

# Review Article: Technical Approaches of PM2.5 Control for Spatial Design in Thailand

Jitiporn Wongwatcharapaiboon<sup>1\*</sup>, Saffa B. Riffat<sup>2</sup>

<sup>1</sup> *Design, Business and Technology Management, Faculty of Architecture and Planning, Thammasat University Pathumthani, Thailand*

<sup>2</sup> *Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, UK*

\* Corresponding author e-mail: [jjpinx4391@gmail.com](mailto:jjpinx4391@gmail.com)<sup>1\*</sup>, [jitiporn@ap.tu.ac.th](mailto:jitiporn@ap.tu.ac.th)<sup>1</sup>, [saffa.riffat@nottingham.ac.uk](mailto:saffa.riffat@nottingham.ac.uk)<sup>2</sup>

Received: 2 Apr 2021; Revised from: 22 June 2021; Accepted: 24 June 2021

Print-ISSN: 2228-9135, Electronic-ISSN: 2258-9194 doi: 10.14456/built.2021.1

## Abstract

According to PM2.5 situation in Thailand, the monitoring of dust concentration has been exceeding 100 µg/m<sup>3</sup> for longer a month period. This level is harmful to all local livings standardized by National Ambient Air Quality standards (NAAQs) and World Health Organization (WHO). However, this problem is specific to location in terms of tropical climate, geographical land, existing policy and people behaviours. Social intervention reviews are separately concerned in another research part of study series. Thus, this paper aims to find suitable PM2.5 purification and techniques matched to tropical climate and high concentration conditions. Environmental factors, probably affect PM2.5 situations, are considered in priority. Systematic reviews of different techniques are literally analysed and synthesized for optimum benefits to local applicants, further research and case studies in teaching class. The results are scoped to three levels of living conditions from outdoor situation for landscape study to architectural integration for architecture study and indoor applicable functions for interior designer study. For outdoor approaches, well connectivity of information in terms of Internet of Things (IoTs) and smart satellite technology are mainly concerned to provide accuracy and reliability, when planting landscape in city is proved to reduce PM2.5. In case of architectural scale, the details of technical and chemical approaches can support physical approaches for design. Lastly, interior scale concerning of air pollution is exemplified for further space design. Suggestions, installations and cautions of applications are perhaps included in each specific session.

**Keywords:** PM2.5 controls, design approaches, Thailand situations, air purifier techniques

## 1. Introduction

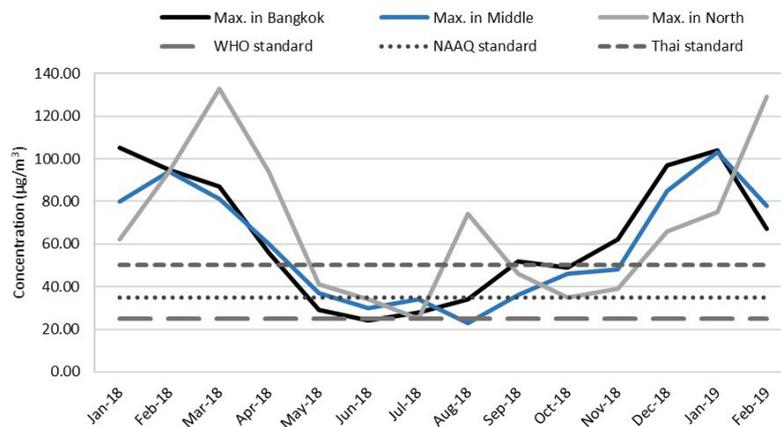
During the past 23-year of monitored air quality in Table 1, PM2.5 has been monitored from 2013 in Samutsakorn peri-urban area which average collection was approximately  $62 \mu\text{g}/\text{m}^3$  (Air Quality and Noise Management Bureau., 2019). Then in Bangkok Metropolitan and other peri-urban areas were extended to later collect Total Suspended Particles (TSP) and PM2.5 levels. This transforming data collection resulted from agricultural activities to open-burning in neighbor countries and local communities. Then it becomes serious problem in 2018 and 2019 winter seasons.

In 2019, air quality has become more concerning as the exceeding level of particulate matter diameter sized 2.5 micron (PM2.5) in middle and northern part of Thailand. The end and early year period in Thailand is winter season which climate pressure possibly block air refreshment in Thailand. Also, agricultural burning activities and forest fires have mainly sourced air dust elements via natural ventilation. Consequently, throughout 14-month period from January 2018 to February 2019, Figure 1 shows overall maximum PM2.5 concentrations in Bangkok, middle and north part of Thailand (Air Quality and Noise Management Bureau., 2019). Monitoring results of Bangkok, middle and northern parts have been collected amongst 10, 4 and 16 weather stations respectively. Also, Bangkok monitoring trend is fairly similar to middle part trend because it is a part of middle land. The peaks of dust concentration in the north delay a few months from middle part which sources are totally unrelated. In the middle part, seasoning wind is from northern-east direction, while northern part is possibly affected from western and eastern neighbourhoods. Average PM2.5 levels in Bangkok, Middle part and Northern Thailand are  $28.23 \mu\text{g}/\text{m}^3$ ,  $30.02 \mu\text{g}/\text{m}^3$  and  $27.07 \mu\text{g}/\text{m}^3$  respectively. All those average results of PM2.5 concentration exceed

**Table 1.** Air pollution monitoring in Pathumthani and Nonthaburi, Thailand

Year	Types of Monitored Air Pollution							
	SO <sub>2</sub>	NO <sub>3</sub>	CO	O <sub>3</sub>	PM <sub>10</sub>	PM <sub>2.5</sub> ( $\mu\text{g}/\text{m}^3$ )	TSP	Pb
1997-2012	•	•	•	•	•	-	-	-
2013-2014	•	•	•	•	•	-	•	•
2015-2016	•	•	•	•	•	-	-	-
2017	•	•	•	•	•	-	•	•
2018	•	•	•	•	•	Pth	29	•
						Nth	-	
2019	•	•	•	•	•	Pth	30.68	•
						Nth	33.96	

Pth = Pathumthani  
Nth = Nonthaburi



**Figure 1.** Maximum PM2.5 monitoring in Thailand.

World Health Organization (WHO) standard at  $25 \mu\text{g}/\text{m}^3$ , but are acceptable in National Ambient Air Quality (NAAQ) standard at  $35 \mu\text{g}/\text{m}^3$ .

However, the most severity of dust situation is not only level concern; suffering periods are now more than 60 days. These situations have affected dramatically respiratory systems among sensitive receptors in Thailand such as children, elderly and hospital patients. Also, as being local people, it is difficult to avoid facing hazardous environment. Therefore, this research aims to investigate literally approaches or techniques to suitably clean

particulate matter in tropical climate within three scope approaches including outdoor approaches, architectural envelope adaptations and indoor applications.

## 2. Outdoor Approaches

In urban scale of dust problems, network monitoring and analysis systems help to warn immediately local people for predictable situations and for the purpose of reliability. Then preparing process of pre-filtration by greenery area is required for long term environment which is directly affecting building scale and functioning space.

### 2.1 Internet of Things (IoT)

Internet of Things (IoT) is computationally used to collect data and provide environmental comfort including air temperature (T), relative humidity (RH) and Particulate Matter (PM<sub>2.5</sub>). For examples, Network Function Virtualization (NFV), Software-Defined Networks (SDN) and Service Function Chain (SFC) can improve system potentials by shortening time of data transmission and balancing load of data (Chien, Lai, Cho & Chao, 2018, p. 88).

The concept of IoTs is well known in international scale but adapting to Thai facilitating process is pretty slow.

In European countries, to improve air quality in trapping area such as subway station, numeric data is real-time calculated the optimize solution for air quality based on 4 keys of open-closed systems, train interval, bypass and flexibility of ventilation ducts. Then the solution showed in terms of train-induced unsteady airflow (TIUA) model which is supported strongly by environmental control system (ECS) to adjust seasoning heat and ventilation in functional area (Zhang et al., 2019, p. 87). Those smart technologies in European Community somehow are integrated to contemporary kitchen as smart hood which can optimize environmental impact and energy consumptions (Castorani, Rossi, Germani, Mandolini & Vita, 2018, p. 499). Within Thailand climate, seasoning wind, high relative humidity and temperature possibly affect air dust level.

To notice, dealing with technology and data management, reliability is important to continue analysing process and link other systems. So, quality and stability of intelligent effectiveness and reliability are exemplified to develop by general algorithm and back-propagation (GA-BP) neural network and increase in number of testing data (Haorui, Manhao, Ge, Li & Yu, 2018, p. 99). However,

system and network investments are emergently and importantly concerned. For the next consideration of IoTs, further research may point in details of sensor and monitoring process related to reliability and data management. To calibrate and validate information, smart network is the next session.

### 2.2 Smart Technologies for Satellite Networking Predictions

Moving from small scale of IoTs, satellite data is used for reliably reporting previous to current situations and predicting future area of harmful dust concentration. This is possible technique to apply in Peri-urban of Bangkok according to free authority to download data from satellite network.

Intelligent system can provide complex analysis and climatic uncertainty simulations for acceptable results. From satellite database, Aerosol Optical Depth (AOD) is used to analyse PM<sub>2.5</sub> level by land use regression map and machine algorithm settings. Such algorithms support analysis result of relationship between PM<sub>2.5</sub> level and other cause factors, for examples, land surface temperature and other weather station data (Xu et al., 2018, p. 1417). Based on the Moderate Resolution Imaging Spectroradiometer (MODIS), relative humidity, temperature, pressure and wind are added information to predict monthly climatic and air pollution. The limitation of satellite aerosol optical depth (AOD) is considered over the Beijing-Tianjin-Hebei (BTH) region in 2018. On ground (3 km data) PM<sub>2.5</sub> concentration is proved to affect seasonally an improved geographically and temporally weighted regression (iGTWR) or cross-validation (CV) model (He, & Huang, 2018, p. 236). Additionally, in case of PM<sub>2.5</sub> monitoring, analysis approaches including cross-correlation analysis, time-series clustering, Voronoi diagram and polygon smoothing demonstrate possibly clearer density area and different characters of density in winter and summer seasons. Those dust characters in winter season are crowded and covered larger areas in China (Liu, Li & Wu, 2018, p. 642). This result is similar to the 15-year statistic data in Asian and African regions, whereas decreasing areas of low dust level is found (Li, Wang, Wang, & Li, 2018, p. 471). Moreover, within remote system of Light Detection and Ranging (LIDAR) in Shenzhen, 3-month data is analysed in winter time. Result points out main PM<sub>2.5</sub> source contributed 50% from regional transmission and 10% from local source (Liu et al., 2019). Consistent with complex layers of intelligent analysis, it is possible that exceeding standard of PM<sub>2.5</sub> level can happen cover larger area in every winter season.

Another performance of satellite networking shows in uncertainty analysis with specific assumption models. For example, air quality predictable model in China normally focuses on accuracy, stability and uncertainty analysis which results in inadequate data. To come across this problem, the fuzzy time data collection is processed as uncertainty analysis, then the effectiveness of model is improved remarkably (Wang, Li, & Lu, 2018, p. 783). In southern China, biomass burning pollutant emissions from the Fire Inventory from NCAR (FINN) can improve accuracy of daily forecast by reducing bias of PM2.5 simulation in back-propagation neural network (BPNN) (Feng et al., 2019, p. 22). Number of monitors and Bayesian probabilistic model are applied to tolerate errors and the sensitivity of satellite-based PM2.5 information in the Community Multi-scale Air Quality Model (CMAQ) simulations in the southeast U.S. (Geng, Murray, Chang, & Liu, 2018, p. 550). Uncertainty and sensitivity analysis is also the key factor to improve decision-making process of modelling tool named Screening for High Emission Reduction Potentials on Air quality (SHERPA) in European region. This model can reliably optimize decision based on scenarios from uncertainty quantification and influential identification of input sources (Pisoni et al., 2018, p. 84).

Main performance of smart technological satellite is to report monitoring data of air pollution with accuracy and validating types of model on nearly real time. All accuracy and validating process need reliability of sensor and monitoring process from monitoring and connected devices from IoTs part.

### 2.3 Planting Techniques for Air Quality Concern

In large scale of city and peri-urban, zoning of mining industry is recommended integrating with natural and techno vehicle corresponding to Federal Target Programs to avoid harmful gas and fine particle emissions (Fedotov, & Afanasiev, 2018, p. 179). As same as sand fog seal (SFS) tool on road surface which is claimed to be environmentally friendly equipment integrated to air cooling and purifying techniques. It performs 16% increase gaseous purifier efficacy and 20% improvement of PM2.5 cleaning from the traffic road (Guo, Wang, Yang, & Sun, 2017, p. 608). Perhaps, vehicle emission provides environmental impacts with diesel combustion gases such as nitrogen oxides (NO and NO<sub>2</sub>), carbon oxides (CO and CO<sub>2</sub>), formaldehyde, acetaldehyde and acrolein, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). Some types are possibly cleaned by effective technical plasma system voltage system (Chang et al., 2019, p. 336), plant morphology and stomatal

absorption (Brilli et al., 2018., p. 507). If urbanization allows preserving some proper green areas in peri-urban, local community and transportation will be able to clean naturally air quality.

In Thailand context, the main source of PM2.5 is from agricultural waste burning and forest fire which emit tons of polycyclic aromatic hydrocarbons (PAHs). Mechanical purifier is needed to shortly clean, while bio-filter is possibly used in city street for long term effect.

Moreover, Atomic Force Microscope (AFM) scanning is partially used to prove correlation between plant leaf surfaces and water-soluble ionic components in China. Water soluble ions of air PM2.5 are mostly identified as SO<sub>4</sub><sup>2-</sup>, Na<sup>+</sup>, NO<sub>3</sub><sup>-</sup> and NH<sub>4</sub><sup>+</sup>. Adaptation of leaf surface is examined as different roughness in each sampling park depended on level of air pollution. Also leaf morphology, is similar to fibre mop, provides higher potential to collect PM2.5 ions (Lu et al., 2018, p. 64). This can be supported by Computational Fluid Dynamics (CFD) simulation of gasses and the Leaf Angle Distribution (LAD). It is found that NOx and PM2.5 concentrations can be reduced up to 18% based on LAD and aerodynamic winds. While a 108% increase in PM2.5 is found close to trees in case of perpendicular winds (Buccolieri, Jeanjean, Gatto, & Leigh, 2018, p. 227).

To promote natural cleaning as pre-filter, surrounding data is the main effect on plant growth ability and purifying performance. For instance, environmental factors are proved to affect air flow in active green wall. Approximate 50% increase in air flow is found in plant-filter with water spray, though the maximum capacity of bio-filter accumulation is found when reducing around 15.5% of air flow. If allowing 10 mm on top of bio-filter, direction can force up level of air flow throughout the system (Abdo, Huynh, Irga, & Torpy, 2019, p. 75). Among 28 species of tree, 5 species of shrubs and 3 species of liana in urban scale of Beijing, China, comparison results show effectiveness to reduce PM2.5 in case of horizontal installations of shrubs and trees. Vertical version, however, examines adversely effects to surrounding. Trapping abilities of PM types are specifically depended on species and configuration design (Chen, Liu, Zou, Yang, & Zhang, 2016, p. 198). This result is similar to urban street trees study in New York City that greater density of trees links to better air quality, even though asthma and allergenic patients are rising among local populations (Lai & Kontokosta, 2019, p. 80).

Specific species of plant and various installations of plants consequently result in air cleaning performance and types of air pollution. However, plants can be pre-filter in wide area from street to landscape around residential building. If density of plant leaves is sufficient, this bio-filter will be effective method within suitable installation before reaching architectural scale.

### 3. Architectural Scale Approaches

Within building scale techniques, envelope and wall shape are possibly multi-layer of air filters to protect indoor users or blocking negatively indoor refreshment. Also, industrial techniques of cyclone dust gravity and electrostatic field are considered as adaptable approaches for building designs. Then mixed-method integration is finally optimized benefit for cleaning air quality.

#### 3.1 Physical Designs for Filtration

Natural ventilation is now problem related to high concentration of dust. Building surface which allow natural ventilation pass through should be integrated air cleaning techniques. For example, shape of PM2.5 trap is studied as concave and convex cavity wall. Within natural turbulence condition, trapping wall can reduce effectively PM2.5 (Wang, Zhang, & Wang, 2017, p. 3285). To acquire better benefit, somehow, this technique is integrated to others based on local environment. For pre-filter process of PMs in Taiwan, gravimetric method is recommended to simply separate type of dust. Then wet-scrubber is introduced to optimize classification of respiratory dust with low energy consumption (Hoeflinger & Laminger, 2019, p. 53). To concern wet system of air purification, flow rate and PMs concentration in fluidized bed system are related significantly to density of spraying bed. Optimize flow rate is identified at 38 ml/min which can reduce PM2.5, PM1.0 and PM0.1 by 93.5%, 93.6% and 93.7% respectively (Chen, Tang, Liang & Wu, 2018, p. 245).

These applications are feasibly replaced ventilation cement block which is generally used in low income houses in peri-urban of Bangkok. Also, free space around natural ventilation building can be adapted spraying technic for supporting air cleaning performance.

#### 3.2 Engineering Technical Applications

To trap PM2.5 in China, the most popular methodology is two-stage electrostatic precipitator techniques which provide up to 90-99% of PM2.5 purifications (Jaworek, Marchewicz, Sobczyk, Krupa & Czech, 2017, p. 180, Jaworek, Marchewicz, Sobczyk, Krupa, & Czech, 2018, p. 206).

Then the Electrical Low Pressure Impactor (ELPI+) in the Electrostatic-bag-precipitator (EBP) is developed higher trapping performance and lower energy consumption (Jianan, Xue, Tingyu & Yi, 2018, p.14).

However, in long term effect, the weakness is found in terms of accumulation of charged particles which is needed to maintain after full capacity of dust load (Xiong, Lin, Zhang, Chen, & Zhao, 2018, p. 119). It is exemplified, after half month use in commercial space, filtration of intense field dielectric (IFD) drop dramatically to 80-85% and one-month maintenance can recover by 60-65% filter performance (Ren & Liu, 2019, p. 468). Changing material to polypropylene (PP) filter helps possibly increasing purification performance and energy efficiency in building.

Performance of air purifier somehow should be evaluated by life cycle and pressure drop which second one is generally hidden in commercial information. Pressure drop can reduce air cleaning performance, while increase energy cost in 7-month use of F7 filter or Electrostatic Precipitation (ESP) filter (Soh, Dubey, Hedlund & Kaushal, 2019, p. 4465). Nonetheless agglomerations can promote performance of ESP based on chemical agents, for example, sodium alginate solution, pectin and water etc. Also, it is proved that sodium alginate solution can increase 20% air cleaning performance of ESP (Bin et al., 2018, p. 27). Another electrostatic field is exemplified on glass surface that indium tin oxide (ITO) cleans effectively lunar dust within the low-frequency mechanic vibration (Kawamoto & Hashime, 2018, p. 38).

Most of electrostatic approaches are applied into air purified devices for claiming low energy consumption with the most effectiveness of air cleaning. However, dust accumulation in system should be maintained in every 6-8 months. To be noted, technical devices and techniques in this part are normally used for indoor devices. The maintenance period is possibly changed or unappropriated for uncontrollable closure.

#### 3.3 Chemical Application

Focusing on building element, window and door net screen is popular to be coated by photocatalytic chemicals. This is for the purpose of preserving high natural ventilation rate and cleaning air pollution. The effect of air cleaning can reduce depended on types of chemicals. Silver (Ag) is effective photocatalytic chemical and high stability of performance, however, it is still too expensive for low income people. Titanium dioxide (TiO<sub>2</sub>) and zinc oxide (ZnO) are really active in photocatalytic process, but chemical phases are not stable.

Nano coating on nylon fibre is innovative method to clean PM2.5. For (Ag NWs) coating with high wind speed, it is found to reach more than 99% of PM2.5 cleaning efficiency in 50 seconds. Only one limitation of chemical coating technique is unstable chemical action to other air elements. For example, Ag NWs coating is electrolyzed by sulphur (S) (Huang et al., 2019 p. 333), while TiO<sub>2</sub> can sensitively change internal phase and band gap based on environmental temperature (Tsang et al., 2019, p. 200). To claim self-cleaning performances, TiO<sub>2</sub> solvent is found to support colour surface protection if it is applied in the early state of coating on limestone surface. This process is effective in just 8 months, and then partial loss of titania and deactivation will possibly affect photocatalytic performance (Lettieri, Colangiuli, Masieri & Calia, 2019, p. 506).

Because of demanding in lighting and air humidity, Thai tropical climate is perfectly applied chemical techniques to building envelop. Only one excuse for chemical, it should be guaranteed not to be carcinogen for building users.

#### 4. Indoor Air Controlling Techniques

Since indoor space is the most closeness to users, indoor space should be treated by air purified technologies or permanent separation from air pollution sources.

For indoor air quality (IAQ) in China, there are specific methods to control PM2.5, for example, air tightness improvement, room pressure control, air filtration depended on existing conditions. To combine these controlling methods, PM2.5 concentrations is reduced to lower 25 µg/m<sup>3</sup> (Chu, Xu, Yang, & Li, 2017, p. 3222). For indoor kitchen, biomass burning emission affects 40% household air, while cooking hood with filter system can help to reduce PM2.5 to zero in 35 minutes (Still et al., 2018, p. 129). To mention the importance of ventilation, the estimation of indoor air pollutants in kitchen rise up to 63% from initial exposure without additional ventilation. The estimate model is based on better indoor air quality assumption and it is included indoor/outdoor ratio of PM2.5, NO<sub>2</sub> and CO in London residential unit (Taylor et al., 2019, p. 390).

Furthermore, chemical integration is really support air cleaning equipment in indoor condition. For instance, to improve performance of air cleaning, silver (Ag) component is integrated to porous calcium phosphate

(CaP) for filtering bioaerosol. Then results demonstrate high efficiencies of PM10, PM2.5, PM1.0 and staphylococcus aureus aerosol reaching 96%, 91%, 85% and 96% respectively (Zhao et al., 2018, p. 387). Moreover, multi-layers of fabricate structure in filter bag are combined from silver metal-organic frameworks (Ag-MOFs) and cellulose nanofiber (CNF) and results show outstanding performances of 94% PM2.5 cleaning and against Escherichia coli. (Ma et al., 2019, p. 415). Within indoor condition, bioaerosol is concerned as supporting doubly PM2.5 effect on health.

#### 5. Discussions and Conclusions

Since 1997, Thailand has continually extended air quality monitoring stations to cover peri-urban Bangkok and rural provinces for monitoring SO<sub>2</sub>, NO<sub>3</sub>, CO, O<sub>3</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, TSP and P<sub>b</sub>. The latest monitored data in peri-urban Bangkok in 2018 was PM2.5 which long-term impacts became higher severity in sensitive people or even healthy people. So, this paper aims to investigate possible solutions for cleaning air quality in tropical climate and semi-urban areas.

According to reviews of air quality solutions for Thai tropical climate, environmental factors are concerned to disturb satellite data collections, air cleaning performance of plants and chemicals in outdoor condition. Reliabilities of air pollution data collection and satellite monitoring are based on environmental and uncertainty data analysis. Green pre-filtration of air pollution can start from public space such as peri-urban Bangkok's streets until landscape around buildings.

In building scale, there are 3 types of application demonstrated in dust gravity adaptation on wall, electrostatic application and photocatalytic chemical coating. It is nearly to indoor concept of applying holistic approaches for cleaning. But indoor condition is more concerned in bioaerosol cleaning techniques and system control to reach low air pollutions.

All reviewing techniques contribute brief information of high potential air cleaning approaches for researchers and provide possible applications for tropical climate and peri-urban Bangkok residents. These technical optional approaches and environmental conditions will possibly be applied in design studio classes, for example, eco-design for landscape, building design and interior design.

As being strictly to indoor condition, air purified device and system are suggested for all climate conditions. It is also recommended in case of severe situation in winter season too. Specific conditions of indoor and outdoor conditions are mainly concerned in terms of engineering controlling system. However, in the role of designer's discussion, all technical approaches are not completed yet which these all adaptable techniques can be selected for adjusting to specific local conditions. It is possible to integrate some techniques as a part of building or space elements which are required design process for each applicable space. Also, local implementation for these innovative approaches have been exemplified in another serial review (Wongwatcharapaiboon, 2020) which pointed willingness to pay tax for air quality in China. Consequently, Thai designers may start survey value opportunity for local implementation of air quality innovations.

## References

- Abdo, P., Huynh, B. P., Irga, P. J., & Torpy, F. R. (2019). Evaluation of air flow through an active green wall biofilter. *Urban Forestry & Urban Greening*, *41*, 75-84. doi:https://doi.org/10.1016/j.ufug.2019.03.013
- Air Quality and Noise Management Bureau. (2019, 10th February). Thailand's air quality and situation reports. Available: <http://air4thai.pcd.go.th/webV2/download.php>
- Bin, H., Yang, Y., Lei, Z., Ao, S., Cai, L., Linjun, Y., & Roszak, S. (2018). Experimental and DFT studies of PM2.5 removal by chemical agglomeration. *Fuel*, *212*, 27-33. doi:https://doi.org/10.1016/j.fuel.2017.09.121
- Brilli, F., Fares, S., Ghirardo, A., de Visser, P., Calatayud, V., Muñoz, A., . . . Menghini, F. (2018). Plants for Sustainable Improvement of Indoor Air Quality. *Trends in Plant Science*, *23*(6), 507-512. doi:https://doi.org/10.1016/j.tplants.2018.03.004
- Buccolieri, R., Jeanjean, A. P. R., Gatto, E., & Leigh, R. J. (2018). The impact of trees on street ventilation, NOx and PM2.5 concentrations across heights in Marylebone Rd street canyon, central London. *Sustainable Cities and Society*, *41*, 227-241. doi:https://doi.org/10.1016/j.scs.2018.05.030
- Castorani, V., Rossi, M., Germani, M., Mandolini, M., & Vita, A. (2018). Life Cycle Assessment of Home Smart Objects: Kitchen Hood Cases. *Procedia CIRP*, *69*, 499-504. doi:https://doi.org/10.1016/j.procir.2017.11.113
- Chang, K.-L., Amesho, K. T. T., Lin, Y.-C., Jhang, S.-R., Chou, F.-C., & Chen, H.-C. (2019). Effects of atmospheric-plasma system on energy efficiency improvement and emissions reduction from a diesel engine. *Journal of Environmental Management*, *234*, 336-344. doi:https://doi.org/10.1016/j.jenvman.2019.01.017
- Chen, H., Tang, X., Liang, C., & Wu, X. (2018). Attapulgite suspension mitigates fine particulate matter (PM2.5) emission from coal combustion in fluidized bed. *Journal of Environmental Management*, *209*, 245-253. doi:https://doi.org/10.1016/j.jenvman.2017.12.072
- Chen, L., Liu, C., Zou, R., Yang, M., & Zhang, Z. (2016). Experimental examination of effectiveness of vegetation as bio-filter of particulate matters in the urban environment. *Environmental Pollution*, *208*, 198-208. doi:https://doi.org/10.1016/j.envpol.2015.09.006
- Chien, W.-C., Lai, C.-F., Cho, H.-H., & Chao, H.-C. (2018). A SDN-SFC-based service-oriented load balancing for the IoT applications. *Journal of Network and Computer Applications*, *114*, 88-97. doi:https://doi.org/10.1016/j.jnca.2018.04.009
- Chu, Y., Xu, P., Yang, Z., & Li, W. (2017). Existing building retrofitting for Indoor PM2.5 Concentration Control on Smog Days: Case study in China. *Procedia Engineering*, *205*, 3222-3227. doi:https://doi.org/10.1016/j.proeng.2017.10.290
- Fedotov, V., & Afanasiev, A. (2018). Concept of air environment cleaning of natural and technogenic systems of motor transport using mobile devices. *Transportation Research Procedia*, *36*, 179-184. doi:https://doi.org/10.1016/j.trpro.2018.12.061
- Feng, X., Fu, T.-M., Cao, H., Tian, H., Fan, Q., & Chen, X. (2019). Neural network predictions of pollutant emissions from open burning of crop residues: Application to air quality forecasts in southern China. *Atmospheric Environment*, *204*, 22-31. doi:https://doi.org/10.1016/j.atmosenv.2019.02.002
- Geng, G., Murray, N. L., Chang, H. H., & Liu, Y. (2018). The sensitivity of satellite-based PM2.5 estimates to its inputs: Implications to model development in data-poor regions. *Environment International*, *121*, 550-560. doi:https://doi.org/10.1016/j.envint.2018.09.051
- Guo, T., Wang, C., Yang, X., & Sun, X. (2017). Development and performance of sand fog seal with cooling and air purification effects. *Construction and Building Materials*, *141*, 608-618. doi:https://doi.org/10.1016/j.conbuildmat.2017.03.003

- Haorui, J., Manhao, L., Ge, H., Li, Z., & Yu, D. (2018). Quality stability evaluation model based on intelligent control. *IFAC-PapersOnLine*, 51(32), 99-104. doi:<https://doi.org/10.1016/j.ifacol.2018.11.361>
- He, Q., & Huang, B. (2018). Satellite-based high-resolution PM2.5 estimation over the Beijing-Tianjin-Hebei region of China using an improved geographically and temporally weighted regression model. *Environmental Pollution*, 236, 1027-1037. doi:<https://doi.org/10.1016/j.envpol.2018.01.053>
- Hoeflinger, W., & Laminger, T. (2019). PM2.5 or respirable dust measurement and their use for assessment of dust separators. *Journal of the Taiwan Institute of Chemical Engineers*, 94, 53-61. doi:<https://doi.org/10.1016/j.jtice.2017.07.035>
- Huang, W.-R., He, Z., Wang, J.-L., Liu, J.-W., & Yu, S.-H. (2019). Mass Production of Nanowire-Nylon Flexible Transparent Smart Windows for PM2.5 Capture. *iScience*, 12, 333-341. doi:<https://doi.org/10.1016/j.isci.2019.01.014>
- Jaworek, A., Marchewicz, A., Sobczyk, A. T., Krupa, A., & Czech, T. (2017). Two-stage electrostatic precipitator with co- and counter-flow particle prechargers. *Journal of Electrostatics*, 87, 180-194. doi:<https://doi.org/10.1016/j.elstat.2017.04.012>
- Jaworek, A., Marchewicz, A., Sobczyk, A. T., Krupa, A., & Czech, T. (2018). Two-stage electrostatic precipitators for the reduction of PM2.5 particle emission. *Progress in Energy and Combustion Science*, 67, 206-233. doi:<https://doi.org/10.1016/j.peccs.2018.03.003>
- Jianan, W., Xue, W., Tingyu, Z., & Yi, Z. (2018). Experimental study on the impact of electrostatic effect on the movement of charged particles. *Journal of Electrostatics*, 94, 14-20. doi:<https://doi.org/10.1016/j.elstat.2018.04.012>
- Kawamoto, H., & Hashime, S. (2018). Practical performance of an electrostatic cleaning system for removal of lunar dust from optical elements utilizing electrostatic traveling wave. *Journal of Electrostatics*, 94, 38-43. doi:<https://doi.org/10.1016/j.elstat.2018.05.004>
- Lai, Y., & Kontokosta, C. E. (2019). The impact of urban street tree species on air quality and respiratory illness: A spatial analysis of large-scale, high-resolution urban data. *Health & Place*, 56, 80-87. doi:<https://doi.org/10.1016/j.healthplace.2019.01.016>
- Lettieri, M., Colangiuli, D., Masieri, M., & Calia, A. (2019). Field performances of nanosized TiO2 coated limestone for a self-cleaning building surface in an urban environment. *Building and Environment*, 147, 506-516. doi:<https://doi.org/10.1016/j.buildenv.2018.10.037>
- Li, J., Wang, N., Wang, J., & Li, H. (2018). Spatiotemporal evolution of the remotely sensed global continental PM2.5 concentration from 2000-2014 based on Bayesian statistics. *Environmental Pollution*, 238, 471-481. doi:<https://doi.org/10.1016/j.envpol.2018.03.050>
- Liu, C., He, L., Pi, D., Zhao, J., Lin, L., He, P., . . . You, Y. (2019). LIDAR analyzing the transmission of PM2.5 in Shenzhen with LIDAR data and four-dimensional flux method. *Physics and Chemistry of the Earth, Parts A/B/C*. doi:<https://doi.org/10.1016/j.pce.2019.04.001>
- Liu, J., Li, W., & Wu, J. (2018). A framework for delineating the regional boundaries of PM2.5 pollution: A case study of China. *Environmental Pollution*, 235, 642-651. doi:<https://doi.org/10.1016/j.envpol.2017.12.064>
- Lu, S., Yang, X., Li, S., Chen, B., Jiang, Y., Wang, D., & Xu, L. (2018). Effects of plant leaf surface and different pollution levels on PM2.5 adsorption capacity. *Urban Forestry & Urban Greening*, 34, 64-70. doi:<https://doi.org/10.1016/j.ufug.2018.05.006>
- Ma, S., Zhang, M., Nie, J., Tan, J., Yang, B., & Song, S. (2019). Design of double-component metal-organic framework air filters with PM2.5 capture, gas adsorption and antibacterial capacities. *Carbohydrate Polymers*, 203, 415-422. doi:<https://doi.org/10.1016/j.carbpol.2018.09.039>
- Pisoni, E., Albrecht, D., Mara, T. A., Rosati, R., Tarantola, S., & Thunis, P. (2018). Application of uncertainty and sensitivity analysis to the air quality SHERPA modelling tool. *Atmospheric Environment*, 183, 84-93. doi:<https://doi.org/10.1016/j.atmosenv.2018.04.006>
- Ren, J., & Liu, J. (2019). Fine particulate matter control performance of a new kind of suspended fan filter unit for use in office buildings. *Building and Environment*, 149, 468-476. doi:<https://doi.org/10.1016/j.buildenv.2018.12.047>
- Soh, A., Dubey, S., Hedlund, K., & Kaushal, J. (2019). Field Testing of General Ventilation Devices and Systems for Particles Removal Efficiency and Pressure Drop. *Energy Procedia*, 158, 4465-4470. doi:<https://doi.org/10.1016/j.egypro.2019.01.767>
- Still, D. K., Bentson, S., Murray, N., Andres, J., Yue, Z., & MacCarty, N. A. (2018). Laboratory experiments regarding the use of filtration and retained heat to reduce particulate matter emissions from biomass cooking. *Energy for Sustainable Development*, 42, 129-135. doi:<https://doi.org/10.1016/j.esd.2017.09.011>
- Taylor, J., Shrubsole, C., Symonds, P., Mackenzie, I., & Davies, M. (2019). Application of an indoor air pollution metamodel to a spatially-distributed housing stock. *Science of The Total Environment*, 667, 390-399. doi:<https://doi.org/10.1016/j.scitotenv.2019.02.341>

- Tsang, C. H. A., Li, K., Zeng, Y., Zhao, W., Zhang, T., Zhan, Y., . . . Huang, H. (2019). Titanium oxide based photocatalytic materials development and their role of in the air pollutants degradation: Overview and forecast. *Environment International*, *125*, 200-228. doi:<https://doi.org/10.1016/j.envint.2019.01.015>
- Wang, J., Li, H., & Lu, H. (2018). Application of a novel early warning system based on fuzzy time series in urban air quality forecasting in China. *Applied Soft Computing*, *71*, 783-799. doi:<https://doi.org/10.1016/j.asoc.2018.07.030>
- Wang, F., Zhang, E., & Wang, J. (2017). A Study of Particle Deposition in Ventilation Ducts With Convex or Concave Wall Cavity. *Procedia Engineering*, *205*, 3285-3292. doi:<https://doi.org/10.1016/j.proeng.2017.10.336>
- Wongwatcharapaiboon, J. (2020). Review Article: Toward Future Particulate Matter Situations in Thailand from Supporting Policy, Network and Economy. *Future Cities and Environment*, *6*(1), 1. DOI: <http://doi.org/10.5334/fce.79>
- Xiong, W., Lin, Z., Zhang, W., Chen, T., & Zhao, C. (2018). Experimental and simulation studies on dust loading performance of a novel electrostatic precipitator with dielectric barrier electrodes. *Building and Environment*, *144*, 119-128. doi:<https://doi.org/10.1016/j.buildenv.2018.08.008>
- Xu, Y., Ho, H. C., Wong, M. S., Deng, C., Shi, Y., Chan, T.-C., & Knudby, A. (2018). Evaluation of machine learning techniques with multiple remote sensing datasets in estimating monthly concentrations of ground-level PM<sub>2.5</sub>. *Environmental Pollution*, *242*, 1417-1426. doi:<https://doi.org/10.1016/j.envpol.2018.08.029>
- Zhang, X., Ma, J., Li, A., Lv, W., Zhang, W., & Li, D. (2019). Ventilation for subway stations with adjustable platform doors created by train-induced unsteady airflow. *Building and Environment*, *152*, 87-104. doi:<https://doi.org/10.1016/j.buildenv.2019.02.001>
- Zhao, L., Jiang, L., Li, H., Hu, C., Sun, J., Li, L., . . . Zhou, C. (2018). Synthesis and characterization of silver-incorporated calcium phosphate antibacterial nanocomposites for mask filtration material. *Composites Part B: Engineering*, *153*, 387-392. doi:<https://doi.org/10.1016/j.compositesb.2018.09.004>

