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ชื่อโครงการ	Comparison of $PM_{2.5}$ concentrations in an indoor fitness center and an outdoor gym within Chulalongkorn University
ชื่อนิสิต	Mister Sorakit Boonwirut
ภาควิชา	Environmental Science
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คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

SENIOR PROJECT

Project Title **Comparison of $PM_{2.5}$ concentrations in an indoor fitness center and an outdoor gym within Chulalongkorn University**

Student Name Mister Sorakit Boonwirut Student ID 583 33497 23

Department Environmental Science

Academic Year 2018

Faculty of Science, Chulalongkorn University

Comparison of $PM_{2.5}$ concentrations in an indoor fitness center and an outdoor gym within Chulalongkorn University

การเปรียบเทียบปริมาณฝุ่นละออง $PM_{2.5}$ ในอากาศของศูนย์ออกกำลังกายในร่มและโรงยิมกลางแจ้ง ภายในจุฬาลงกรณ์มหาวิทยาลัย

Sorakit Boonwirut

A Senior Project Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science Program in Environmental Science Faculty of Science, Chulalongkorn University, Academic Year 2018

Project Title	Comparison of $PM_{2.5}$ concentrations in an indoor fitness center and an outdoor gym within Chulalongkorn University
Student Name	Mister Sorakit Boonwirut Student ID 583 33497 23
Project Advisor	Chidsanuphong Chart-asa, Ph.D.
Project Co-advisor	Assistant Professor Pasicha Chaikaew, Ph.D.
Department	Environmental Science
Academic Year	2018

Accepted by the Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfilment of the Requirements for the Bachelor's Degree

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หัวข้อ	การเปรียบเทียบปริมาณฝุ่นละออง $PM_{2.5}$ ในอากาศของศูนย์ออกกำลังกายในร่มและโรงยิมกลางแจ้งภายในจุฬาลงกรณ์มหาวิทยาลัย
โดย	นายสรกฤษณ์ บุญวิรัตน์ รหัสประจำตัวนิสิต 583 33497 23
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ภาควิชา	วิทยาศาสตร์สิ่งแวดล้อม
ปีการศึกษา	2561

บทคัดย่อ

การออกกำลังกายสามารถแบ่งตามสภาพแวดล้อมได้ 2 ประเภท ได้แก่ สภาพแวดล้อมภายในอาคารและสภาพแวดล้อมภายนอกอาคาร การพิจารณาเลือกใช้สถานออกกำลังกายที่มีสภาพแวดล้อมต่างกันในแต่ละช่วงเวลาจึงมีความสำคัญ โครงงานวิจัยนี้มีวัตถุประสงค์เพื่อ 1.ตรวจหาค่าความเข้มข้นของปริมาณฝุ่นละออง $PM_{2.5}$ ในอากาศของศูนย์ออกกำลังกายในร่มและโรงยิมกลางแจ้งภายในจุฬาลงกรณ์มหาวิทยาลัย 2.หาความสัมพันธ์ระหว่าง $PM_{2.5}$, อุณหภูมิและความชื้นสัมพัทธ์ 3.เปรียบเทียบปริมาณความเข้มข้นของ $PM_{2.5}$ ระหว่างศูนย์ออกกำลังกายในร่มและโรงยิมกลางแจ้งในช่วงเวลาที่แตกต่างกัน วิธีการตรวจวัดคุณภาพอากาศจะดำเนินการโดยอุปกรณ์วัดคุณภาพอากาศยี่ห้อ Bosean Electronic รุ่น LY062701 จากนั้นทำการเก็บข้อมูลในศูนย์ออกกำลังกายในร่มและโรงยิม กลางแจ้งในวันและเวลาเดียวกัน โดยเริ่มตั้งแต่วันที่ 1 เมษายนถึงวันที่ 26 เมษายน พ.ศ.2562 เป็นเวลาทั้งสิ้น 12 วัน โดยในแต่ละวันจะเก็บทั้งหมด 3 ช่วงเวลา คือ 8.00 น. – 9.00 น., 13.00 น. – 14.00 น. และ 17.00 น. – 18.00 น. จากนั้นนำข้อมูลที่รวบรวมได้มาวิเคราะห์ด้วยสถิติเชิงพรรณนา, สัมประสิทธิ์สหสัมพันธ์แบบเพียร์สันและวิเคราะห์ความแปรปรวนแบบสองทาง จากการศึกษาพบว่าค่าของ $PM_{2.5}$ ในอากาศบริเวณศูนย์ออกกำลังกายในร่มและโรงยิมกลางแจ้งมีความสัมพันธ์กันอย่างมีนัยสำคัญ (p-value < 0.01) เนื่องจากเกิดการแทรกซึมจากภายนอก (Infiltration) และยังพบว่าสภาพแวดล้อมภายในอาคารและภายนอกอาคารมีผลต่อปริมาณความเข้มข้นของ $PM_{2.5}$ อย่างมีนัยสำคัญ (p-value < 0.05) โดยภายนอกอาคารมีปริมาณ $PM_{2.5}$ มากกว่าภายในอาคาร ดังนั้นจึงควรเข้าใช้บริการสถานออกกำลังกายภายในอาคารหากพิจารณาในเรื่องการรับสัมผัสฝุ่นละออง $PM_{2.5}$

คำสำคัญ : ฝุ่นละออง $PM_{2.5}$, สถานออกกำลังกาย, สภาพแวดล้อมภายในอาคาร, สภาพแวดล้อมภายนอกอาคาร

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Abstract

Exercise environments can be classified into 2 main types of indoor setting, and outdoor setting. The two settings then become a factor to consider of which to choose over another, considering $PM_{2.5}$ concentration in the atmosphere. This project aimed to i) measure the concentrations of $PM_{2.5}$ in the environment of indoor fitness center and outdoor gym in Chulalongkorn University, ii) observe the correlations between $PM_{2.5}$, temperature, and relative humidity, iii) compare $PM_{2.5}$ concentrations between indoor fitness center and outdoor gym in the different times of the day. The project is carried out by measuring the quality of the atmospheric air from an indoor fitness center and an outdoor gym precisely at the same time, using the air quality detector device Bosean Electric (LY062701). Starting from the 1st of April 2019 until the 26th of April 2019 for 12 days, three sessions a day: 08:00 - 09:00 A.M., 01:00 - 02:00 P.M., and 05:00 - 06:00 P.M... The data collected were then analyzed using descriptive statistic and Pearson's correlation coefficient, and two-way ANOVA method. The analysis illustrated that the correlation between atmospheric $PM_{2.5}$ concentration of indoor fitness center and outdoor gym is caused by infiltration from the outdoor air. Therefor the outdoor atmospheric $PM_{2.5}$ concentration affects the atmospheric $PM_{2.5}$

concentration of the indoor fitness center. Consequently, indoor fitness center is more favorable to those who concerns about $PM_{2.5}$ exposure.

Keywords: $PM_{2.5}$, Fitness center, Indoor environment, Outdoor environment

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CHAPTER I

INTRODUCTION

1.1. Introduction

Growing trend towards health and wellness across the world driving the demand for wellness industry. Between 2015 and 2017, the global wellness industry grew by 12.8%, from $3.7 trillion to $4.2 trillion (Global Wellness Institute, 2018). The growth is nearly twice as fast as the global economic growth. In the United States, the health and fitness industry growth is by at least 3 - 4% annually for the past ten years with an average investment of $30 billion, and shows no signs of slowing down (Forbes, 2018). For the top ten countries with leading growth for wellness tourism, Thailand ranked 10th on the global list and 4th among Asia-Pacific countries (Global Wellness Institute, 2018). This trend clearly shows the willingness of people to place more value on health and wellness which will also grow exponentially along with the attention to do physical activity. The popularity of physical workout trends differ across groups of people. The reasons include the desire to improve well-being, the choice of a healthy lifestyle, the increase of ageing and wealthy population, the need to prevent diseases such as cardiovascular and respiratory problems, and the reduction of the risk of cancer and diabetes.

The two basic exercise environments indoor and outdoor are under an ongoing debate whether which is the best for exercising. The bright sides of exercising outdoors include improvement of mental well-being by connecting physical-mental exercise with nature (Coon, et al., 2011), reduction of cortisol, a hormone that triggers stress (Logan & Selhub, 2012). Heighten strengths and ability to endure longer workouts (Fellin, et al., 2010; Kerr, et al., 2012), vitamin D intake, and free of charge are benefits from outdoor exercise. The downsides out the outdoors are weather hazards and exposure to air pollutants and possible allergens, especially in a city. In contrast to exercising indoors, the advantages of indoor include controlled environment, availability of group classes with a safe and effective workout, and access to facilities. Disadvantages of indoor gyms are service charge and possible exposure to indoor air pollution. However, in both environments, athletes and individuals can be at risk when they practice exercise in polluted environments. The reason is because (1) when the minute ventilation increases, the quantity of inhaled pollutants increase proportionally, (2) most air is taken into the body through oral passageway rather than nasal mechanisms, and (3) the increased airflow velocity carries pollutants deeper into the respiratory tract (Carlisle & Sharp, 2001).The total amount of particulate matter deposited in the respiratory tract during moderate exercise may be up to five times higher than at the rest, increasing along with the intensity of physical activity (Daigle et al., 2003).From the previous studies, ambient fine particulate matter($PM_{2.5}$) levels are correlated with premature mortality and other health effects. Urban populations spend a majority of their time in indoor environments, and thus exposures are modified by building envelopes. Ambient particles have been found to penetrate indoors very efficiently (penetration efficiency P≈1.0), where they are slowly removed by deposition, adsorption, and other mechanisms.

In spite of the seriousness of air pollutions, indoor and outdoor air quality studies have been focused almost particularly on commercial buildings (e.g., Challoner & Gill, 2014; Seppanen, Fisk, & Mendell, 1999), residential buildings (e.g., Chao & Wong, 2002; Massey, Masih, Kulshrestha, Habil, & Taneja, 2009; Zhou, et al., 2016), school (e.g., Braniš, Řezáčová, & Domasová, 2005; Roosbroeck, et al., 2007; Fromme, et al., 2008; Wichmann, Lind, Nilsson, & Bellander, 2010) and hospital (e.g., Wang, Bi, Sheng, & Fu, 2006); yet the indoor and outdoor air quality comparison programs accomplished in sports centers are remarkably insufficient. The indoor and outdoor generated $PM_{2.5}$ are currently not well understood, and require information on concentrations and exposure levels. Therefore, the current study aims to quantify $PM_{2.5}$ concentrations in indoor and outdoor exercise environments to obtain data for targeting protection against the risks of fine PM exposure. The results can as well provide data for athletes and individuals for exercising alternatives.

Two sports facilities, belonging to the Chulalongkorn University, Thailand, were chosen to carry out the measuring program: Fitness center and Chula outdoor gym. Fitness center is located on the second floor of the CU sports complex building. The

Chula outdoor gym is built in a public park in Chulalongkorn University near the CU sports complex building.

1.2 Objectives

1.2.1 To measure concentrations of $PM_{2.5}$ in indoor fitness center and outdoor gym environments within Chulalongkorn University.

1.2.2 To investigate relationships between $PM_{2.5}$, temperature, and relative humidity.

1.2.3 To compare $PM_{2.5}$ concentrations between indoor fitness center and outdoor gym environments in different periods of time.

1.3 Outcome of research

1.3.1 For people to use this study as an important factor to consider when appoint a sport center.

1.3.2 For sport center proprietor to use this study as a data to develop air ventilation in their own place.

CHAPTER II

LITERATURE REVIEW

2.1 Fine particulate matter ($PM_{2.5}$)

Fine particle is a mixture of solid particles and liquid droplets. These particles are very small and are measured in micrometers (µm). $PM_{2.5}$ particles are smaller than 2.5 micrometers (0.0025 mm) in diameter. Often described as fine particles. The concentration of all sizes of particulate matter was found to be highest in winter season due to increase human activities and more space heating in indoors and due to low windspeed and high humidity in outdoors in comparison with other seasons. There was a strong correlation between indoor and outdoor particulate at both the sites. Health problems in occupants of the houses with higher concentrations of the fine particulate matter were more prominent. Household activities like cooking on stoves, indoor smoking and outdoor vehicular traffic, and garbage burning were found to be the major sources of particulate emissions indoor as well as outdoors (Massey, Kulshrestha, Masih, & Taneja, 2012).

2.2 Sources of $PM_{2.5}$

Due to air exchange between indoors and outdoors, chemical component of indoor $PM_{2.5}$ is related to indoor origins and outdoor infiltrations. Indoor origins include smoking, cooking, fuel combustion, human activities, and burning incenses. Whereas outdoor infiltrations consist of outdoor penetration and ventilation (natural and mechanical) (Li et al., 2017).

Yu et al. (2013) studied in China and found seven sources and their contributions to the total $PM_{2.5}$ mass which were identified and quantified. These include secondary sulphur– 13.8 μg/m^3, 26.5%; vehicle exhaust– 8.9 μg/m^3, 17.1%; fossil fuel combustion– 8.3 μg/m3, 16%; road dust– 6.6 μg/m^3, 12.7%; biomass burning– 5.8 μg/m^3, 11.2%; soildust– 5.4 μg/m^3, 10.4%; and metal processing– 3.1 μg/m^3, 6.0%. Fugitive dusts (including soil dust and road dust) showed the highest contribution of 20.7 μg/m^3 in the spring, doubling those in other seasons. Besides, motor vehicles, power plant emissions and bushfires are all major sources of fine particles.

2.3 Health effects of $PM_{2.5}$

Particulate air pollution is consistently and independently related to the most serious effects, including lung cancer and other cardiopulmonary mortality. There is a general association that the smaller the size of particles, the greater the health effects. In terms of fine particulate air pollution ($PM_{2.5}$), causes about 3% of mortality from cardiopulmonary disease, about 5% of mortality from cancer of the trachea, bronchus, and lung, and about 1% of mortality from acute respiratory infections in children under 5 years, worldwide. This amounts to about 0.8 million (1.2%) premature deaths and 6.4 million (0.5%) years of life lost (YLL). This burden occurs predominantly in developing countries; 65% in Asia alone. These estimates consider only the impact of air pollution on mortality (i.e., years of life lost) and not morbidity (i.e., years lived with disability), due to limitations in the epidemiologic database. If air pollution multiplies both incidence and mortality to the same extent (i.e., the same relative risk), then the disability-adjusted life years (DALYs) for cardiopulmonary disease increase by 20% worldwide (Cohen, et al., 2005).The influence of $PM_{2.5}$ is associated with concentration, component, size, human age, and exposure time (Li et al., 2017). This implies that the longer the cumulative lag, the greater the adverse impact of $PM_{2.5}$ to respiratory mortality.

2.4 The relationship between indoor $PM_{2.5}$, outdoor $PM_{2.5}$, and physical activity

In Agra, India. Massey et al. (2009) measured PM 2.5 μm, 1.0 μm, 0.5 μm and 0.25 μm inside and outside 14 residential homes located in different microenvironment during a six-month period (October 2007–March 2008). Particulate mass concentrations were measured using Grimm aerosol spectrometer for 24 h inside and outside the homes located in roadside, rural and urban area, along with the field survey study done in the same region. The average I/O ratios for $PM_{2.5}$, $PM_{1.0}$, $PM_{0.5}$, and $PM_{0.25}$ in roadside and rural areas were close to or above 1.00 and less than 1.00 for urban areas. The I/O ratios obtained were linked to the indoor activities using occupant's diary entries. The positive values of correlation coefficient (r) also indicated the indoor concentrations of particulate matter were correlated with the corresponding outdoor concentrations.

Schools are considered micro-environments characterized by high PM concentrations, especially when the buildings are located near highly trafficked roads (Fromme et al., 2007; Diapouli et al., 2008; Buonanno et al., 2011a; Canha et al., 2011). PM concentrations in schools are higher than outdoor ones due to dust resuspension caused by the activity of the students (Brunekreef et al., 1997; Fromme et al., 2008). Here, resuspension is the process by which particles are reintroduced into the air from a surface on which they were previously deposited. Although the first scientific studies of resuspension processes focused on soil erosion and the related transport of dust, recent studies have found that particle resuspension in indoor micro- environments could be an important factor in indoor air quality evaluation (Kim et al., 2010).

Buonanno et al. (2012) investigated the exposure of children to particle resuspension in 12 school gyms for a 3-month experiment. The concentrations of different particle sizes in these gyms were compared to outdoor values. The effect on coarse particles was found to be the most significant in the range of 1.5 to 8.9 mg/min. The average concentrations of coarse PM from 12 school gyms were 4.8 ± 2.0 times higher than the outdoor background values.

Ramos et al. (2014) conducted research about exposure to indoor air pollutants during physical activity in 11 fitness centers. The average particulate matters varied across studied gyms. Exceeded PM_{10} and $PM_{2.5}$ were found in two gyms. An increase in levels of PM_{10} and $PM_{2.5}$ when the gym spaces were occupied during exercise classes, implying that the resuspension of dust is originated from the practitioners of physical activity.

Alves et al. (2013) compared indoor air quality in two university sports facilities. The findings revealed that in the fronton, PM_{10} ranged from 38 to 43 μg/m^3 during the occupancy periods. Much higher values were recorded in the gymnasium between 154 and 198 μg/m^3. The particles value lower than 20 μg/m^3 were measured on weekend in both sports facilities.

CHAPTER III

METHODOLOGY

3.1 Study area

3.1.1 Fitness center (CU sports complex)

The CU Sports Complex is a fully functional sports facility where students, faculty, and the staff can experience and enjoy a variety of sports. The building has specific areas for badminton, swimming, boxing, judo, karate, taekwondo, yoga, aerobics, volleyball, and basketball, along with a fitness center equipped with full range of exercise machines and sports equipment. The complex also serves as a venue for a number of sports competitions and trainings. Additional services, provided to CU students and staff free of charge and with paid membership for the public, include the access to the university’s stadium, tennis courts, indoor sports gyms, golf driving range, golf putting area, beach volleyball court, 25-meter and 50-meter swimming pools, and outdoor gym areas. The fitness center sits on the second floor of CU sports complex building (Figure 3.2). The global dimensions of the square room is 36 meters by 36 meters and 3.5 m in height. The Indoor fitness is essentially a vast square shaped room divided into 4 smaller square chambers (Figure 3.1). The two chambers on the left are completely connected, without a wall, making them one spacious fitness area. The right inner chamber is connected to the left fitness area with a door that is normally opened as a result causing the air from the right inner chambers to flow rather freely to the left fitness area. Meanwhile, the outer right chamber is a separate aerobic studio which is connected to the left fitness area with a rarely opened door blocking the air from the outer right chamber to behave in such manner.

Sources of $PM_{2.5}$ in the studied indoor fitness center theoretically are infiltration and opening and closing of doors and windows. Given that there were no combustion occurring inside of the gym or only minimal combustion from motorized treadmills and other fitness equipment.

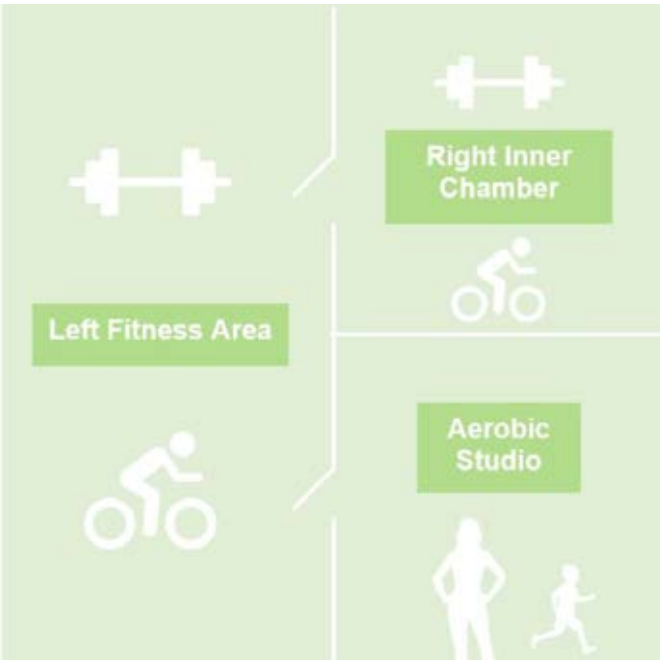

Figure 3.1 *Diagram of the indoor fitness center, which the $PM_{2.5}$ detector device is located in the center of the right inner chamber.*

Figure 3.2 CU fitness center facilities within an indoor gym environment

3.1.2 Chula outdoor gym

Chula outdoor gym is located 200 meters away from the CU sports complex building (Figure 3.3). The right trapezoid shaped area contains various outdoor fitness equipment (Figure 3.4) with the length of the parallel sides approximately at 30 and 13 meters, and width of 17.5 meters. The calculated area is 376.25 square meters.

Figure 3.3 Location of Chula outdoor gym and indoor fitness center

Figure 3.4 Chula outdoor gym facilities and outdoor environment

Sources of $PM_{2.5}$ of the studied outdoor gym mainly are vehicle exhaust and road dust.

3.2 Study framework

Figure 3.5 shows the project framework. The framework illustration includes the location, and session of where and when air data were collected, along with the method of data analysis. The data are strictly collected on weekdays as those data would be a good representation of data.

The data collection is from two locations, an indoor fitness center, and an outdoor gym. The data on both locations are collected in three sessions each day, each session is an hour long as follows: morning session: 8-9 A.M., afternoon session: 1-2 P.M., and evening session 5-6 P.M.

3.3 Instrument validation

To measure the validity of the air quality detector instrument for outdoor air pollution, we compared our air data to the data from Pollution Control Department (PCD), and Air Quality and Noise Management Division, Department of Environment,

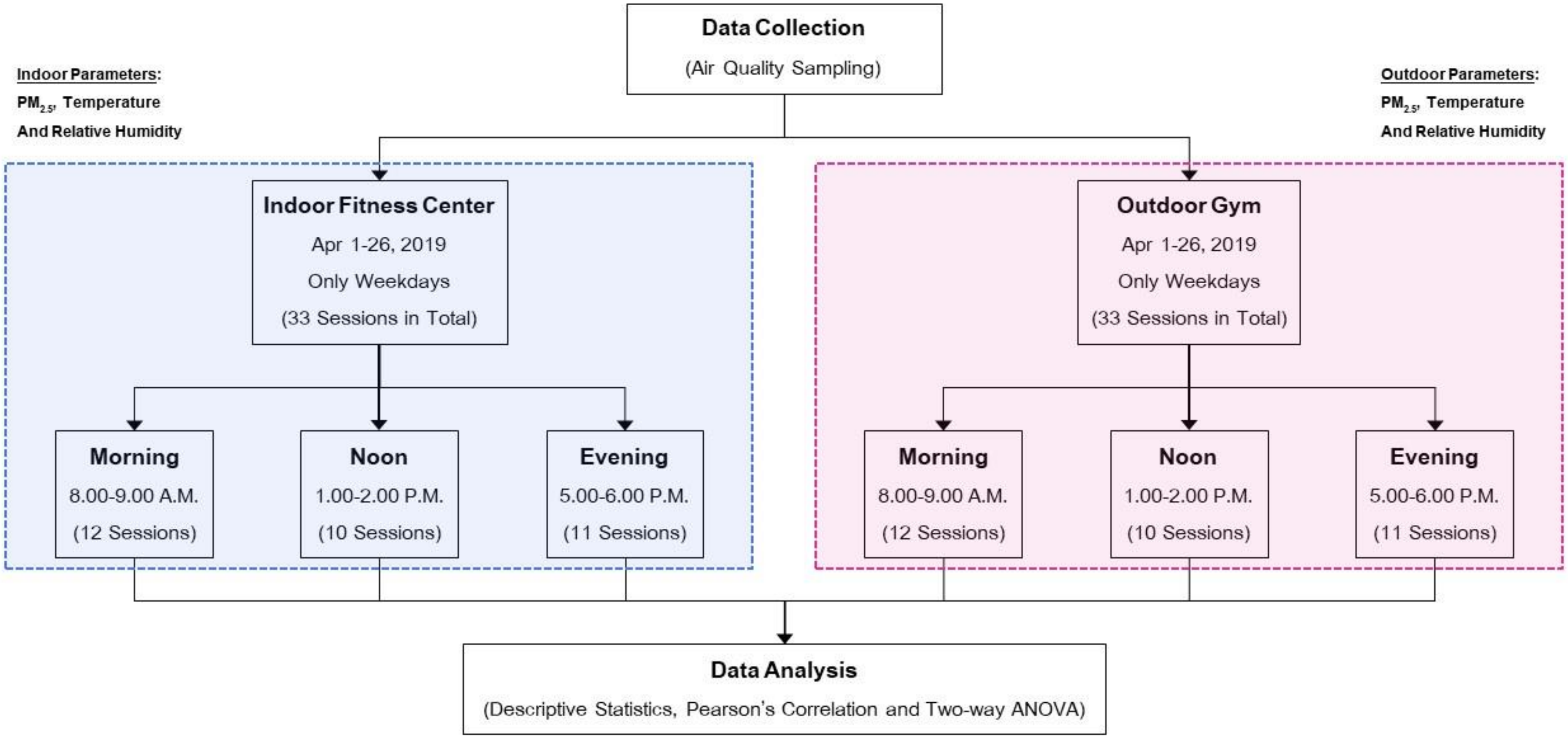

Figure 3.5 Study framework

Bangkok Metropolitan Administration (BMA), by implementing coefficient of determination method.

3.4 Measurement of indoor and outdoor $PM_{2.5}$ and environmental factors

The brand Bosean Electric provides affordable air quality sensors and detectors. The Bosean Electric air quality detector model LY062701 (Figure 3.6) was used in the measurement of $PM_{2.5}$, temperature and relative humidity of both indoor gym and outdoor fitness centers.

Figure 3.6 *The Bosean Electric air quality detector model LY062701*

Figure 3.7 *The measurement of outdoor air quality*

The air samples were collected at both fitness centers in the morning (8–9 A.M.), afternoon (1–2 P.M.), and evening (5–6 P.M.) on weekdays from Apr1, 2019 to Apr 26, 2019. During the sampling, the sampling kit is at the location which did the minimum interruption to exercising activities and is nearest to the center of the fitness centers with at least 30 centimeters from any air flow obstacle (Figure 3.7). The sampling range is at the breathing zone of a standing person (i.e., about 150 centimeters). The sampling intervals are 60 minutes for each sampling period.

Table 3.1 $PM_{2.5}$ *detection of the Bosean Electric air quality detector*

$PM_{2.5}$ detection	
Detection principle	Laser scattering principle
Detection time	3 seconds
Detection method	Concentration (per liter)
Detection range	0 – 999 μg/m^3

Table 3.1 shows the $PM_{2.5}$ detection details of the Bosean Electric air quality detector. The detectable range of temperature is between -20°C and 70°C, and the detectable range of relative humidity is between 20% and 90%.

3.5 Data analysis

3.5.1 The basic characteristics of indoor parameters and outdoor parameters (i.e., $PM_{2.5}$, temperature, and relative humidity) were summarized by using descriptive statistics including minimum, maximum, mean, median, range, and standard deviation.

3.5.2 Pearson's correlation coefficients were calculated to determine whether the measured $PM_{2.5}$ concentrations of the indoor fitness center are in correlation with those of the outdoor gym or not.

3.5.3 Two-way ANOVA and post-hoc tests were performed to determine any statistical differences between the mean $PM_{2.5}$ concentrations of three sampling period for the indoor and outdoor environment.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Instrument validity

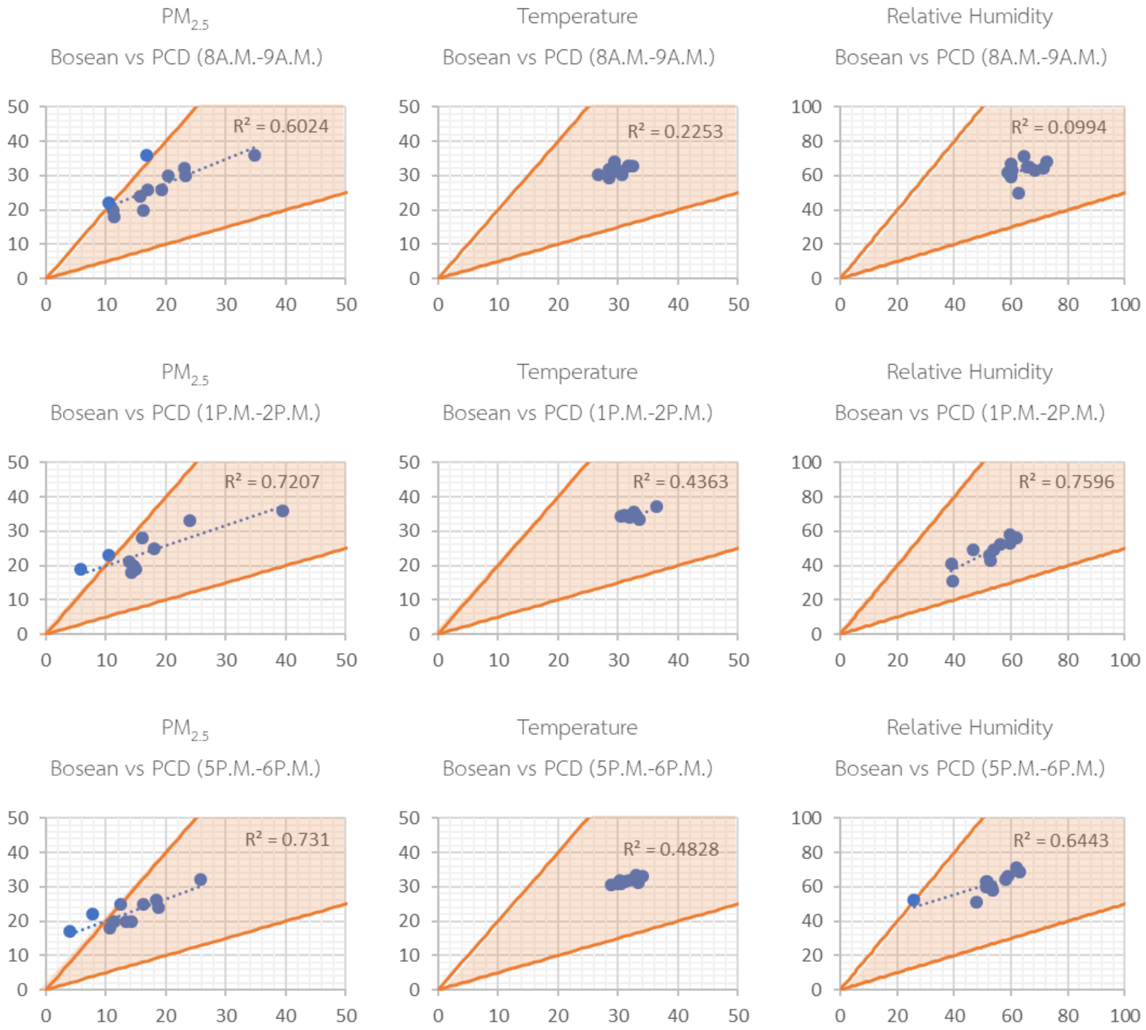

Figure 4.1 *Comparisons between air quality data collected from Bosean air quality detector and PCD, which the x-axis stands for the data from Bosean and the y-axis stands for the data from PCD.*

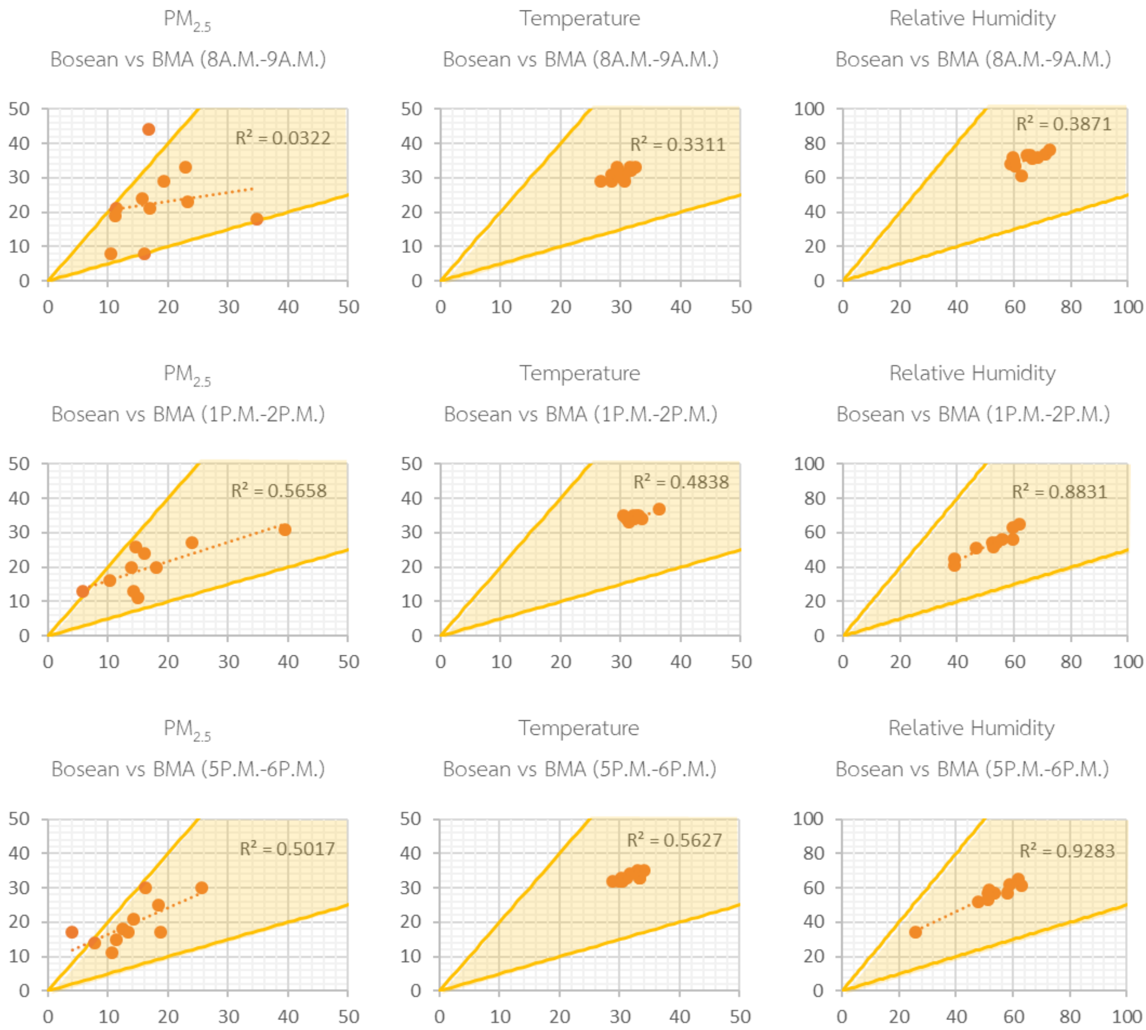

Figure 4.2 *Comparisons between air quality data collected from Bosean air quality detector and BMA, which the x-axis stands for the data from Bosean and the y-axis stands for the data from BMA.*

Figure 4.1 and Figure 4.2 show the relationship between the Bosean Electric air quality detector and air quality report from PCD, and BMA, respectively. For clarity, the correlation coefficients (in absolute value) that are ≤ 0.35 are generally considered to represent low or weak correlations, the ones that are 0.36 to 0.67 are modest or moderate correlations, the ones that are 0.68 to 1.0 are strong and high, and the ones with R^2 coefficients ≥ 0.90 very high correlations (Taylor, 1990).

Thus, Figure 4.1 and Figure 4.2 show moderate agreement of $PM_{2.5}$ concentrations between Bosean Electric air quality readings and air quality report from BMA. The orange (yellow) area is a factor-of-two envelope that indicates whether the compared data are more than twice as higher as one another. Although scatterplots and fit linear curve of the measured data from Bosean Electric and the data from PCD or BMA has low R^2, which shows negative linear relationship, but The differences between the compare data are no higher than double the other data.

4.2 Descriptive characteristics of measured $PM_{2.5}$ and environmental factors

In the indoor fitness center, the average $PM_{2.5}$ concentrations obtained during 8A.M.-9A.M., 1P.M.-2P.M., and 5P.M.-6P.M. are 7.91, 9.45, and 8.37 μg/m^3. The average $PM_{2.5}$ average of outdoor gym are 18.27, 17.13, and 13.91 μg/m^3 respectively to the time sessions of indoor fitness center (Table 4.1).

There is no accepted threshold limit for $PM_{2.5}$ on 1-hour average concentration. PCD in Thailand have developed guidelines for acceptable IAQ, recommending that $PM_{2.5}$ average concentration should be maintained at 50 μg/m^3 during a 24-h time period and 25 μg/m^3 for the annual mean. Environment Protection Authority Victoria (EPA Victoria) recommends a guideline for one-hour $PM_{2.5}$ amount, that it should not exceed 40 μg/m^3. Any value higher than 40 μg/m^3 would be considered as 'poor' or 'unhealthy for all.'

Table 4.1 Concentrations of $PM_{2.5}$ in an indoor and outdoor gym environment ($\mu g/m^3$)

$PM_{2.5}$ ($\mu g/m^3$)	8A.M.-9A.M.		1P.M.-2P.M.		5P.M.-6P.M.	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Max	20.00	41.00	22.00	50.00	18.00	30.00
Min	1.00	7.00	1.00	3.00	1.00	1.00
Mean	7.91	18.27	9.45	17.13	8.37	13.91
SD	3.68	7.17	4.60	8.87	4.00	5.85
Median	7.00	18.00	8.00	15.00	8.00	13.00
Range	19.00	34.00	21.00	47.00	17.00	29.00

Table 4.2 Values of temperature in an indoor and outdoor gym environment (°C)

Temperature (°C)	8A.M.-9A.M.		1P.M.-2P.M.		5P.M.-6P.M.	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Max	28.90	35.50	29.00	39.40	30.30	35.70
Min	22.00	24.40	19.60	28.50	20.60	27.20
Mean	26.43	29.99	25.29	32.50	26.58	31.74
SD	1.61	2.19	1.77	2.09	1.67	1.94
Median	26.60	29.90	25.60	32.40	26.55	31.80
Range	6.90	11.10	9.40	10.90	9.70	8.50

Table 4.3 Amounts of relative humidity level in an indoor and outdoor gym environment (%)

Relative humidity (%)	8A.M.-9A.M.		1P.M.-2P.M.		5P.M.-6P.M.	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Max	60.00	84.00	71.00	71.00	66.00	72.00
Min	42.00	50.00	42.00	28.00	37.00	19.00
Mean	50.03	64.19	52.57	52.06	50.96	52.41
SD	3.73	6.79	5.16	8.52	5.47	9.95
Median	49.50	64.00	52.00	53.00	52.00	53.00
Range	18.00	34.00	29.00	43.00	29.00	53.00

Table 4.2 and Table 4.3 show the basic characteristics of temperature and relative humidity collected from indoor fitness center and outdoor gym.

The American National Standard Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommend a standardized thermal condition considering indoor environmental and personal factors called 'Thermal Environmental Conditions for Human Occupancy' (ANSI/ASHRAE 55-2013). Assuming slow air movement (less than 40 feet per minute) and 50% indoor relative humidity, the operative temperatures recommended by ASHRAE range from 68.5°F (20.3°C) to 75°F (23.9°C) in winter, and from 75°F (23.9°C) to 80.5°F (26.9°C) in summer. The difference in temperature ranges between each season is largely due to clothing selection. ASHRAE also recommends that indoor relative humidity be maintained at or below 65% (ANSI/ASHRAE 55-2013). The EPA recommends maintaining indoor relative humidity between 30% and 60% to reduce mold growth (EPA 2002).

The Occupational Safety and Health Administration (OSHA) suggest that appropriate relative humidity should stays in between 20% - 60%, The International Fitness Association (IFA) suggest an appropriate relative humidity in all areas should be in between 40% - 60%. The American College of Sports Medicine (ACSM) recommended the temperature should be in between 68F (20°C) to 72F (22.2°C), and IFA suggested temperature for aerobics, cardio, weight training, and pilates areas should be in between 65F (18.3°C) to 68F (20°C), and 65F (18.3°C) - 80F (26.7°C) for yoga.

Nonetheless, indoor environment can be easily changed by air conditioning, methods for making an outdoor environment comfortable are very limited. For the outdoor environment, the indoor comfort indices were sometimes applied (Honjo, 2009).

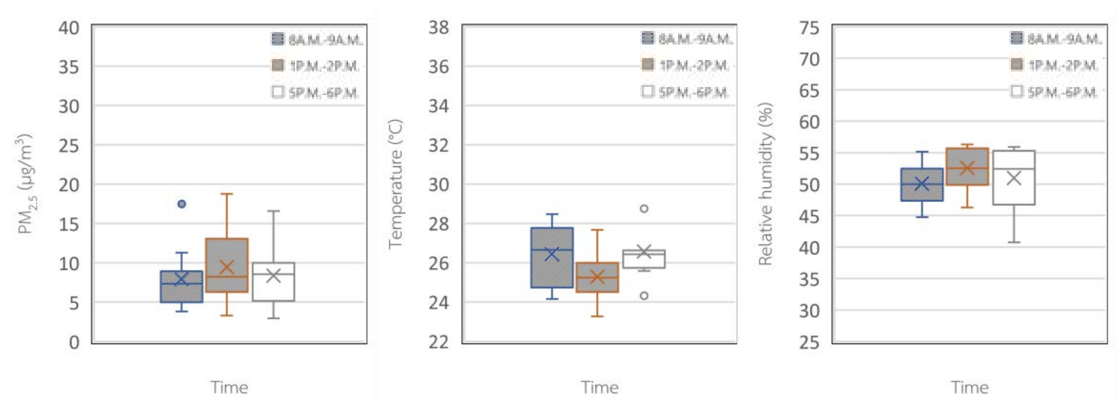

Figure 4.3 *Concentrations of $PM_{2.5}$, temperature and relative humidity in an indoor gym environment*

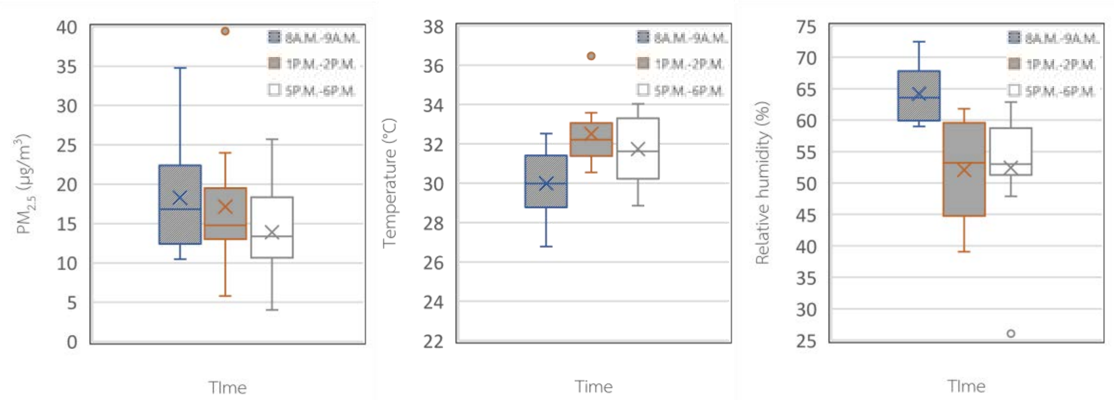

Figure 4.4 *Concentrations of $PM_{2.5}$, temperature and relative humidity in an outdoor gym environment*

The box plots in Figure 4.3 and Figure 4.4 show the statistics of concentrations of $PM_{2.5}$, temperature and relative humidity in an indoor gym environment and an outdoor gym environment. The boxes stretch from the lower quartile to the upper quartile values. The thin lines across the boxes represent the medians, and the crosses represent the means. The "whiskers" on box plots extend from Q1 and Q3 to the most extreme data points. In turn, each of these outliers is represented by a mark. Among all the data, the data of each perimeters from the outdoor gym seem to have larger ranges compared to those of the indoor fitness center data

4.3 Relationship between $PM_{2.5,}$ temperature and relative humidity

Table 4.4 $PM_{2.5}$, temperature and relative humidity correlation matrix

		T_indoor	RH_indoor	PM_indoor	T_outdoor	RH_outdoor	PM_outdoor
T_indoor	Pearson Correlation	1	-.625**	-.015	-.074	.225	-.142
	Sig. (2-tailed)		.000	.934	.681	.209	.429
	N	33	33	33	33	33	33
RH_indoor	Pearson Correlation	-.625**	1	.281	-.028	.270	.316
	Sig. (2-tailed)	.000		.113	.875	.128	.073
	N	33	33	33	33	33	33
PM_indoor	Pearson Correlation	-.015	.281	1	.385*	.029	.880**
	Sig. (2-tailed)	.934	.113		.027	.871	.000
	N	33	33	33	33	33	33
T_outdoor	Pearson Correlation	-.074	-.028	.385*	1	-.728**	.076
	Sig. (2-tailed)	.681	.875	.027		.000	.676
	N	33	33	33	33	33	33
RH_outdoor	Pearson Correlation	.225	.270	.029	-.728**	1	.252
	Sig. (2-tailed)	.209	.128	.871	.000		.158
	N	33	33	33	33	33	33
PM_outdoor	Pearson Correlation	-.142	.316	.880**	.076	.252	1
	Sig. (2-tailed)	.429	.073	.000	.676	.158	
	N	33	33	33	33	33	33

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

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

$PM_{2.5}$ concentrations were correlated with both temperature and relative humidity (Table 4.4). The associations between the measured indoor $PM_{2.5}$ and outdoor $PM_{2.5}$ hold the strongest positive correlation (p = 0.880). According to Chen and Zhao (2011), outdoor air pollutants may intrude indoors by two main mechanisms: through opened windows or doors (natural ventilation) and by infiltration through cracks and leaks in the building envelope (the latter being uncontrolled and having a relatively low exchange rate). Therefore, the association could be related to the infiltration of ambient $PM_{2.5}$ and levels of indoor $PM_{2.5}$

The less significant of positive correlation were between the measured indoor $PM_{2.5}$ and outdoor temperature (p = 0.385). However, Hernandez, Berry, Wallis, & Poyner (2017) studied in New Zealand and found that temperature was observed to have a negative correlation with PM_{10}.

The correlation that were found to be negative is the measured of both indoor and outdoor temperature comparing with relative humidity (p = -0.625, p = -0.728, respectively). As relative humidity depends on air temperature. This means, if the water vapor remains the same as the temperature decreases, the relative humidity then increases, and vice versa. Colder air requires less moisture to become saturated as warmer air does (North Carolina Climate Office).

Lou, et al. (2017) studied in China and found that the very-dry (RH < 45%), dry (RH = 45–60%) and low-humidity (RH = 60–70%) conditions positively affected PM2.5 and exerted an accumulation effect, while the mid-humidity (RH = 70–80%), high-humidity (RH = 80–90%), and extreme-humidity (RH = 90–100%) conditions played a significant role in reducing particle concentrations.

4.4 Comparison of $PM_{2.5}$ concentrations in different locations and times

Table 4.5 Levene's test of equality of error variances

Levene's Test of Equality of Error Variances[a]

Dependent Variable: PM

F	df1	df2	Sig.
1.144	5	60	.347

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Time + Location + Time * Location

The SPSS returns F = 1.144 and p = 0.347 for Levene's test. As $p > 0.05$, equal variances can be assumed (Table 4.5).

Table 4.6 Two-Way ANOVA

Dependent Variable: PM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1169.302[a]	5	233.860	6.643	.000	.356
Intercept	10262.715	1	10262.715	291.504	.000	.829
Time	61.382	2	30.691	.872	.423	.028
Location	1014.151	1	1014.151	28.806	.000	.324
Time * Location	66.933	2	33.467	.951	.392	.031
Error	2112.368	60	35.206			
Total	13591.254	66				
Corrected Total	3281.670	65				

a. R Squared = .356 (Adjusted R Squared = .303)

There was no statistically significant difference between different period of times (p = 0.423), but there were statistically significant differences in mean $PM_{2.5}$

concentration between indoor fitness center and Chula outdoor gym ($p < 0.05$) (Table 4.6).

Further, there was no statistically significant interaction between the effects of times and locations on $PM_{2.5}$ concentrations ($p = 0.392$).

CHAPTER V

CONCLUSIONS

The average both temperature and relative humidity as well as $PM_{2.5}$ concentrations data collected from the outdoor gym environment were higher than the values collected from indoor fitness center. The relationship between the measured indoor $PM_{2.5}$ and outdoor $PM_{2.5}$ hold the strongest positive correlation. The correlation shows that the infiltration affects the levels of indoor $PM_{2.5}$., as there were only two sources of $PM_{2.5}$: the air from outside leaking in through infiltration and natural ventilation

A two-way ANOVA was conducted, examining the effect of times and locations on $PM_{2.5}$ concentrations. There was no statistically significant interaction between the effects of times and locations on $PM_{2.5}$ concentrations. Outdoor environment has significantly higher levels of $PM_{2.5}$ than indoor environment, and the time of the day has no effect on the level of $PM_{2.5}$.

Based on the result, indoor fitness centers are a better option regarding to the level of $PM_{2.5}$, compared to outdoor gym.

Due to the limitations of time and equipment supply, further experiments and studies of this topic are highly advised in order to deliver a <u>dependable</u> result

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