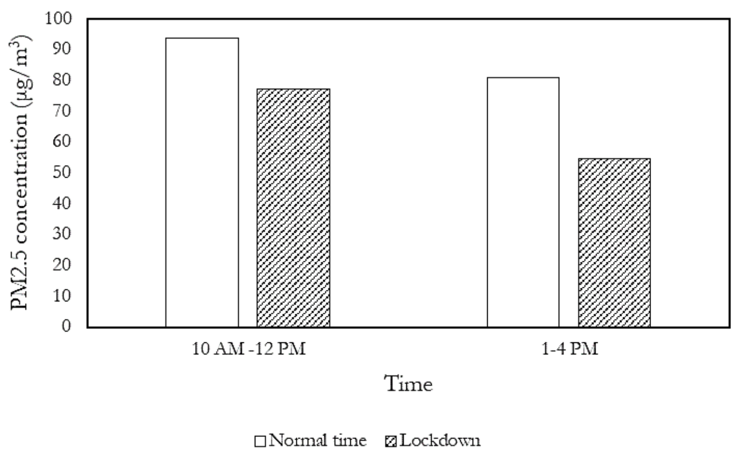

Fig. 11. Comparison of $PM_{2.5}$ concentration at the air quality monitoring station area during the normal time and the city lockdown period (simulated based on the traffic volume and meteorological data on 14 Jan 2019 and 21 Jan 2021, respectively).

Table 3. Emission rate and meteorological data on Rama I road on 14 Jan 2019.

Time	Wind speed (m/s)	Wind direction	Temperature (K)	Emission rate (kg/s)
7 – 9 AM	0.04	S ➞ N	302.9	6.24e-06
10 AM – 12 PM	0.08	E ➞ W	306.3	6.47e-06
1 – 4 PM	0.13	E ➞ W	309.1	9.71e-06
5 – 7 PM	0.07	W ➞ E	307.9	6.64e-06

Table 4. Emission rate on Phayathai road around the air quality monitoring station during the normal time (14 Jan 2019) and the city lockdown period (21 Jan 2021).

Time	Emission rate (kg/s)	
	Normal	Lockdown
10 AM – 12 PM	9.89E-06	7.89E-06
1 – 4 PM	1.48E-05	1.18E-05

4. Conclusions

The dispersion of $PM_{2.5}$ in street canyons can be influenced by many factors such as city configuration, emission source and meteorological characteristics. The city configuration in Pathumwan district, Bangkok, is consisted of several tall buildings in the shopping mall and university areas, and the skytrain structure located between the high-rise buildings (i.e., along the street canyon). These constructions obstruct the airflow, causing poor ventilation and accumulation of $PM_{2.5}$. From the demonstration of the skytrain effect, the presence of skytrain structure increases $PM_{2.5}$ concentration at the area under the skytrain by 1.2 times and at the area away from the skytrain (i.e., around the air quality monitoring station) by 1.07 times. This study also shows that the meteorological conditions such as air temperature, wind speed and direction strongly influence $PM_{2.5}$ concentration in the focused area. Moreover, the city lockdown due to the COVID-19 pandemic clearly illustrates the effect of traffic emission which is a major source of particulate air pollution in Bangkok. The reduction of traffic volume by 20.25% reduces $PM_{2.5}$ concentration around the air quality monitoring station by about 25.24%.

Based on the results in this study, $PM_{2.5}$ concentration in an area with similar city configuration as Pathumwan district, Bangkok, can be reduced by allowing good ventilation through the area. This may be done by decreasing the street canyon aspect ratio or avoid a construction that obstructs the air flow, especially the construction of the skytrain structure in high-rise building area. Since the skytrain structure is located on the road, where the $PM_{2.5}$ is emitted, the structure above the road will cause $PM_{2.5}$ to be trapped within the canyon and difficult to disperse out of the area. If there are tall buildings surrounding the skytrain structure, it will cause more $PM_{2.5}$ accumulation in the canyon. This recommendation is based on the results of the effect of skytrain structure on $PM_{2.5}$ concentration at the area under the skytrain which show that the presence of the skytrain structure between tall buildings increases the concentration of $PM_{2.5}$. Furthermore, a significant decrease of $PM_{2.5}$ concentration during the lockdown period, which is associated with the reduction of traffic volume, implies that a policy regarding traffic control during the period of low wind speed and low temperature would help reduce the particulate air pollution substantially. Based on the apparent results from the investigation of the effect of skytrain structure on $PM_{2.5}$ concentration at the air quality monitoring station area during 10 am – 12 pm and at the area under the skytrain during 7-9 am, this study shows that the high $PM_{2.5}$ concentration results even with low emission rate. The wind speed and temperature in both cases are low resulting in poor ventilation and high concentration. Thus, the traffic should be controlled during the period of low wind speed and low temperature. The impact would be even more amplified in an area with street canyon characteristics.

However, there are some limitations in this study consisting of the limitations of traffic data and meteorological data. The traffic data is limited to one day per year; thus, it is impossible to simulate the influence of different weather conditions in each season on $PM_{2.5}$ concentration. For meteorological data, there is only one air quality monitoring station in the study area. Thus, there are limitations in the meteorological data which will be used as boundary conditions. In this study, there is incomplete meteorological data during 7 – 9 AM of the lockdown period.

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