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ชื่อโครงการ Investigation of Particulate Air Pollution of a University Classroom: Indoor-outdoor Relationships

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ภาควิชา Environmental Science

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คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

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ชื่อโครงการ การตรวจสอบมลพิษทางอากาศจากฝุ่นละอองขนาดเล็กในห้องเรียนมหาวิทยาลัย: ความสัมพันธ์ระหว่างสภาวะภายในและภายนอก

Investigation of Particulate Air Pollution of a University Classroom: Indoor-outdoor Relationships

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คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

SENIOR PROJECT

Project Title	**Investigation of Particulate Air Pollution of a University Classroom: Indoor-outdoor Relationships**
Student Name	Miss Pornwanat Ukritsiri Student ID 5933330823
Department	Environmental Science
Academic Year	2019

Faculty of Science, Chulalongkorn University

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อตรวจสอบมลพิษ $PM_{2.5}$ และพารามิเตอร์ทางกายภาพของอากาศในห้องเรียนมหาวิทยาลัย และหาความสัมพันธ์ระหว่างภายในและภายนอกห้องเรียนในช่วงที่มีวิกฤตมลภาวะทางอากาศ เราเลือกห้องเรียน 310 อาคารวิทยาศาสตร์ทั่วไป คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัยเป็นพื้นที่ศึกษา เราวัดความเข้มข้นของ $PM_{2.5}$, อุณหภูมิ, ความชื้นสัมพัทธ์, และความเร็วลมรายนาที ภายในและภายนอกห้องเรียน ในช่วงตอนบ่ายของเดือนมกราคม-กุมภาพันธ์ 2563 เราแบ่งข้อมูลออกเป็น 4 กลุ่ม ตามคาบเรียน (มี/ไม่มี) และระดับดัชนีคุณภาพอากาศ (ส่ง/ไม่ส่งผลกระทบต่อสุขภาพ) จากนั้นทำการวิเคราะห์เชิงสถิติ ซึ่งพบว่า ข้อมูลกลุ่มที่ 3 “ไม่มีคาบเรียนในวันที่ระดับดัชนีคุณภาพอากาศส่งผลกระทบต่อสุขภาพ” มีความเข้มข้นของ $PM_{2.5}$ เฉลี่ยรายนาทีสูงสุด ทั้งภายในและภายนอกห้องเรียน (44.40 ± 7.04 µg/m^3 และ 56.75 ± 6.57 µg/m^3 ตามลำดับ) ในขณะที่ข้อมูลกลุ่มที่ 1 “ไม่มีคาบเรียนในวันที่ระดับดัชนีคุณภาพอากาศไม่ส่งผลกระทบต่อสุขภาพ” มีความเข้มข้นของ $PM_{2.5}$ เฉลี่ยรายนาทีต่ำที่สุดในทั้งสองสภาวะเช่นกัน (14.78 ± 1.29 µg/m^3 และ 20.27 ± 4.19 µg/m^3 ตามลำดับ) นอกจากนี้ ความเข้มข้นของ $PM_{2.5}$ เฉลี่ยรายนาทีภายในห้องเรียนจะมีความสัมพันธ์เชิงเส้นตรงอย่างมีนัยสำคัญในระดับปานกลาง-สูงแบบมีทิศทางเดียวกันกับความเข้มข้นของ $PM_{2.5}$ เฉลี่ยรายนาทีภายนอกห้องเรียน แต่ว่าในระดับต่ำ-ปานกลางแบบไม่มีทิศทางที่แน่นอนกับระดับอุณหภูมิ, ความชื้นสัมพัทธ์, และความเร็วลม ($p < 0.05$) ซึ่งแนวโน้มในลักษณะนี้สามารถพบได้เมื่อทำการวิเคราะห์เชิงสถิติด้วยข้อมูลเฉลี่ยรายชั่วโมงเช่นกัน

คำสำคัญ: ความเข้มข้น $PM_{2.5}$, พารามิเตอร์ทางกายภาพของอากาศ, สภาวะภายในและภายนอก, สหสัมพันธ์, การถดถอยเชิงเส้นพหุคูณ

Project Title	**Investigation of Particulate Air Pollution of a University Classroom: Indoor-outdoor Relationships**
Student Name	**Miss Pornwanat Ukritsiri Student ID 5933330823**
Project Advisor	**Chidsanuphong Chart-asa, Ph.D.**
Department	**Environmental Science**
Academic Year	**2019**

Abstract

This study aimed to investigate $PM_{2.5}$ pollution and air physical parameters in the university classroom and to address the relationships between indoor and outdoor during a high-polluted period. We selected the classroom 310 of the General Science Building, Faculty of Science, Chulalongkorn University as a study area. We measured $PM_{2.5}$ concentration, temperature, relative humidity, and air velocity, at 1-minute intervals, inside and outside the classroom in the afternoon during January–February 2020. We divided the data into four groups by class activity (no class or having a class) and air quality index (healthy or unhealthy), and then performed statistical analysis. The results showed that the Group 3 "having a class on an unhealthy day" data had the highest 1-minute average $PM_{2.5}$ concentrations for both inside and outside the classroom (44.40 ± 7.04 μg/m^3 and 56.75 ± 6.57 μg/m^3 respectively), while the Group 1 "no class on a healthy day" data had the lowest 1-minute average concentrations for both environments as well (14.78 ± 1.29 μg/m^3 and 20.27 ± 4.19 μg/m^3 respectively). Moreover, $PM_{2.5}$ inside the class showed a statistically significant moderate-to-high correlation to $PM_{2.5}$ outside the classroom, with a positive direction, but statistically significant low-to-moderate correlations to temperature, relative humidity, and air velocity, with uncertain directions ($p < 0.05$). This pattern was also found when perform the statistical analysis with the 1-hour average data.

Keywords: $PM_{2.5}$ concentration, Air physical parameters, Indoor and outdoor, Correlations, Multiple linear regression

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CHAPTER I

INTRODUCTION

1.1 Background and significance

Thailand is a developing country where the transition from an agricultural-based economy to an industrial-based economy has been promoted over the past few decades. However, the transition processes lead to continuous urbanization and increasing emissions from vehicles, biomass burning, and industrial activities and thereby cause more and more serious air pollution problems. Several cities in Thailand were ranked as the most polluted regional cities in Southeast Asia based on annual average concentrations of $PM_{2.5}$ (IQAir AirVisual, 2018).

Particulate matter with a diameter less than 2.5 micrometers ($PM_{2.5}$) is an air pollution problem that should be given attention because it can affect people's work efficiency and health in the long term such as respiratory disease, lung cancer, cardiovascular disease and the increase in mortality has a significant relationship with $PM_{2.5}$ exposure. (Pope III & Dockery, 2006).

The classroom environment is very important because students have been spent most of their time in there. Most of the classrooms have poor ventilation systems that causes dusts to accumulate and remain inside. Highly concentrated $PM_{2.5}$ tends to be the main pollution (Chen & Zhao, 2011). When students exposed particulate pollution in the classroom for either short-term or long-term, it would be affected the learning efficiency and health of students such as cognitive impairment, asthma exacerbation, and so on. (Carrion-Matta et al., 2019). These issues should be realized and turned more attention to seriously determining measures or recommendations for reducing and preventing $PM_{2.5}$ concentrations in the classroom.

Previous study has determined the concentration of $PM_{2.5}$ in school classrooms and investigated the correlations to air physical conditions, especially for temperature and relative humidity, in order to examine the influences of the local environment on indoor air quality (IAQ) in the school classroom (Razali et al., 2015). However, it was conducted during the low-polluted period, which leaves the effects during the high-polluted period unaddressed. Even though several studies have reported the relationship between indoor and outdoor air quality during high-polluted periods, there are only few studies conducted in the university classroom environment. So, to expand the current knowledge, this study aims to investigate $PM_{2.5}$ pollution and air physical parameters in the university classroom during high-polluted periods and further address the relationships between indoor and outdoor.

1.2 Objectives

1. To measure the concentrations of $PM_{2.5}$ and air physical parameters (i.e., temperature, relative humidity, and air velocity) inside and outside the university classroom.

2. To investigate indoor-outdoor relationships of $PM_{2.5}$ concentrations and air physical parameters in the university classroom environment.

1.3 Expected outcomes

1. The findings and recommendations provided in this research could be useful for the university sections responsible for indoor air quality improvement.

2. This research could be a reference for people who are interested in studying indoor air pollution.

CHAPTER II

LITERATURE REVIEW

2.1 $PM_{2.5}$ and the trend of $PM_{2.5}$ concentration in the classroom

Particulate matter (PM) is defined as a mixture of solid and liquid particles commonly found in the atmosphere. It comes in a wide range of size up to 100 micrometers in diameter or more, which could be suspended in the air over a certain time period. Some particles are big enough to be seen with the naked eye, such as soot or smoke. Others are so small they can be inhaled and passed into the lower respiratory tract, causing health effects. The small particles are divided into 2 types: coarse dusts (PM_{10}) as particles with a diameter of 2.5–10 micrometers, and fine dusts ($PM_{2.5}$) as particles with a diameter less than 2.5 micrometers (United States Environmental Protection Agency [USEPA], 2018). The sources of fine dusts can be generally divided into two groups: natural sources and human activities. Natural sources include soil dust, flown from agricultural areas and soot from forest fires. Sources from human activities are fuel use transportation and traffic (automobile exhaust), industrial plants, power plants, demolition and construction of buildings, biomass burning and agriculture, etc. (Pollution Control Department [PCD], 2019). These sources emit particles in many sizes and shapes with different chemical compositions. The classroom environment is facing air pollution problems. This is caused by emissions from outdoor sources, human activities and ventilation system in the classroom causing dust accumulation in the classroom that affects the health of the students and teachers. (Deng et al., 2016).

The previous studies have reported the trends of $PM_{2.5}$ concentrations in the classroom as following:

Othman, Latif , & Matsumi (2019) measured 1-minute concentrations of $PM_{2.5}$ inside and outside the school classroom in Kuala Lumpur City Center, Malaysia. They found that the overall trends on the weekdays were similar for inside and outside the school classroom. $PM_{2.5}$ was rapidly increased when the students moved around and left the classroom for recess. The concentration was highest when the students got back from recess, and then suddenly decreased after teaching resumed. After that, $PM_{2.5}$ was gradually decreased until school time ended. $PM_{2.5}$ inside the school classroom was peaked at higher concentrations compared to the outside situation, suggesting the potential contribution of school activities to $PM_{2.5}$ pollution. On the weekends, inside and outside classroom $PM_{2.5}$ concentrations were much higher than those on the weekdays, probably due to close by tourist activities and heavy traffic.

Razali et al. (2015) also examined the trends of $PM_{2.5}$ concentrations inside and outside classrooms at 1-minute intervals, in Bandar Baru Bangi and Putrajaya, Malaysia. The results showed that $PM_{2.5}$ was at higher concentrations when students entered the classrooms and at the school day. During break time, $PM_{2.5}$ tends to be increased, probably due to the resuspension procession from the movements of students. However, $PM_{2.5}$ was stable during the class sessions.

2.2 Air Quality Standard for $PM_{2.5}$

Government entities and environmental-related organizations around the world have set their air quality standards for indoor and outdoor (ambient) $PM_{2.5}$. Typically, the indoor standards are based on average exposure concentrations over 1-hour, 8-hour, 24-hour, and 1-year, while the outdoor standards are based on only those over 24-hour, and 1-year. Different entities or organizations may set different acceptable limits for the average exposure concentrations to protect their public health and/or welfare. From table 2.1 and 2.2, the indoor standards tend to have higher average exposure concentrations compared to those in the outdoor standards over the same period. For example, the indoor standards from the United States Environmental

Protection Agency (USEPA) are 60 μg/m^3 and 15 μg/m^3 for 24-hour and 1-year average exposure concentrations respectively, while the indoor standards from the World Health Organization (WHO) are 25 μg/m^3 and 10 μg/m^3 for 24-hour and 1-year average exposure concentrations respectively. In Thailand, the outdoor standards from the National Environment Board are 25 μg/m^3 and 10 μg/m^3 for 24-hour and 1-year average exposure concentrations respectively.

Table 2.1 The standard value of the concentration of $PM_{2.5}$ indoor quality.

Country	Value	Organization	Reference
Canada	• 100 μg/m^3 as 1–h average • 40 μg/m^3 as 8–h average	Health Canada	Health Canada (1989)
Singapore	• 150 μg/m^3 as 8–h average	NEA	Institute of Environmental Epidemiology (1996)
US	• 60 μg/m^3 as 24–h average • 15 μg/m^3 as 1–y average	US EPA	International Society of Indoor Air Quality and Climate Change [ISIAQ] (2004)

Table 2.2 The standard value of the concentration of $PM_{2.5}$ outdoor quality.

Country	Value	Organization	Reference
Europe	• 25 µg/m³ as 24–h average • 10 µg/m³ as 1–y average	WHO	World Health Organization [WHO] (2013)
Singapore	• 37.5 µg/m³ as 24–h average • 12 µg/m³ as 1–y average	NEA	National Environment Agency [NEA] (2020)
Thailand	• 50 µg/m³ as 24–h average • 25 µg/m³ as 1–y average	National Environment Board	National Environmental Board [NEA] (2010)

2.3 Health effects of $PM_{2.5}$

$PM_{2.5}$ is a particular matter that small enough to pass through the lower respiratory tract and the alveoli causing in acute (hours, days) and chronic (months, years) health effects depending on the exposure period, particle composition and personal health. Particulates can cause many health effects such as respiratory system (cough, respiratory illnesses, and asthma), cardiovascular system (heart attack, irregular heartbeats), mortality from coronary artery disease and respiratory system and increased lung cancer. (Department of health & Department of Disease Control, 2015) and there are risk groups that are sensitive to $PM_{2.5}$ exposure, such as patients with lung disease or heart disease, the elderly and children. These groups are most at risk when exposed to $PM_{2.5}$ for example, exposure to PM affects lung development in children can cause decreased lung growth rate and deficits in lung function. (WHO, 2013). Research supports that $PM_{2.5}$ has health effects such as

Bai et al. (2020) studied real-time indoor and outdoor $PM_{2.5}$ monitoring for 1 year in northeast universities in China and questionnaires were used to assess the health impact of $PM_{2.5}$ pollution on students in the area by using the DALY model and the USEtox model. The results show that $PM_{2.5}$ concentrations were highest in the winter, 41.59 μg/m³ indoors and 105.85 μg/m³ outdoors. In summer, the lowest concentration was 11.15 μg/m³ and 18.71 μg/m³. There was a significant relationship between indoor and outdoor $PM_{2.5}$ concentrations. The contribution value of outdoor $PM_{2.5}$ to indoor air pollution was 11.22 μg/m³ and 14.28 μg/m³ respectively in autumn and winter and 7.30 μg/m³ and 3.61 μg/m³ respectively in spring and summer. The contribution rate of autumn and winter was 26.47% and 27.00% respectively. In spring and summer were 48.13% and 65.63% respectively. Among 145,200 students, in this area 109–134 prematurely died due to $PM_{2.5}$ pollution, 71–75 was caused by indoor $PM_{2.5}$ pollution. Indoor and outdoor $PM_{2.5}$ pollution resulted in 42 chronic bronchitis patients, 19 coronary heart disease, and 5 respiratory diseases. These findings make more awareness to finding effective solutions for controlling air pollution in buildings such as control at the source or installation of purification equipment.

2.4 Indoor air quality measurement

The Department of Health provides guidelines for assessment and measurement methods for indoor $PM_{2.5}$ as follows (Department of Health, 2016)

1. Number of sampling

- Low-rise buildings should be chosen random sampling 80 percent of the number of floors. For the selected floor, samples should be collected at least 1 point for each area separated by the air conditioning system and select the area with the highest density of building users or areas that have air quality complaints.

- The outside of the building should collect at least 2 samples at the entrance of the building or areas that contaminated and should collect measurements every day.

2. Location for sampling

The sampling location should be chosen to cover the actual use area with a height between 75-120 centimeters in the middle of the room or densely used building and near the breathing level of the building users. The sampling location should not interfere with the pathway with ventilation and at least 1 meter away from the source of pollution.

3. Equipment for measuring indoor air quality is divided into 2 types which are thermal comfort and indoor air pollution

- Thermal comfort consists of temperature that can be measured by using a thermometer or relative humidity sensors. There are 3 types of sensors including capacity humidity sensor, resistive humidity sensor, and thermal conductivity. Also, air movement is monitored by measuring the wind speed perform measurements with a rotor uniform or heating wire.

- Indoor air pollution composed of particles in the air. There are 2 methods for measuring particles: light scattering and weighing. Light scattering can continuously measure by shooting light through the air pulled into the machine and measure the distribution of light. Weighing is a direct measurement can collect samples through filter paper and weigh the particles that are stuck on the paper cage to weigh. There is also a measure of carbon dioxide, carbon monoxide, ozone gas, formaldehyde gas all volatile organic compounds, and total bacteria.

2.5 Related research

Research related to measuring the relationship of $PM_{2.5}$ concentration between indoor and outdoor such as

Deng et al. (2016) studied the relationship of the $PM_{2.5}$ concentration between indoor and outdoor. Seven samples were collected: basketball courts, hotels, shopping centers, research centers, commercial offices, apartments, and villas. To study indoor and outdoor relations of $PM_{2.5}$ concentration in the center of Beijing from February 2014 to March 2014 and assess the influence of ventilation systems on the ratio of indoor and outdoor $PM_{2.5}$ concentrations (I/O ratio). The study found that the average I/O ratio of all 7 locations is 0.36 when the outdoor $PM_{2.5}$ concentration is more than 150 µg/m³ and 1.1 when the outdoor $PM_{2.5}$ concentration is less than 100 µg/m³, which means that the increase of $PM_{2.5}$ concentration comes from the internals activities. The average I/O ratio is 0.69 for public buildings and 0.94 for residential houses, which means that the house has an increase in $PM_{2.5}$ concentration due to outdoor sources, while the public building has an air purification system and air system causing the outdoor particles to be eliminated.

Braniš, Řezáčová , & Domasová (2005) examined the concentration of PM_{10}, $PM_{2.5}$, and PM_1 by installing between 8 October to 11 November 2001 in Prague, the Czech Republic for 12 hours in the classroom using 3 Harvard impact testers. Dust concentration was analyzed by the gravimetric method. The data of particle concentrations are collected into four periods: Monday to Thursday (daytime working hours), Monday to Thursday (working nights), Friday to Sunday (daytime holidays) and Friday to Sunday (night periods). The average concentration of indoor PM_{10}, $PM_{2.5}$, and PM_1 for daytime working hours were 42.3, 21.9 and 13.7 µg/m³, nighttime working hours were 20.9, 19.1 and 15.2 µg/m³, day time holiday were 21.9, 18.1 and 11.4 µg/m³, and the night period were 24.5, 21.3, and 15.6 µg/m³. The average maximum is 12 hours, the median and the maximum concentration of PM_{10} during the daytime were 42.3, 43.0 and 76.2 µg/m³ respectively, with statistical significance ($r = 0.68$, $P < 0.0009$) between the number of students per hour and coarse particles inside the classroom, which mean that people are the source of coarse dust in the indoor of the daytime. The I/O ratio of PM_{10} was positively correlated ($r = 0.93$) indicating that indoor PM_{10} concentrations were sourced from classroom activities and all measured indoor particles are highly correlated with the outdoor PM_{10} and have a negative relationship with wind speed, which shows that the outdoor particles influence the indoor concentration.

Othman, Latif , & Matsumi (2019) examined air quality in the classroom. The objective is to measure the concentration of $PM_{2.5}$ and analyze the chemical composition of dust inside and outside the classroom in Kuala Lumpur. Examines between 19 September 2017 to 16 February 2018 for 8- and 24-hours during weekdays and weekends. $PM_{2.5}$ concentration was measured by using a light scattering sensors method. Ions and metal concentrations were analyzed using ion chromatography (IC). In this study, the average 24 hours of $PM_{2.5}$ inside and outside the classroom were 11.2 ± 0.45 µg/m³ and 11.4 ± 0.44 µg/m³ respectively. The average 8 hours of $PM_{2.5}$ were between 3.2 and 28 µg/m³ for indoors and 3.2 and 19 µg/m³ for outdoors. The highest concentration of ions for indoor dust was Ca^{2+}, while outdoor dust was SO_4^{2-} which means that indoor $PM_{2.5}$ concentrations are caused by internal activities and compositions of indoor and outdoor dust is caused by particles from industrial and traffic.

Razali et al. (2015) conducted research on indoor air quality (IAQ) by selecting 3 schools in the suburban, rural areas of Bandar Baru Bangi and Putrajaya to study the classroom environment or IAQ because it is important to the efficiency and learning of students and teachers by using weather conditions portable spectrometers, then measure the concentration of gaseous pollutants (CO, CO_2) and dust (PM_{10}, $PM_{2.5}$, and PM_1). According to the research, the overall average concentration is 31 µg/m³ (PM_{10}), 18 µg/m³ ($PM_{2.5}$), 16 µg/m³ (PM_1), 502 ppm (CO_2) and 0.3 ppm (CO), which is below the Malaysian Department of Safety and Health (DOSH) standard, the Singapore National Environmental Agency (NEA) and the Hong Kong IAQ Guidelines for Offices and Public Places. The concentration of air pollution and meteorological factors (temperature and relative humidity) are significantly related and the ratio of different indoor and outdoor air pollution may not necessarily be influenced by air pollution outside the classroom.

CHAPTER III

METHODOLOGY

3.1 Study area

In this study, we chose Chulalongkorn University as a study area. It is a university in the center of Bangkok surrounded by streets and high-rise buildings. Therefore, the main sources of $PM_{2.5}$ pollution appear to be from traffic, outdoor incineration of waste and combined with stagnant weather conditions that block the dispersion of pollution resulting in the accumulation of dust in the air (PCD, 2019). As a result, this area has high concentrations of $PM_{2.5}$ in certain periods (IQAir AirVisual, 2018). We selected the classroom 310 of the General Science Building, Faculty of Science, Chulalongkorn University. It is a small classroom located on the 3rd floor. It has an approximate volume of about 217 m^3 and natural ventilation, which the measurements of $PM_{2.5}$ concentrations and air physical parameters can be covered by a limited number of detectors.

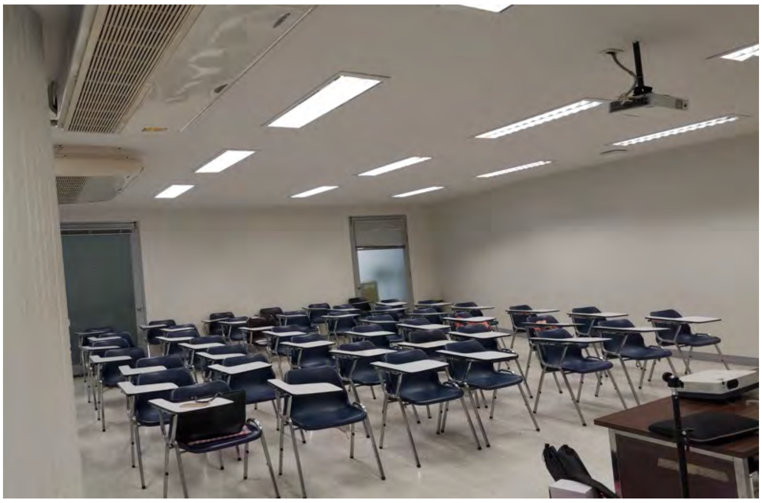
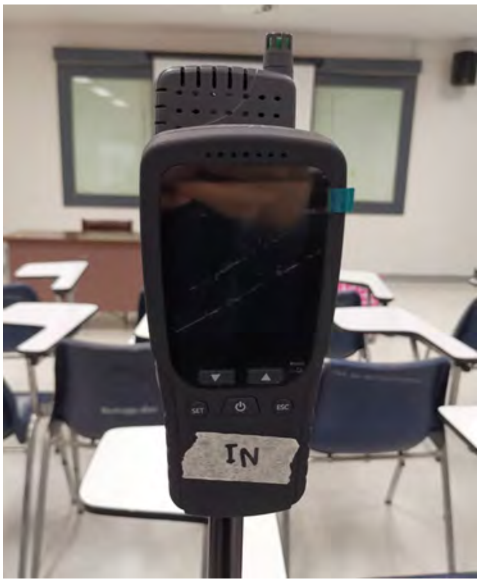


Figure 3.1 The classroom 310 of the General Science Building, Faculty of Science, Chulalongkorn University

3.2 $PM_{2.5}$ measurement

We measured $PM_{2.5}$ concentrations at 1-minute intervals inside and outside the classroom by using two light-scattering $PM_{2.5}$ sensor detectors (the Air Quality detector Model DM106A) between January to February 2020, every afternoon (1:00-3:00 P.M.) on Monday (no class), Wednesday (a class of about 28 average occupants), and Thursday (a class of about 33 average occupants). Then, the 1-minute measured data were averaged over one hour to obtain the 1-hour dataset for further analysis. For the measurements within the classroom, we installed one detector at the center of the classroom, at 1-1.3 meters above the ground (as normal heights for the students' breathing zone) (Braniš, Řezáčová , & Domasová, 2005). For the measurements outside the classroom, we installed another detector near the entrance of the classroom at the same height as the measurement in the classroom.



Detection specifications:

$PM_{2.5}$ range: 0–999 μg/m^3

$PM_{2.5}$ sampling time: 3 seconds

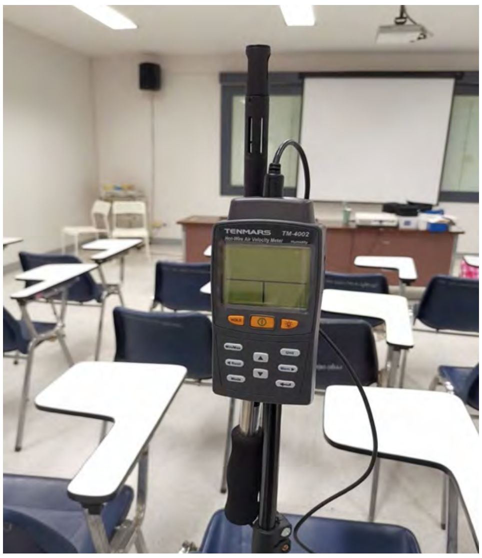
Temperature range: -20°C–70°C

Relative humidity range: 20%–90%

Figure 3.2 The Air Quality Detector Model DM106A for the measurements of $PM_{2.5}$, temperature, and relative humidity inside and outside the classroom

3.3 Air physical parameters measurement

We measured air physical parameters at 1-minute intervals by using the Air Quality detector Model DM106A (for temperature and humidity inside and outside the classroom), the Tenmars Model TM-4001 (for air velocity inside the classroom), and the Digital Anemometer model AM-4836C (for air velocity outside the classroom). The measurement settings were the same as those for the $PM_{2.5}$ measurement. The 1-minute measured data were also averaged over one hour to obtain the 1-hour datasets for further analysis.



Detection specifications:
Air velocity range: 0.01-40 m/s
(inside the classroom)

Figure 3.3 The Tenmars Model TM-4001 for the measurements of air velocity inside the classroom

Detection specifications:
Air velocity range: 0.4-45.0 m/s
(outside the classroom)

Figure 3.4 The Digital Anemometer Model AM-4836C for the measurements of air velocity outside the classroom

3.4 Data analysis

We used the IBM Statistical Package for the Social Sciences (SPSS) (version 22.0) and Microsoft Excel (version 16.32) as the main tools for data analysis. Also, the descriptive statistic was used to determine characteristics of $PM_{2.5}$ and air physical parameters. The Pearson's correlation coefficients were evaluated to determine the relationships among $PM_{2.5}$ and air physical parameters inside and outside the classroom. Moreover, the multiple linear regression analyses were further performed to examine the influences of the $PM_{2.5}$ and air physical parameters outside classroom (the independent variables) on the $PM_{2.5}$ inside classroom (the dependent variable).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Characteristics of $PM_{2.5}$ and air physical parameters inside and outside the classroom

Table 4.1 and table 4.2 shows the summary statistics of $PM_{2.5}$ concentrations and air physical parameters (i.e., temperature, relative humidity, and air velocity) inside and outside the classroom at 1-minute and 1-hour intervals. The datasets were divided into four groups corresponding to class activity (no class or having a class) and air quality index (AQI) (healthy or unhealthy): Group 1 for “no class on a healthy day”, Group 2 for “having a class on a healthy day“, Group 3 for “no class on an unhealthy day”, and Group 4 for “having a class on an unhealthy day”. It should be noted that the healthy day refers to the day with AQI less than or equal to 100 or 24-hour $PM_{2.5}$ less than or equal to 50 $\mu g/m^3$, and the unhealthy day refers to the days with AQI greater than 100 or 24-hour $PM_{2.5}$ greater than 50 $\mu g/m^3$ (PCD, 2018). This study used the AQI data based on the ambient air quality from the closet PCD’s monitoring station (50t, Rama IV Road., Pathum Wan, Bangkok) (PCD, 2020).

Table 4.1 Summary statistics of $PM_{2.5}$ concentrations and air physical parameters (i.e., temperature, relative humidity, and air velocity) inside the classroom at 1-minute and 1-hour intervals

Group	Statistics	Indoor air							
		Minutes				Hours			
		$PM_{2.5}$ (μg/m^3)	T (°C)	RH (%)	Air (m/s)	$PM_{2.5}$ (μg/m^3)	T (°C)	RH (%)	Air (m/s)
1: No class on a healthy day	Min	12	21.1	53	0	14.4	23.8	55.5	0.02
	Max	19	24.9	67	0.27	15.17	24.5	58	0.03
	Avg	14.78	24.2	56.8	0.02	14.78	24.2	56.8	0.02
	SD	1.29	0.67	2.66	0.05	0.54	0.46	1.81	0.01
2: Having a class on a healthy day	Min	5	18.8	46	0	6.2	23.4	49.1	0
	Max	47	25.4	78	0.23	41.87	24.8	56.6	0.04
	Avg	27.21	24.3	53	0.01	27.21	24.3	53	0.01
	SD	10.88	0.8	4.53	0.03	11.16	0.42	2.58	0.01
3: No class on an unhealthy day	Min	31	19.4	47	0	34.62	23.1	50.1	0.01
	Max	60	24.8	70	0.22	54.73	24.5	61.6	0.02
	Avg	44.4	23.9	56	0.01	44.4	23.9	56	0.01
	SD	7.04	0.76	4.47	0.03	7.39	0.51	4.51	0
4: Having a class on an unhealthy day	Min	24	21.8	46	0	31.43	24.2	47.9	0
	Max	53	25.1	65	0.27	44.7	24.7	54.6	0.01
	Avg	38.5	24.3	50.8	0.01	38.5	24.3	50.8	0.01
	SD	6.35	0.66	4.3	0.03	6.65	0.27	3.15	0.01

From table 4.1, the highest average concentration of $PM_{2.5}$ at 1-minute intervals is Group 3 for “no class on an unhealthy day” followed by Group 4 for “having a class on an unhealthy day” and then Group 2 for “having a class on a healthy day”, which are 44.40 ± 7.04 μg/m^3, 38.50 ± 6.35 μg/m^3 and 27.21 ± 10.88 μg/m^3 respectively. The highest average temperature is Group 4 for “having a class on an unhealthy day” followed by Group 2 for “having a class on a healthy day” and then Group 1 for “no class on a healthy day”, which are 24.3 ℃, 24.3 ℃ and 24.2 ℃ respectively. The highest average relative humidity is Group 1 for “no class on a healthy day” followed by Group 3 for “no class on an unhealthy day” and then Group 2 for “having a class on a healthy day”, which are 56.8 %, 56 % and 53 % respectively. The highest average air velocity is Group 1 for “no class on a healthy day” followed by Group 2 for “having a class on a healthy day” and then Group 3 for “no class on an unhealthy day”, which are 0.02 m/s, 0.01 m/s and 0.01 m/s respectively.

From table 4.1, the highest average concentration of $PM_{2.5}$ at 1-hour intervals is Group 3 for “no class on an unhealthy day” followed by Group 4 for “having a class on an unhealthy day” and then Group 2 for “having a class on a healthy day”, which are 44.40 ± 7.39 μg/m^3, 38.50 ± 6.65 μg/m^3 and 27.21 ± 11.16 μg/m^3 respectively. The average of temperature, relative humidity and air velocity as well as the 1-minute intervals.

Table 4.2 Summary statistics of $PM_{2.5}$ concentrations and air physical parameters (i.e., temperature, relative humidity, and air velocity) outside the classroom at 1-minute and 1-hour intervals

Group	Statistics	Outdoor air							
		Minutes				Hours			
		$PM_{2.5}$ (μg/m^3)	T (°C)	RH (%)	Air (m/s)	$PM_{2.5}$ (μg/m^3)	T (°C)	RH (%)	Air (m/s)
1: No class on a healthy day	Min	12	27.1	49	0	18.15	29.1	53	0.24
	Max	27	31.3	65	2	22.38	29.6	57.3	0.9
	Avg	20.26	29.3	55.1	0.56	20.26	29.3	55.1	0.57
	SD	4.19	0.88	4.4	0.61	2.99	0.4	3.06	0.46
2: Having a class on a healthy day	Min	6	23.9	46	0	8.12	26.3	48.3	0.11
	Max	72	28.8	71	2.3	62.25	27.5	66.8	0.85
	Avg	35.77	26.9	59.8	0.47	35.77	26.9	59.8	0.47
	SD	15.18	0.78	6.11	0.54	15.36	0.33	6.11	0.21
3: No class on an unhealthy day	Min	43	24.1	28	0	47.68	27.1	35.4	0.31
	Max	69	30.6	71	1.9	63.82	29.2	61.1	0.48
	Avg	56.75	28.4	47.9	0.4	56.75	28.4	47.9	0.4
	SD	6.57	1.03	9.83	0.5	6.84	0.8	10.5	0.06
4: Having a class on an unhealthy day	Min	39	25.1	32	0	47.35	27	37.9	0.43
	Max	65	30	69	2.1	55.93	28.4	65.5	0.69
	Avg	50.94	27.7	48.6	0.53	50.94	27.7	48.6	0.53
	SD	5.05	0.86	10.6	0.52	3.93	0.58	11.9	0.11

From table 4.2, the highest average concentration of $PM_{2.5}$ at 1-minute intervals is Group 3 for “no class on an unhealthy day” followed by Group 4 for “ having a class on an unhealthy day” and then Group 2 for “ having a class on a healthy day”, which are 56.75 ± 6.57 µg/m^3, 50.94 ± 5.05 µg/m^3 and 35.77 ± 15.18 µg/m^3 respectively. The highest average temperature is Group 1 for “no class on a healthy day” followed by Group 3 for “no class on an unhealthy day” and then Group 4 for “having a class on an unhealthy day”, which are 29.3 ℃, 28.4 ℃ and 27.7 ℃ respectively. The highest average relative humidity is Group 2 for “having a class on a healthy day” followed by Group 1 for “no class on a healthy day” and then Group 4 for “having a class on an unhealthy day”, which are 59.8 %, 55.1 % and 48.6 % respectively. The highest average air velocity is Group 1 for “no class on a healthy day” followed by Group 4 for “having a class on an unhealthy day” and then Group 2 for “having a class on a healthy day”, which are 0.56 m/s, 0.53 m/s and 0.47 m/s respectively.

From table 4.2 at 1-hour intervals, the highest average concentration of $PM_{2.5}$ is Group 3 for “no class on an unhealthy day” followed by Group 4 for “ having a class on an unhealthy day” and then Group 2 for “ having a class on a healthy day”, which are 56.75 ± 6.84 µg/m^3, 50.94 ± 3.93 µg/m^3 and 35.77 ± 15.36 µg/m^3 respectively. The average of temperature, relative humidity and air velocity as well as the 1-minute intervals.

A comparison with Othman, Latif , & Matsumi (2019) shows that the indoor average concentrations of $PM_{2.5}$ recorded in this study were much higher compared with results from another study, which has the average 8 hours of $PM_{2.5}$ were between 3.2 and 28 µg/m^3 for indoors and 3.2 and 19 µg/m^3 for outdoors.

4.2 Predict the trend of $PM_{2.5}$ concentration inside the classroom.

The analysis of the relationship between $PM_{2.5}$ and air physical parameters outside the classroom on the $PM_{2.5}$ inside the classroom using Pearson's correlation coefficients analysis. The overall relationships between the indoor and outdoor variables were significant at $p < 0.01$ and $p < 0.05$.

Table 4.3 Pearson's correlation coefficients analysis of Group 1 for "no class on a healthy day" at 1-minute intervals

	$PM_{2.5}$_in	$PM_{2.5}$_out	T_out	RH_out	Air_out
$PM_{2.5}$_in	1				
$PM_{2.5}$_out	-0.040	1			
T_out	-0.052	0.425**	1		
RH_out	-0.040	-0.844**	-0.769**	1	
Air_out	0.200*	-0.197*	-0.508**	0.348**	1

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

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

From table 4.3, it was found that $PM_{2.5}$ inside the classroom has a weak positive relationship with outside air velocity (r = 0.200, sig. = 0.028) but $PM_{2.5}$ inside the classroom has no relationship with $PM_{2.5}$ outside the classroom.

Table 4.4 Pearson's correlation coefficients analysis of Group 2 for "no class on a healthy day" at 1-minute intervals

	$PM_{2.5}$_in	$PM_{2.5}$_out	T_out	RH_out	Air_out
$PM_{2.5}$_in	1				
$PM_{2.5}$_out	0.934**	1			
T_out	0.107**	0.156**	1		
RH_out	-0.639**	-0.727**	-0.384**	1	
Air_out	-0.222**	-0.230**	-0.406**	0.320**	1

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

From table 4.4, it was found that $PM_{2.5}$ inside the classroom has a high positive relationship with $PM_{2.5}$ outside the classroom (r = 0.934, sig. = 0.000).

Table 4.5 Pearson's correlation coefficients analysis of Group 3 for "no class on a healthy day" at 1-minute intervals

	$PM_{2.5}$_in	$PM_{2.5}$_out	T_out	RH_out	Air_out
$PM_{2.5}$_in	1				
$PM_{2.5}$_out	0.678**	1			
T_out	-0.541**	-0.094	1		
RH_out	0.480**	-0.197**	-0.759**	1	
Air_out	0.071	0.172**	-0.285**	-0.003	1

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

From table 4.5, it was found that $PM_{2.5}$ inside the classroom has a moderate positive relationship with $PM_{2.5}$ outside the classroom (r = 0.678, sig. = 0.000).

Table 4.6 Pearson's correlation coefficients analysis of Group 4 for “no class on a healthy day” at 1-minute intervals

	$PM_{2.5}$_in	$PM_{2.5}$_out	T_out	RH_out	Air_out
$PM_{2.5}$_in	1				
$PM_{2.5}$_out	0.675^{**}	1			
T_out	0.101	0.006	1		
RH_out	0.392^{**}	0.493^{**}	-0.383^{**}	1	
Air_out	0.052	0.173^{**}	-0.244^{**}	-0.079	1

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

From table 4.6, it was found that $PM_{2.5}$ inside the classroom has a moderate positive relationship with $PM_{2.5}$ outside the classroom (r = 0.675, sig. = 0.000).

Table 4.7 Pearson's correlation coefficients analysis of Group 2 for “no class on a healthy day” at 1-hour intervals

	$PM_{2.5}$_in	$PM_{2.5}$_out	T_out	RH_out	Air_out
$PM_{2.5}$_in	1				
$PM_{2.5}$_out	0.968^{**}	1			
T_out	0.327	0.468	1		
RH_out	-0.685^{**}	-0.779^{**}	-0.500	1	
Air_out	-0.578^{*}	-0.662^{*}	-0.216	0.735^{**}	1

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

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

From table 4.7, it was found that $PM_{2.5}$ inside the classroom has a high positive relationship with $PM_{2.5}$ outside the classroom (r = 0.968, sig. = 0.000).

The influences of the $PM_{2.5}$ and air physical parameters outside classroom on the $PM_{2.5}$ inside classroom were investigated through the stepwise multiple linear regression. The dependent and independent variables were given as following: the $PM_{2.5}$ inside classroom (Y), the $PM_{2.5}$ outside classroom (X_1), the temperature outside classroom (X_2), the relative humidity outside classroom (X_3), and the air velocity outside classroom (X_4).

Table 4.8 Regression analysis of Group 1 for "no class on a healthy day" at 1-minute intervals

Variables	B	SE	t	Sig.	VIF
constant	14.544	0.158	91.854	0	
Air_out	0.42	0.189	2.218	0.028	1

r= 0.200, AdjustR^2= 0.032, R^2= 0.04, SEE= 1.27

From Table 4.8, the analysis results show that the variables that can predict the trend of $PM_{2.5}$ concentration in the classroom were air (X_4), which can explain the variation of variables by 3.2 percent (adjusted R^2 = 0.032). It can be written as the equation to predict the trend of concentration of $PM_{2.5}$ inside the classroom as follows: $Y = 14.544 + 0.42 (X_4)$.

Air velocity (X_4) had a positive statistically significant with the concentration of $PM_{2.5}$ in the classroom at the level of 0.01 with a coefficient equal to 0.420, which means that the air was a factor determining the concentration trend of $PM_{2.5}$ in the classroom. There were 3 variables not related to $PM_{2.5}$ concentration in the classroom: $PM_{2.5}$ concentration outside the classroom (X_1), temperature (X_2), and humidity (X_3) was not the factors that determined the concentration trend of $PM_{2.5}$ in the classroom.

Table 4.9 Regression analysis of Group 2 for "having a class on a healthy day" at 1-minute intervals

Variables	B	SE	t	Sig.	VIF
constant	-7.307	2.331	-3.135	0.002	
$PM_{2.5}$_out	0.713	0.013	54.033	0	2.121
RH_out	0.15	0.033	4.591	0	2.121

r= 0.936, AdjustR^2= 0.875, R^2= 0.876, SEE= 3.84

From Table 4.9 the analysis results show that the variables could predict the trend of $PM_{2.5}$ concentration in the classroom were $PM_{2.5}$ concentration outside the classroom (X_1) and relative humidity (X_3), which can explain the variation of variables by 87.5 percent (adjusted R^2 = 0.875). It can be written as an equation to predict the trend of $PM_{2.5}$ concentration in the classroom as follows: $Y = -7.307 + 0.713 (X_1) +0.150 (X_3)$

The concentration of $PM_{2.5}$ outside the classroom (X_1) and the humidity (X_3) had a positive statistically significant with the concentration of $PM_{2.5}$ in the classroom at the level of 0.01 with the coefficients of 0.713 and 0.150 respectively, which means that the concentration of $PM_{2.5}$ outside the classroom (X_1) and the humidity (X_3) was the factors that determine the trend of $PM_{2.5}$ concentration in the classroom. There were 2 variables not related to $PM_{2.5}$ concentration in the classroom: temperature (X_2) and air velocity (X_4). It was not the factor that determines the trend of $PM_{2.5}$ concentration in the classroom.

Table 4.10 Regression analysis of Group 3 for "no class on an unhealthy day" at 1-minute intervals

Variables	B	SE	t	Sig.	VIF
constant	-26.759	1.562	-17.129	0	
$PM_{2.5}$_out	0.873	0.022	39.076	0	1.073
RH_out	0.459	0.015	31.158	0	1.042
Air_out	-0.929	0.286	-3.25	0.001	1.031

r= 0.925, AdjustR^2= 0.854, R^2= 0.855, SEE= 2.68

From Table 4.10 the results show that the variables could predict the trend of $PM_{2.5}$ concentration in the classroom were $PM_{2.5}$ concentration outside the classroom (X_1), relative humidity (X_3) and air velocity (X_4), which can explain the variation of variables by 85.4 percent (adjusted R^2 = 0.854). It can be written as an equation to predict the trend of $PM_{2.5}$ concentration in the classroom as follows: Y = -26.759 + 0.873 (X_1) +0.459 (X_3) -0.929 (X_4)

The concentration of $PM_{2.5}$ outside the classroom (X_1), relative humidity (X_3) and air velocity (X_4) had a positive statistically significant with the concentration of $PM_{2.5}$ in the classroom at the level of 0.01 with the coefficient of 0.873, 0.459, and 0.929, which means the concentration of $PM_{2.5}$ outside the classroom (X_1) relative humidity (X_3) and air velocity (X_4) are the factors that determine the trend of $PM_{2.5}$ concentration in the classroom. There was 1 variable not correlated $PM_{2.5}$ concentration in the classroom: temperature (X_2) was not the factor that determines the trend of $PM_{2.5}$ concentration in the classroom.

Table 4.11 Regression analysis of Group 4 for "having a class on an unhealthy day" at 1-minute intervals

Variables	B	SE	t	Sig.	VIF
constant	-36.676	11.022	-3.328	0.001	
$PM_{2.5}$_out	0.749	0.07	10.73	0	1.403
T_out	1.169	0.386	3.028	0.003	1.245
RH_out	0.096	0.036	2.645	0.009	1.644

r= 0.694, AdjustR^2= 0.474, R^2= 0.481, SEE= 4.61

From Table 4.11 the analysis results show that the variables could predict the trend of $PM_{2.5}$ concentration in the classroom were $PM_{2.5}$ concentration outside the classroom (X_1), temperature (X_2) and relative humidity (X_3), which can explain the variation of variables by 47.4 percent (adjusted R^2 = 0.474). It can be written as an equation to predict $PM_{2.5}$ concentration in the classroom as follows: $Y = -36.676 + 0.749 (X_1) +1.169 (X_2) +0.096 (X_3)$

The concentration of $PM_{2.5}$ outside the classroom (X_1), temperature (X_2), and relative humidity (X_3) had a positive statistically significant with the concentration of $PM_{2.5}$ in the classroom at the level of 0.01 with the coefficient of 0.749, 1.169, and 0.096, which means the concentration of $PM_{2.5}$ outside the classroom (X_1), temperature (X_2), and relative humidity (X_3) are the factors to determine the trend of $PM_{2.5}$ concentration in the classroom. There was 1 variable not related to $PM_{2.5}$ concentration in the classroom: air velocity (X_4) was not the factor that determines the trend of $PM_{2.5}$ concentration in the classroom.

Table 4.12 Regression analysis of Group 2 for “having a class on a healthy day” at 1-hour intervals

Variables	B	SE	t	Sig.	VIF
constant	143.736	62.671	2.293	0.045	
$PM_{2.5}$_out	0.755	0.052	14.548	0	1.238
T_out	-5.328	2.356	-2.262	0.047	1.238

r= 0.979 AdjustR^2= 0.951 R^2= 0.959 SEE= 2.48

From Table 4.12, the results show that the variables could predict the trend of $PM_{2.5}$ concentration in the classroom were $PM_{2.5}$ concentration outside the classroom (X_1) and temperature (X_2), which can explain the variation of variables by 95.9 percent (adjusted R^2 = 0.959). It can be written as an equation to predict the trend of $PM_{2.5}$ concentration in the classroom as follows: $Y = 143.736 + 0.755 (X_1) -5.328 (X_2)$

The concentration of $PM_{2.5}$ outside the classroom (X_1) and the temperature (X_2) had a positive statistically significant with the concentration of $PM_{2.5}$ in the classroom at the level of 0.01 with the coefficients of 0.755 and 5.328 respectively which means the concentration of $PM_{2.5}$ outside the classroom and temperature were the factors that determine the trend of $PM_{2.5}$ concentration in the classroom. There were 2 variables not related to $PM_{2.5}$ concentration in the classroom: relative humidity (X_3) and air velocity (X_4) were not the factors that determine the trend of $PM_{2.5}$ concentration in the classroom.

From the analysis using Pearson's correlation coefficients and stepwise multiple linear regression, the concentration of $PM_{2.5}$ outside the classroom is the most influence on the concentration of $PM_{2.5}$ in the classroom except Group 1 for "no class on a healthy day" at 1-minute intervals due to there was no air pollution crisis (lowest concentration) and don't have class, the door was opened and closed rarely. However, the data collected is only 1 day if more data is collected, there may be different trends in relationships. The concentration of $PM_{2.5}$ outside the classroom does not influence $PM_{2.5}$ concentration in the classroom. For 1-hour intervals of Groups 1 for "no class on a healthy day", Group 3 for "no class on an unhealthy day" and Group 4 for "having a class on an unhealthy day" were unable to analyze regression due to the small amount of dataset and data was not statistically significant.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study, there are 3 types of statistical analysis, which are descriptive statistic, the Pearson's correlation coefficients, and multiple linear regression analyses to describe the characteristics and the relationship between $PM_{2.5}$ and air physical parameters inside and outside the classroom.

Characteristics of $PM_{2.5}$ and air physical parameters. There are different trends of measurement data inside and outside the classroom during class activity (no class or having a class) and AQI (healthy or unhealthy), which reflects the differentiation issues of relationships between inside and outside the classroom such as inside the classroom, Group 3 for "no class on an unhealthy day" at 1-minute intervals recorded the highest average concentration of $PM_{2.5}$, which is 44.40 ± 7.04 $\mu g/m^3$. While Group 1 for "no class on a healthy day" at 1-minute intervals recorded the lowest average concentration of $PM_{2.5}$, which is 14.78 ± 1.29 $\mu g/m^3$.

The analysis of the relationship between $PM_{2.5}$ and air physical parameters outside the classroom on the $PM_{2.5}$ inside the classroom using Pearson's correlation coefficients analysis. It was found that $PM_{2.5}$ inside the classroom has a moderate to high relationship with $PM_{2.5}$ outside the classroom except Group 1 for "no class on a healthy day". The influences of the $PM_{2.5}$ and air physical parameters outside classroom on the $PM_{2.5}$ inside classroom were investigated through the stepwise multiple linear regression. It was found that the concentration of $PM_{2.5}$ outside the classroom is the most influence on the concentration of $PM_{2.5}$ in the classroom but the second most influence is the relative humidity.

The results of this study can be used as a supplementary document to find ways to prevent dust in the classroom to a low level that does not affect learning and the health of students and teachers in the classroom during the high-pollution period such as attaching dust filters in the air conditioner, wearing a hygienic mask and the installation of air filters.

5.2 Recommendations

The datasets were divided into four groups corresponding to class activity (no class or have class) and air quality index (AQI) (healthy or unhealthy days): Group 1 for “no class on a healthy day”, Group 2 for “having a class on a healthy day“, Group 3 for “no class on an unhealthy day”, and Group 4 for “having a class on an unhealthy day” and analyzed at 1-minute and 1-hour intervals. The data collected is insufficient for the analysis of Pearson’s correlation coefficients and stepwise multiple linear regression no class days and at 1-hour intervals. Therefore, the sampling period should be extended resulting in sufficient for investigating relationships of $PM_{2.5}$ concentrations and air physical parameters in the university classroom environment.

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