Comparative Indoor Air Quality Analysis among the Schools of Roadside and Residential Areas of Dhanmondi

In Partial Fulfillment of the Requirements

For the Degree of

Bachelor of Environmental Science and Disaster Management

By

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DECLARATION

This is to certify that the dissertation titled: “Comparative Indoor Air Quality Analysis Among the Schools of Roadside and Residential Areas of Dhanmondi” submitted in partial fulfillment of the requirements for the degree of Bachelor of Environmental Science and Disaster Management under the university of Daffodil International University is a record of bonafide research work carried out by me under the supervision of Dr. A.B.M Kamal Pasha, Associate Professor and Head of Environmental Science and Disaster Management. I, further, declare that this has not been previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar title of recognition.

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CERTIFICATE OF APPROVAL

I am pleased to certify that the Thesis Report on **"Comparative Indoor Air Quality Analysis among the Schools of Roadside and Residential Areas of Dhanmondi"** prepared by **MD. Shihabul Shakib** bearing **ID NO: 151-30-117** of the **Department of Environmental Science and Disaster Management** is approved for Presentation and Defense.

MD. Shihabul Shakib works as an independent researcher under my supervision. He completed the work as partial fulfillment of the requirement for the degree of Bachelor of Science in Environmental Science and Disaster Management, which has been examined and hereby recommended for approval and acceptance.

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Md. Shihabul Shakib, 2019

ABSTRACT

The study aims at determining indoor air quality (IAQ) in selected schools of open and close structured types, located on roadside and residential area of Dhanmondi, Dhaka, Bangladesh. Using appropriate instruments, different parameters of IAQ such as CO_2, PM2.5, PM10, HCHO, Temperature and Relative Humidity have been measured inside the classrooms. The study has further reviewed relevant standards to reveal the IAQ status of classrooms vis-à-vis permissible limits under international IAQ standards. Overall, IAQ of selected schools has been found inferior compared to international standards, though HCHO concentration has found well within the recommended limits. However, the concentrations of CO_2 have been measured much higher in the close structured school while open structured schools have shown better result within the acceptable limits. Lack of air circulation with ductless air conditioning systems could be attributed to higher concentration of CO_2 in close structured school. On the other hand, PM2.5 and PM10 have found more than the standard limits and significantly higher concentrations in roadside schools. Particulates from traffic, dust in summer season and industrial activity of Dhaka city result in higher concentrations of PM2.5 and PM10 in all these four schools. The Study being the first of its kind in Bangladesh and taking into account that students spend major part of their time in a day in schools, recommends to use waters sprinkler to reduce dust and suspended particles in roads adjacent to the schools and keep provision for sufficient air circulation systems to improve indoor air quality in schools.

Keywords: Carbon Dioxide, Particulate Matter 2.5, Particulate Matter 10 and Indoor Air Quality

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ABBREVIATIONS

WHO= World Health Organization

ASHRAE= American Society of Heating, Refrigerating and Air- Conditioning Engineering

CO_2= Carbon Dioxide

PM= Particulate Matter

PM2.5= Particulate Matter 2.5

PM10= Particulate Matter 10

HCHO= Formaldehyde

IAQ= Indoor Air Quality

AQI= Air Quality Index

IEQ= Indoor Environmental Quality

EPA= Environmental Protection Agency

REL= Reference Exposure Level

SBS= Sick Building Syndrome

DPT= Dew Point Temperature

WBT= Wet Bulb Temperature

RH= Relative Humidity

PPM= Parts Per Million

$\mu g/m^3$= Micro Grams per Cubic Meter of Air

℃= Degree Celsius

Chapter 1 Introduction

1.0 Introduction

1.1 Air Pollution

Air pollution is now a common word that we have habituated with. However, it's a serious concern in the world. Air pollution can be narrated as alterations in the chemical compound of atmosphere because of insertion of chemicals, particles, or organic materials in air. These materials are already present in air but when these materials are more than natural limit, air pollution occurs. These materials are also called air pollutants that can cause discomfort or negatively affect humans or other living organisms. These pollutants can also cause damage to the natural environment or built environment (Marie et al., 2011). All living organisms are affected if imbalance in proportion of components of air is caused due to increase or decrease in the percentage of these gases (Lomax et al., 2005). Burning of fossil fuels, farming activities, emission from factories and industries, mining operations, household cleaning activities etc. causing air pollution. Air pollution affects both outdoor and indoor environments. While indoor activities have influences on pollution, indoor air pollution generally occurs due to excessive outdoor air pollution (Belanger, K. et al., 2006).

1.2 Indoor Air Quality

Indoor Air Quality (IAQ) gives an impression of the air quality of the building and its structure and surroundings, particularly when it connects to the health and comfort of building dwellers. IAQ may be affected by gas, substances, microbial pollutants, or any mass or energy pressure, which can cause adverse health conditions (Bruce et al., 2000). IAQ is a part of the indoor environmental quality (IEQ), which includes IAQ, as well as other psychological and physical aspects of life in indoors such as lighting, visual quality, acoustics, and thermal comfort etc. The qualities of good IAQ should include comfortable temperature and humidity, adequate supply of fresh outdoor air, and inside and outside pollutants control (Bruce et al., 2000).

1.3 Indoor Environment and Urban People

A number of scientist highlighted that urban people spend most of their time in indoor environments. Besides staying at home, they spend time in private and public indoor environments such as schools, colleges, offices, industrial buildings and restaurants. Therefore, the risk of being affected by indoor air pollution is greater for urban people than the outdoor air pollution (EPA Indoor Air Quality, 2013).

1.4 Indoor Air Quality and Health Risk

Indoor air quality is very important for human health because exposure to indoor air with poor quality may cause harmful effects such as respiratory diseases, cardiopulmonary pathologies, allergic reaction, headache and asthma (Wolkof, 2018). According to indoor environment and its function, location and time, there is large variability in concentration of pollutants in indoor air. These disparities depend on different characteristics, such as behavior of residents, climatic condition and ventilation system. Study has identified that exposure to indoor air pollution can be responsible for about 2 million additional deaths in developing countries and 4% of global compulsion of the disease (Bruce et al., 2000).

1.5 Indoor Air Quality and Children

Pure indoor air is very important for the sound health of the people, especially vulnerable group like children (Rosbach et al., 2013). As tissues and organs of children are being developed by the volume of air they breathe relative to their body weights, they are more susceptible to air pollutants than adults. Normally, children spend large amount of their time in school buildings. The indoor air quality in schools may affect the health of children while indirectly affecting their learning ability (Datta et al., 2017).The school should maintain indoor environmental quality (IEQ) in order to provide a healthy and comfortable learning environment. Health, performance, presence and comfort of students largely depend on IEQ factors including indoor air pollutants and thermal condition of school building (Wolkof, 2018). Students spend their time in school up to 30% of their day time. As such they are more likely to be exposed to indoor air pollutants. This demands for maintaining indoor environmental quality to provide children a healthy and comfortable learning environment (Wolkof, 2018).

Considering this, the study will look into indoor air quality and possible health risks at school buildings.

1.6 Indoor Environment and Pollutants

CO_2, HCHO, PM2.5 and PM10 have been identified as the pollutants that result in serious health problems such as respiratory diseases, allergies, nausea, asthma etc. Concentrations of various pollutants vary in different seasons and different times of the day (Ferreira, Cardoso. 2014). Among different pollutants, interest on studying concentration of particulate matter (PM) is growing. In recent studies, scientists have found that concentration of PM2.5 and PM10 in school building is higher than other indoor environment because of closed ventilation system. The concentration is higher particularly during the winter and extreme summer season. In a study conducted in in Chennai, India, it is being reported that the PM10 and PM2.5 concentrations in the classrooms are higher than the acceptable level in a naturally ventilated educational building (Chitra and Nagendra, 2012).

CO_2 concentration in classroom is found higher than outdoor environment because of lower ventilation system that was studied in Italy (De Guili et al., 2012). About 1000 ppm Indoor CO_2 insertion is usually considered as inadmissible with respect to the body's odor which indicates the rate of ventilation. The specific concern is the risk of infection of some specific infectious respiratory illnesses, such as the possibility of influenza and general cold in the classroom because of higher CO_2 concentration (De Guili et al., 2012).

Severe symptoms are found occasionally from HCHO exposures, for example eye, nose and throat irritation, as well as lower air and pulmonary effects. Acute HCHO toxicity IAQ guidelines for various settings range from 60 to 100μg/m³ (0.055–0.08 ppm, OEHHA, 1999; WHO, 1987; CDNHW, 1987). The most recent HCHO Reference Exposure Level (REL) is 3μg / m³, based on possible cancer effects. A recent study has stated that the lower level HCHO exposures of the current guidelines may be at risk of exposure to allergic reaction. Concentration of this type of parameter in the air may cause breathing problem, stress, irritability, headache, dizziness, cough, insomnia, lack of concentration, chronic bronchitis, asthma, allergic reaction etc (Ferreira and Cardoso, 2014).

1.7 Indoor Environment and Developed World

The developed countries have been working with indoor air quality (IAQ) for many years. They identified the indoor air pollutants and investigated their impacts on health. After research on possible way outs, they have found the solution for improving the indoor environment. They have worked with school students and school buildings to ensure a healthy and comfortable environment for students and teachers during the classes (US EPA, 2017).

1.8 Indoor Environment and Bangladesh

Bangladesh, a developing country, is one of the most densely populated countries in the world. As the country is developing, pollution is on the rise. Particularly activities such as industrial production, transportation, construction etc., pollution is increasing with increase of CO_2, PM2.5, PM10, HCHO and different types of dust particle in the air. Deforestation is also affecting the overall situation. The resulting increase in outdoor air pollutants in

Bangladesh also affects indoor air. While the World Bank has studied indoor air quality of poor families with particular attention on household cooking, there has been no research on indoor air quality in schools. Our neighboring country has studied “indoor air quality of school and health of students” but on a limited basis. Since there is no research focused on the indoor air quality in the school buildings of Bangladesh therefore based on these, the study has been carried out to assess indoor air quality of schools specifically in selected schools of Dhaka city. Firstly, Dhaka has been chosen as it is one of the most highly populated mega cities in the world and has ranked among the world’s cities with the most poor air quality (Dhaka Tribune, 2019). Secondly, Dhanmondi, 27, 32, 9A and 11A areas are selected considering Dhanmondi’s importance.

1.9 Objectives

As we know that, Dhaka city is one of the most polluted cities in the world and school students are more vulnerable part in this community. As the students spend more than one fourth of their time in school buildings therefore, it is essential that they are in a healthy environment inside the school buildings. Therefore the study focused on determined the concentrations of different pollutants inside the building. The research main aim is to determine the most deleterious pollutants, pollutants concentration in different floor of the buildings, rainy and sunny day concentrations, showing the comparison between roadside and residential areas schools pollutants concentration and also showing the comparison between close and open structured schools.

a. To determine the concentration of CO_2, PM2.5, PM10, HCHO, Relative Humidity and Temperature in different school buildings
b. To compare different status of the parameters (close structured vs open structured, residential vs roadside school, floor wise concentration and rainy day vs normal day concentration).

Chapter 2 Literature Review

2.0 Literature Review

This chapter gives on idea about the negative impacts of CO_2, PM2.5, PM10, HCHO, Relative Humidity and Temperature, showing the result of developed world and developing world recent above parameter related work and measurement methodologies of above parameters.

2.1 Indoor Air Quality

Many reasons the presence of indoor air pollution such as maintenance activities, the presence of pollutant sources, contamination reduction levels, seasons, indoor humidity and temperature, and ventilation rates. The specific pollutants concentration in the indoor air often can be much higher than the concentration of outdoor air. Indoor air pollutants include CO_2, CO, HCHO, PM2.5, PM10 etc. In addition to indoor air pollutants, people can experience same discomfort and health symptoms similar to those imposed to indoor air pollutants due to environmental factors (KMC Controls, 2016). Often, both indoor air pollutants and other indoor environmental issues are difficult to detect because of the direct causes of occupational discomfort and health symptoms. Poor ventilation system, temperature and relative humidity are causing of indoor occupants discomfort and health problem. Some health effects can be seen shortly after the release of a pollutant or certain pollution. These include eye, nose and throat irritation, headache, dizziness, and fatigue (US EPA, 2006).

2.2 CO_2 Concentrations

Carbon dioxide exposure can produce various health effects. It may include headaches, dizziness, restlessness, germs or pins or needles, breathing difficulties, sweating, fatigue, and heart rate (Steve, 2016). Carbon dioxide levels and potential health problems are indicated in occupied spaces as 350 to 1,000 ppm: good air exchange, 1,000 to 2,000 ppm: level associated with complaints of poor air, 2,000 to 5,000 ppm: very poor and hazardous condition (Steve, 2016). Sick Building Syndrome (SBS) is used to describe a situation in which the residents of a building feel the effects of acute health or comfort which seem to be connected directly at the time spent in the building, although no specific illness or cause can be identified (Sick Classrooms Caused by Rising CO_2 Levels, 2014). Building occupiers have severe discomfort e.g. headache, eyes, nose, or throat irritation, dry cough, dry or radioactive skin, dizziness and nausea, concentration difficulties, fatigue and odor sensitivity (Sick Classrooms Caused by Rising CO_2 Levels, 2014).

Insufficient ventilation system, deficient wind exchange from windows and doors opening and closing, and crowded classrooms can cause high concentration of CO_2 in the classroom. Inhabited and air conditioning rooms measure higher levels of CO_2 concentration compared to cooling rooms with ceiling fans. Other study point out that lower ventilation rate worsening the health of the student and break the concentration of students and teachers as well. In Sweden, they randomly selected 96 classrooms of 38 schools and they found that naturally ventilated classroom had averaged CO_2 concentration 990ppm while closed ventilation system classroom had CO_2 concentration above 1000ppm (maximum 2800). Another study was performed in Danish, Sweden and Norway schools y where 743 classes measured a CO_2 concentration. In the mass study the classes volunteered for the experiment, whereas in the representative study the schools were randomly chosen to make the investigation statistically representative. In Danish schools found that 56% participating classrooms had a CO_2 concentration above 1000ppm and 49% above 1200ppm. The results were from Sweden and Norway respectively 16% and 21%. From the representative study in Danish school, 66% of the occupants were one of the measuring days exposed to CO_2 concentration of 2000 ppm for a minimum 20 minutes (Mena et al., 2010). Our neighboring country India found CO_2 concentration on office buildings of Delhi respectively 1513ppm and 1338ppm which was much higher than the ASHRAE standard (Datta et al., 2017). In the Portugal indoor air of school was recorded averaged CO_2 concentration more than the maximum reference value during the winter and fall season. Concentration was recorded as high as 1942ppm sometimes which implying a considerable health risk for school children (Ferreira, Cardoso. 2014).

In India study was conducted in two office building and one educational building and sampling was taken in every five min interval between 9:30 to 5:30 for five days every week. Low volume sampling pump was used for determine CO_2 concentration in India (Datta et al., 2017). 81 schools and 230 classrooms were monitored in Portugal and series 500 handheld monitor was used in Portugal and sample was taken in every 2-3 hour interval (Ferreira, Cardoso. 2014).

Above all these research they didn't show the comparison at the same time between roadside vs residential areas school and close structured vs open structured school CO_2 concentrations. While in my research I show the comparison between roadside vs residential and close structured vs open structured school concentration at the same time.

2.3 Particulate Matter

Among the indoor air pollutants, nowadays PM is a growing interest. Aerosol exposure by inhalation route represent a potential source for risk of human health, depending on the duration of exposure and concentration, size and chemical composition of airborne particles. In many research, in fact, high density of PM10 concentration exposure increases the risk of death due to cardiovascular or respiratory system. These effects can be largely by the smaller particles, as a result of their larger surface area which can be effective for the transport of various types of pollutants in the lungs. In particular, this small particle exposure can cause short and long-term effects like respiratory symptoms, decrease in lung function, alterations in tissues and structural changes in lung function, respiratory tract and premature death (Marie et al., 2011).

Although in the school environment there is a lack of common indoor PM source such as smoking and cooking, many children attend a limited space over a number of hours. The use of cleanliness products and floor poles temporarily affect air quality, which increases the chemical pollution in the school environment. Particle comes from rapid carriage in the urban road, infrastructure development and road construction can cause the increase of particulate matter in the classroom. Chithra and Shiva Nagendra (2012) examined PM 10, PM 2.5 and PM1 concentrations by environmental dust monitor to study the relationship between outdoor and indoor air quality in eight French schools. PM for indoor-outdoor ratio is more than two for course fractions and smaller than one for finer fractions. The high concentration of PM2.5 and PM10 in the indoor and outdoor value and its behavior mentions significant contributions from the activities of the residents in the classroom and thus the re suspension of the dust. PM2.5 and PM10 were found to be significantly higher in the spring and summer season (Chithra and Shiva Nagendra, 2012). A study in USA found that 0.6% increase in cardiopulmonary mortality per 20μg/m^3 increase in PM10. In Europe reported that 1.5% increase cardiovascular mortality per 20μg/m^3 increase in PM10. When the CV events are divided into classes, the 10-μg /m^3 increase in PM10 is associated with the highest rate of hospitalization for heart attacks and also ischemic heart disease, cerebrovascular disease and heart rhythm. Women Health Initiatives indicated that higher rising levels of stroke and increased risk of cerebrovascular diseases with chronically elevated levels of PM2.5 than of coronary heart disease or myocardial infection (Marie et al., 2011).

Above all these research they didn't show the comparison at the same time between roadside vs residential areas school and close structured vs open structured school PM concentrations. While in my research I show the comparison between roadside vs residential and close structured vs open structured school concentration at the same time.

2.4 Formaldehyde

In general, formaldehyde is a naturally occurring organic compound and it is a very great pioneer to many others chemical mixtures and elements. Because of its widespread use, toxicity, volatility, formaldehyde posture a great impact on human health. In 2011, the US National Toxicology Program described formaldehyde as "known to be a human carcinogen" (Harris et al., 2011). Formaldehyde is one of the more common indoor air pollutants because formaldehyde resins are using as many building materials (Air Resources Board, 2012). Formaldehyde concentration above .1 ppm can cause eye irritating and mucus membrane resulting watery eye (Occupational Safety and Health Administration, 2009). Inhaled formaldehyde in this concentration can cause headaches, burning sensation, and difficulty breathing and may also trigger asthma symptoms (Broder et al., 1991). A recent study found that a strong co relation between formaldehyde exposure and childhood asthma (McGwin et al., 2009). A research from Canada found that in houses formaldehyde level as low as 0.046ppm is positively correlated with eye and nasal irritation (Broder et al., 1991). In the indoor environment, formaldehyde exposure comes from various routes; formaldehyde can be made of wood products such as plywood or particle boards, but it is produced by paints, varnishes, floor finishes and smoking cigarettes (Dales et al., 2008). In new buildings the United State Environmental Protection Agency allows up to 0.016 ppm formaldehyde in the air (Environmental Protection Agency, 2006).

2.5 Relative Humidity

Relative Humidity (RH) is the proportion of vapor pressure equivalent to partial pressure of water vapor at a certain temperature (Perry et al, 2007). Relative humidity depends on the temperature and pressure of a specific environment (Lide, 2005). Relative humidity is usually expressed as a percentage; a high percentage means that the mixture of air water is more humid. Humans are sensitive to high humidity because humans use evaporative cold in the body, enabled by perspiration, as the initial process to free itself from the waste heat process (Arundel et al., 1986). Body experiences greater distress of waste heat burden at high humidity than at lower humidity, given equal temperatures (Arundel et al., 1986). Lower humidity also causes humans discomfort. For example, if the temperature is 27 and relative humidity is 0% then temperature seems like 24 and if it is 100% relative humidity then it look like 30 (Perry et al., 2007). Human can be comfortable within the range of relative humidity 30% to 70%, but ideally in the range of 30% to 50% (Gilmore, 1972). Lower relative humidity also causes eye irritation (Arundel et al., 1986).

2.6 Temperature

Temperature is such things that revealing hot and cold. Normal change of temperature can negatively affect the humans and mammals lifestyle (Xiong et al., 2015). For example, when you entered and existed from air conditioning room suddenly you feel thermal discomfort as well as some other health problems too (Xiong et al., 2015). In China, thirty students were selected for the examination in warm and air conditioning environment. Researcher examined them in different thermal conditions. In 29.2 degree Celsius temperature, 90% of students feel comfort and satisfied (Zhang et al., 2014).

2.7 Ventilation System

Ventilation is a deliberate role of ambient air in place and is used primarily to control the indoor air quality by diluting and transmitting indoor contaminants. It can be used for thermal comfort or dehumidification purposes (Malone et al., 2012). Ventilation substitutes the IAQ level, reducing the density of harmful pollutants. The higher ventilation system is needed for improved health. It is rarely measured in schools, although inadequate ventilation is often suspected as an important condition leading to the signs of health (Malone et al., 2012).

Chapter 3 Methods and Materials

3.0 Methods and Materials:

This chapter aims to give an overview of how the research has been designed, planned and undertaken.

3.1 Research Design

This research design explains how the research within this undergrad thesis has been undertaken. The schematic overview of the methodology, the below figures, gives a visual idea of how it has been preceded.

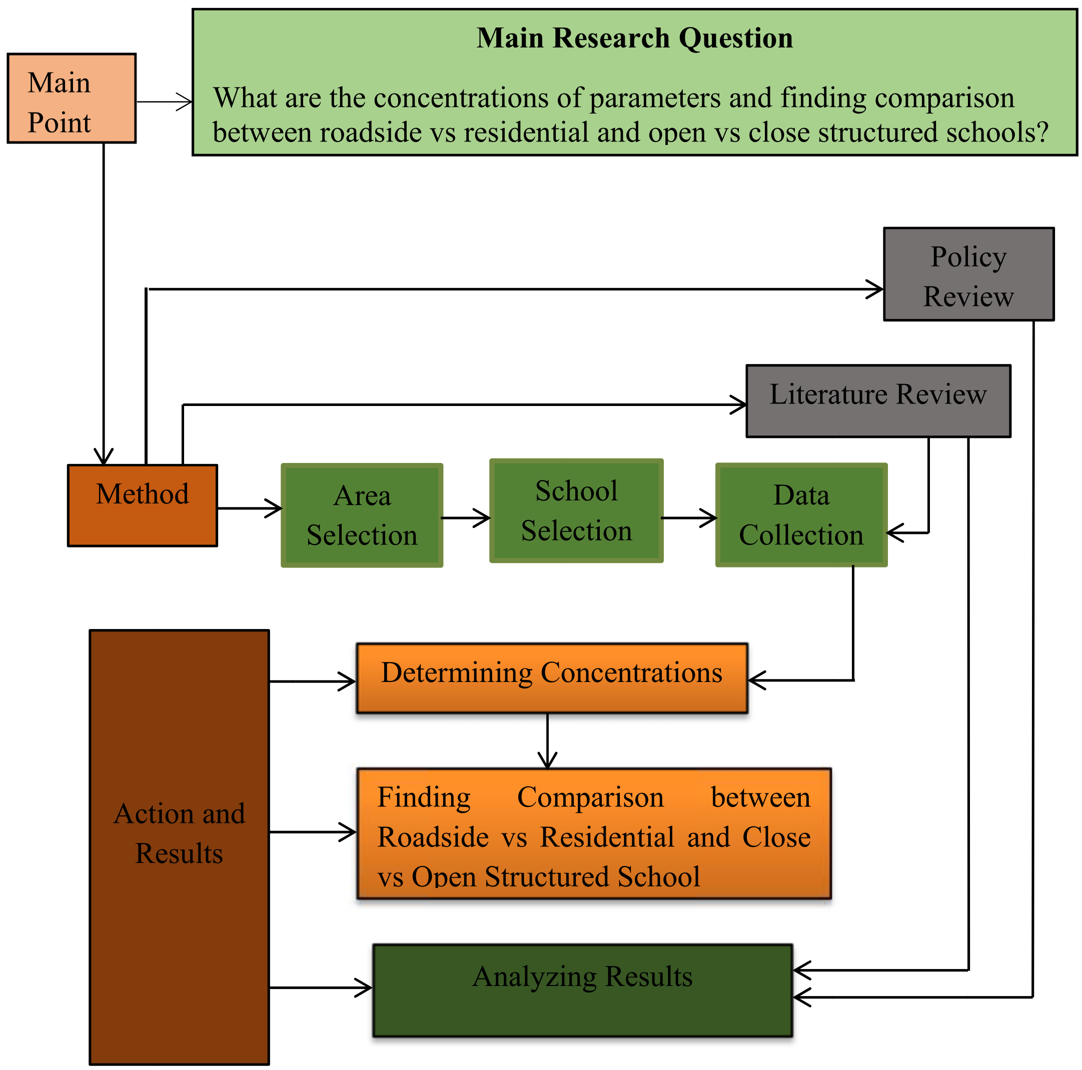


Figure 3.1: Schematic Overview of Methodology

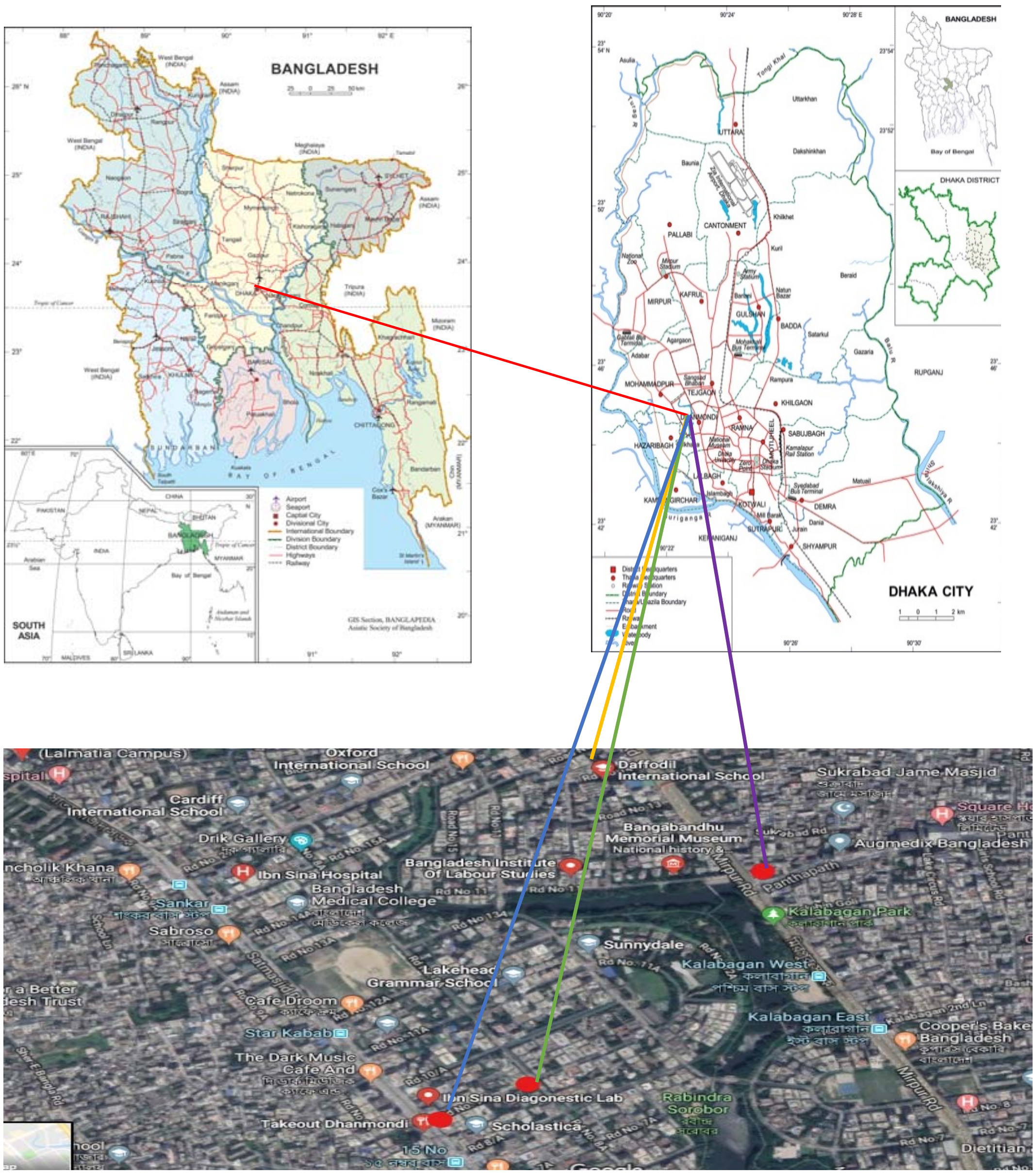
The main point of the research design has been the main research question of this research. The second part is, on the one hand primary data collection and reviews the relevant literature of existing international policy and WHO guideline. From the data collection part includes determining concentrations of parameter, finding comparison between roadside and residential areas school, finding comparison between close and open structured schools. On the other hand from literature review part also give clear idea of possible health impacts from indoor air quality parameters. From literature review and primary data collection identifies the most hazardous parameter.

3.2 Methods of Data Collection

This chapter aims to give an overview of how the research has been designed, planned and undertaken.

3.2.1 Study Area

The study focused on roadside and residential areas close structured and open structured school of Dhanmondi areas. Indoor air samples were taken randomly selected four schools during extreme summer season (April and May) for this study. Schools are located in Dhanmondi 32, 14A, 9A and 11A and 40 classrooms were in this assessment. Four schools are New Model High School, Daffodil International School, Stamford International School and Kakoli High School ((two schools are open(roadside and residential) and two are closed structured(roadside and residential)). New Model Multi-Lateral High School is situated at Road No- 32; Mirpur Road; Dhaka. It runs the classes from Playgroup to SSC. The working hour of this School is 8am-2.00pm. It is in the roadside area of Dhanmondi zone. It is 4 stored building having 6 classrooms in each floor. Monitoring was conducted in first, second and third floor and three rooms in every floor. Two corner rooms and middle room was taken for monitoring. The school has enough ventilation system and moderate trees around the school. Kakoli High School is situated at House no. 84, Road no. 11/A, Dhanmondi, Dhaka 1209. Working hour of this school is 8.00am- 2:00pm. It has fallen in Residential Zone. It has 3 stored building with each level having 5 classrooms. Three classrooms of every floor were taken for monitoring. There is too much ventilation system and trees around the Kakoli School. Daffodil International School is an English Medium School situated at House No. 11, Rd No.14, Dhanmondi, Dhaka 1209. It has 5 stored having 4 classrooms in each level. It runs the classes from playgroup to ‘O’ Level. It runs in 1 shift from 8am-2.00pm. It is in 50 meter away from roadside areas of Dhanmondi. Monitoring was conducted in third and fifth floor because of some limitation. This school is air conditioned and moderate trees around the premises. This school has no playground. Stamford International School is situated at House 36, Road 9/A, Dhanmondi, Dhaka. It is a 4 stored building with 4 classrooms in each floor with running playgroup to 'O' Level. The school's working hour is 8.00am- 2.00pm in one shift. It is in the residential zone of Dhanmondi. Monitoring was conducted in two rooms of first to third floor. This school is air conditioned and has no playground in the premises. All selected buildings were brick-walled with concrete floor assembly.



1. Daffodil International School
2. New Model Bi-Lateral High School
3. Stamford International School
4. Kakoli High School

Figure 3.2: Location of Four Schools

3.2.2 Data Collection

Using instrumental techniques, this study determined concentrations of CO_2, PM2.5, PM10 and HCHO along with temperature, relative humidity and status of ventilation system of the selected rooms. Combo Indoor Air Quality Meter had used for measuring the concentration of CO_2, relative humidity and temperature of the selected classroom. Flank meter had used for measuring the PM2.5, PM10 and HCHO of selected classroom. Sampling was taken on four working days for each school in the month of April to May 2018. The data measurement time was chosen from 8:00am to 2:00pm considering general schools hour from 8:00am to 2:00pm and as the day progresses, sunlight and carriage continued to grow, that's why concentration of pollutants also continued to increase. Air quality in the selected rooms was being taken once in every 2 hour on a random basis. The reference concentration of CO_2 was considered as 984ppm (Ferreira, Cardoso. 2014). ASHRAE Standard 62-1989 (1989) suggested indoor CO_2 levels not exceeding 1,000 ppm is in choosing the right ventilation for acceptable air quality. PM2.5 and PM10 reference concentration was taken 25µg/m^3 from WHO guidelines (WHO, 2006). Relative humidity reference was taken 30% to 60% (Wolkoff et al., 2007). Formaldehyde reference was taken from (Occupational Safety and Health Administration, 2009).

3.2.3 Flank Meter

During the study period flank meter was being used which can be detect formaldehyde, PM2.5, PM0.3, PM10, AQI, air temperature and humidity. Flank meter is a very efficient indoor air quality monitor which was broadly used in office, public area, non-dust workshop, biological technology, air purification area, providing air quality alert in school building. Flank meter have a professional electrochemical sensors which can be separately monitoring and effectively eliminate a variety of gases interference. Formaldehyde range: 0-5mg/m^3, PM2.5 range: 0-999µg/m^3; PM10 range: 0-999µG/m^3, PM0.3 range: 0-999µg/m^3, temperature range: 0-50C, humidity range: 0-90%RH. Big color LCD display with backlight, can use in dark areas. Rechargeable, Li-battery Powered, reusable and durable. Indoor concentrations of PM2.5, PM10, HCHO, Temperature and Relative Humidity can be recorded at every 5 to 10 min interval.

3.2.4 Combo Indoor Air Quality Meter

Combo Indoor Air Quality Meter is an indoor air quality measurement tool which is used for measuring concentration CO, CO_2, DPT, WBT, air temperature and relative humidity. In this research this tool is used for measuring CO_2, air temperature and relative humidity. Big LCD display with blue backlight to use in dark area. One click is needed for displaying CO_2, dew point temperature, wet bulb temperature, temperature, relative humidity, CO in turns. Standardizing limit: CO_2: 0 to 9999 ppm, CO: 0 to 1000 ppm, temperature: -20 to 60°C (-5~140°F), relative humidity: 0.1% to 99.9%, dew point temperature: -20.0 to 59.9°C, wet bulb temperature: -5.0 to 59.9. Accuracy of CO_2 is ±30ppm ±5% of reading (0 to 5000ppm), CO is +/-10ppm for less than 100ppm, temperature is ±0.6°C / ±0.9°F, relative humidity is ±3%RH (at 25°C, 10-90%RH); ±5%RH (at 25°C, other range). CO_2 working time: after 30 seconds. Answer time: (CO_2: <30 seconds, CO: <60 seconds, temperature : <2 minutes, relative humidity: <10 minutes) 90% step change. Working situation: -20 to 50°C (CO_2 sensor), 0 to 50°C (CO sensor), (avoid condensation) -20 to 60°C for other parameters. Storage condition: -20 to 60°C, 10 to 90%RH (avoid condensation). Power supply included AA x 4pcs or 9V adaptor which is not included. Battery survive more or less 24 hours (alkaline battery) and weight 200g.

3.3 Statistical Analysis

Microsoft excel was used to compare primary data from collected survey in the form of mean, maximum, minimum and standard deviation (Datta el al.2017)

4.0 Result and Discussion

4.0 Result and Discussion

This chapter provides details of the data collected from primary sources and possible impact of concentrations from secondary data. This chapter also analyses the results of different calculations under different assumptions. Among the indoor air pollutants monitored PM2.5, PM10 and CO_2 concentrations were found to be most significant in the classrooms. During the study period, CO_2 concentrations of closed structured schools classrooms were 2000ppm above almost every time. Particulate matter concentrations in roadside areas schools classrooms were higher than the residential areas schools. Both roadside and residential either closed or open structured schools PM concentration exceed the WHO guidelines.

4.1 Overall View of the all Indoor Air Parameters:

In this section, all the parameters of these research objectives have been discussed. Among other indoor air pollutants that studied in this research, CO_2 is one of the most hazardous pollutants. In this study, concentrations of CO_2 have been found much higher than the acceptable level in classrooms of close structured schools. Concentrations of CO_2 are much higher in classrooms of close structured schools located in both roadside and residential areas compared to those of open structured schools in the roadside and residential areas. For instance, in the New Model high school, which is located in an open structured roadside area, average concentrations of CO_2 in three different times in a day are found respectively 940ppm, 1015ppm and 909ppm and these values are mostly within the acceptable limit (Table 4.1). However, sometimes, the concentrations exceed the limit as the school is roadside. In the same school, the minimum concentration has been recorded as 598ppm against the maximum concentration of 1698ppm. On the other hand, Kakoli high school, which is also an open structured school but located in residential area, has shown even better results with the average concentrations recorded as 847ppm, 900ppm and 949ppm respectively during different time of observations. Concentrations of this school are acceptable. While maximum concentration has been recorded in classroom of this school as 1234ppm, which it exceeds the limit but still shows better result in comparison to New Model School. Therefore, open structured schools in residential areas are found to be better in terms of CO_2 concentration compared to that of open structured schools in roadside areas.

Table 4. 1 Distribution of Concentration of Pollutants in the Indoor Air of Different Schools on Different Time

Parameter		CO_2 ppm	PM2.5µg/m³	PM10 µg/m³	RH%	Temperature ºC	HCHO mg/m³
New Model	8 to 10am	940	82.81	117.26	66.11	30.55	0.038
	10 to 12pm	1015	88.84	123.6	65.77	31	0.037
	12 to 2pm	909	77.47	108.42	59.11	31.44	0.031
	Min	598	71.9	98.8	53	29	0.027
	Max	1698	108.23	150.7	73	33	0.046
Kakoli	8 to 10am	847	61.3	85.24	74.41	30.41	0.045
	10 to 12pm	900	63.625	86.84	81.66	32	0.038
	12 to 2pm	949	62.21	84.31	64.83	31.66	0.04
	Min	630	56.45	78	56	28	0.033
	Max	1234	68.4	93.3	90	32	0.05
Daffodil	8 to 10am	2064	103.85	143.35	71.10	27.5	0.05
	10 to 12pm	1970	128.35	178.96	73.60	27.8	0.0498
	12 to 2pm	1678	119.94	164.46	75.80	27.5	0.0505
	Min	1357	69.6	95.36	46	25	0.037
	Max	3450	184.55	257.15	86	29	0.069
Stamford	8 to 10am	2578.6	45.49	62.75	69.70	27.7	0.045
	10 to 12pm	2309	50.40	71.45	70.66	28	0.05
	12 to 2pm	2541	54.34	75.316	70.1	28.9	0.032
	Min	1375	33.15	46.1	53	27	0.023
	Max	3467	65.1	97.45	84	31	0.088
	Acceptable Level	1000ppm	25µg/m³	50µg/m³	30 to 60%	25 ºC	.1 mg/m³

On the other hand, maximum and minimum concentrations of CO_2 in close structured school in roadside areas, namely Daffodil school, has been found respectively 1357ppm and 3450ppm. Average concentrations in the day are recorded 2064ppm, 1970ppm and 1678ppm (in the break time). In Stamford school, a close structured school in residential area, minimum and maximum CO_2 concentrations are found 1375ppm and 3467ppm. Average periodical concentrations are recorded as 2578ppm, 2309ppm and 2541ppm. These two close structured schools show that CO_2 concentrations are very high with respect to acceptable limit and compared to open structured schools. As such, students in close structured schools are more exposed to high level of CO_2 concentrations. Probable reasons behind such results include: the rooms are air conditioned and these two schools doesn't have ventilation system. Lack of air circulation and ductless air conditioning system are resulting in high concentrations of CO_2 in these two schools. Therefore, students can be more susceptible to breathing problem, infectious respiratory illness and concentration breaking. To shorten, open structured or naturally ventilated school students are in the healthier environment than the close structured schools. CO_2 concentrations in the different schools and different periods of time are shown in the table 4.1.

Although concentrations of PM2.5 have been recorded more than WHO guidelines value for 24-h period in all classrooms of four schools, concentrations have been significantly higher in classrooms of roadside schools. In classrooms of New Model School, which is open structured and situated along road, average PM2.5 concentrations in three different times in a day have been found 82.81µg/m^3, 88.84µg/m^3 and 77.47µg/m^3 respectively (the table 4.1). At the same time, the maximum and minimum values have been found 108.23µg/m^3 and 71.9µg/m^3. Average concentrations in this school are 3 to 4 times higher than the acceptable limits (the table 4.1). In classrooms of open structured Kakoli School, located in residential area, average PM2.5 concentrations have been recorded 61.3µg/m^3, 63.625µg/m^3 and 62.21µg/m^3 in three different times. Maximum and minimum concentrations in the same school have been 68.4µg/m^3 and 56.45µg/m^3. Moreover, average PM2.5 concentrations of 103.85µg/m^3, 128.35µg/m^3 and 119.94µg/m^3 have been recorded in classrooms of closed structured and roadside Daffodil School in three different times of a day (the table 4.1). For the same school, the maximum and minimum PM2.5 concentrations have been184.5µg/m^3 and 69.6µg/m^3 respectively. Additionally, in classrooms of close structured Stamford School, which is located in residential area, average concentrations are recorded 45.49µg/m^3, 50.40µg/m^3 and 54.34µg/m^3. Maximum and minimum concentrations are found to be 65.1µg/m^3 and 33.15µg/m^3. To shorten, PM2.5 concentrations in classrooms of all fours schools, according to above data, exceed the WHO guideline values for 24-h period (the table 4.1). Above data also show clear distinction between roadside schools and residential schools where roadside schools are more vulnerable than residential areas school on the basis of PM2.5 concentration. It can further be concluded that classrooms of close structured school adjacent to road have the highest concentrations of PM2.5. This is because of deficiency of air circulation system. On the other hand, concentrations of PM2.5 are relatively lower in classrooms of close structured schools located in residential areas but still the concentrations exceed the WHO prescribed values. In general particulate matter comes from motor carriages, wood burning and fireplaces, dust from construction areas, landfills and farming areas, wildfires and waste burning, industrial emission, fly dust from open lands. In Dhaka city particulate matter generate from motor vehicles, building construction areas, road construction areas, dust from roadside and other dry open areas and industrial sources. Construction works and rapid transport causing high concentration of particulate matter in extreme summer season in Dhaka city. High concentrations of PM2.5 in the school classrooms can cause different types of air related illness as well as breaking concentration of students. It may responsible for lung disease worse, asthma attacks, bronchitis, edify it easier for people to get respiratory infections, responsible for uneven heartbeat or heart attacks of human who suffering heart disease.

Apart from higher PM2.5 concentrations, PM10 concentrations are also recorded significantly higher than the WHO guideline values for 24-h (table 4.1). PM10 concentrations in almost every classroom of all four schools are found higher than the acceptable level. Same like PM2.5 concentrations, PM10 concentrations in classrooms of roadside schools classrooms have been recorded much higher. In New Model School, a roadside side open structured school, concentrations of PM10 are measured as in three different times of the day as 117.26µg/m^3, 123.6µg/m^3 and 108.42µg/m^3 respectively. Maximum and minimum concentrations are recorded 150.7µg/m^3 and 98.8µg/m^3 (table 4.1). As heavy duty transports move frequently in this area, PM10 concentration is significantly higher in the New model School. the following table 4.1, concentrations of PM10 have been higher from 8:00am to 12:00pm. This is probably due to the movement of carriages, which is more during this period of the day compared to the rest of the day. In classrooms of Kakoli High School, which is open structured and located in residential area, average concentrations are measured as 85.24µg/m^3, 86.84µg/m^3 and 84.31µg/m^3 during three different times of the day. Maximum and minimum concentrations of PM10 have been 93.3µg/m^3 and 78.8µg/m^3 respectively. While concentrations of PM10 in Kakoli High School are relatively lower than New Model School but still not acceptable according to WHO standards. Daffodil school, which is a close structured school located adjacent to road, is the most vulnerable school identified in the study based on average concentration of PM10. Average PM10 concentrations in this school have been recorded 143.35µg/m^3, 178.96µg/m^3 and 164.46µg/m^3 in three different times of the day. Maximum and minimum concentrations were recorded 257.15µg/m^3 and 95.36µg/m^3 respectively. In close structured Stamford School, located in residential area, PM10 concentrations have been measured in three different times of the day as 62.75µg/m^3, 71.45µg/m^3 and 75.316µg/m^3 (the table 4.1). Maximum and minimum concentrations are found 97.45µg/m^3 and 46.1µg/m^3 respectively. Though it has crossed the acceptable level but classroom environmental and study condition of this school is far better than the other three schools classroom. Finally, it can be concluded, from the measured data, that Daffodil School is the unhealthiest school among the selected schools for the study based on PM10 concentrations. Pertinent reason behind such situation is the close structure of the school and its road side location, which result in high level of PM10 concentrations inside the classrooms of the school. In general particulate matter comes from motor carriages, wood burning and fireplaces, dust from construction areas, landfills and farming areas, wildfires and waste burning, industrial emission, fly dust from open lands. In Dhaka city particulate matter generate from motor vehicles, building construction areas, road construction areas, dust from roadside and other dry open areas and industrial sources. Construction works and rapid transport causing high concentration of particulate matter in extreme summer season in Dhaka city. It is very alarming issues that our school students of Dhaka city cannot get the healthy environment in the school. If today's students cannot get the healthy environment in the school, they can suffer from serious health problem in future as well as present too.

Human feel comforts within the relative humidity of 30% to 60%. But in this study we found comparatively higher in all schools classrooms though thermal comforts depends not only relative humidity. It's also depends on temperature too. From the data collection result we can be called quit good condition in New Model School. All other three schools relative humidity was relatively higher and averaged 70% above (table 4.1).

Since open structured school have enough ventilation, their classrooms relatively do not have higher temperature. Two open structured schools Kakoli High School and New Model School classrooms temperature was in 31 to 32 degree Celsius in extreme summer season. Two close structured Stamford School and Daffodil International School temperature average was in 27 to 28 degree Celsius (table 4.1). As the air conditioned classroom reduces the overall circulation of air in classrooms compared to the well ventilated classrooms. Air conditioned classrooms temperature should be 25 degree Celsius. But human thermal comfort depends not only on temperatures but also on relative humidity and other factors too.

Formaldehyde concentration is relatively very low in the all classrooms of the four schools but concentration was quit ok (table 4.1). In general, acceptable level of HCHO concentration is 0.1mg/m^3 (WHO, 2006). However, concentrations of HCHO have been recorded significantly well in all four schools (table 4.1).

4.2 Overall Indoor Air Quality:

In this section, most hazardous parameters of the research are being discussed. CO_2 and PM are identified to be the most hazardous among the parameters analyzed above. CO_2 concentrations on two close structured schools buildings are recorded significantly higher which might be attributed to its close entry door and lack of proper ventilation. Average CO_2 concentrations in Daffodil, Stamford, New Model and Kakoli schools have been recorded 1904 ppm, 2190ppm, 954ppm and 898ppm respectively. According to (Ferreira, Cardoso. 2014) and ASHRAE CO_2 concentration should not exceed 984ppm and 1000ppm in school buildings. However, standard deviation of CO_2 in Daffodil, Stamford, New Model and Kakoli schools have been found 909ppm, 542.9ppm, 318.4ppm and 178.15ppm respectively. Therefore, fluctuation and average CO_2 concentrations are much higher in the Daffodil and Stamford school where Stamford is the most vulnerable. However, concentration in New Model and Kakoli schools are well within the recommended limit during the study period but fluctuation is much higher in the New Model School. As such, it appears that naturally ventilated school buildings have significantly lower concentration of CO_2 inside the building compared to the air conditioned building.

Table 4. 2 CO_2, PM2.5 and PM10 Concentration on Different School

Parameter	New Model School	Kakoli School	Daffodil School	Stamford School	Acceptable Level
CO_2(±) ppm	954(318.4)	898(178.15)	1904(542.9)	2190(909)	984
PM2.5(±) $\mu g/m^3$	83.042(10.1)	62.40(2.62)	117.37(30.74)	50.08(7.68)	25
PM10(±) $\mu g/m^3$	116.39(14.59)	85.23(7.44)	162.25(42.52)	69.83(12.52)	50

Average PM2.5 concentrations in New Model, Kakoli, Daffodil and Stamford school have been recorded 83.042$\mu g/m^3$, 62.40$\mu g/m^3$, 117.37$\mu g/m^3$ and 50.08$\mu g/m^3$ respectively. According to WHO guidelines average concentration of PM2.5 is found to be significantly higher during the study period in all schools (WHO, 2006). All the four schools are in vulnerable as far as concentration of PM2.5 is considered. But the most notable part in this study is that roadside schools are at risk of higher PM2.5 concentrations than the residential areas school (table 4.2). Two roadside schools, i.e., New Model and Daffodil schools, have PM2.5 concentrations of 83.04 and 117.37µg/m³ respectively. Naturally ventilated New Model School is in a much better situation compared to the air conditioned Daffodil school. Lack of air circulation in Daffodil school and as it is only 50 meters away from the road, PM2.5 concentration is higher in Daffodil School (table 4.2). On the other hand, schools in residential areas, namely Kakoli and Stamford schools, have concentrations of 62.40µg/m³ and 50.080µg/m³ respectively. More importantly, here open structured school has higher PM2.5 concentration than the air conditioned school (table 4.2). As windows and doors are normally kept close in Stamford school, the likelihood of particulate matters entering into the rooms from outside is low. Moreover, PM concentration is relatively lower in the residential areas. In case of Kakoli School, particulate matters produced outside enters into the rooms through ventilation system. In summary, among these four schools, two schools in residential areas are relatively in better condition than the two schools in roadside areas where Daffodil is the most vulnerable school.

Averaged PM10 concentrations have been recorded in four schools are 116.39µg/m³, 85.23µg/m³, 162.25µg/m³ and 69.83µg/m³ respectively. According to WHO guidelines, PM10 concentrations in all these four schools are significantly higher (WHO, 2006). Same like PM2.5, concentration of PM10 is found to be significantly higher in the roadside areas schools than the residential areas schools (table 4.2). As the New model is located beside the very busy road of Dhanmondi and Daffodil is located only 50 meters away from very busy road of Dhanmondi, concentrations of PM10 are higher compared to that of residential areas Kakoli and Stamford school. However, among these four schools, average concentration of PM10 in Stamford school is relatively well though it exceeds the limit (69.83µg/m³) (WHO, 2006). On other hand, Daffodil school is the most vulnerable school on the basis of PM10 concentration. From the analysis of aforementioned three parameters, close structured and roadside areas Daffodil International School is the most vulnerable school as there all three parameters concentration were significantly higher and fluctuating too much (table 4.2). All other three schools also severely vulnerable but open structured residential areas Kakoli School can be called good as concentrations of CO_2 have been found satisfactory while PM2.5 and PM10 are also lower with less fluctuation then others. Open structured roadside areas New Model School's CO_2 concentration has been good but PM concentration has been significantly higher. In this school, fluctuations of both CO_2 and PM have been observed and

PM concentration found too much high. In close structured residential areas Stamford school, all three parameters are found to exceed the limit with high fluctuation (table 4.2).

4.3 Floor Wise CO_2, PM2.5 and PM10 Concentration

In this section, floor wise CO_2, PM2.5 and PM10 concentration was discussed.

Table 4. 3 Floor Wise Concentrations of CO_2, PM2.5 and PM10 in Different School

			Schools										
			New Model			Kakoli			Daffodil		Stamford			Standard
			F1	F2	F3	F1	F2	F3	F3	F5	F1	F2	F3	
Parameters	CO_2	8-10am	846.33 ±112.25	915.33± 176.66	1057.33 ±224.12	853±14	887.5 ±114.5	799 ±128	1844.33± 168.47	2282.33± 861.11	2673.5± 193.5	2529.5± 707.5	2487± 320.5	1000ppm (ASHRAE)
		10-12pm	982.33 ±253.5	1014±424.11	1047.3 ±467.13	854.5 ±0.5	872 ±126	972±258	1730.66± 208.48	2209.66± 654.86	2596±846	2489±727	1375± 180	
		12 - 2pm	867.6 ±155.24	1078.66 ±436.61	778.66 ±231.87	958 ±276	1045 ±35	841.5 ±218.5	1732±235.89	1624±304.43	2743±630	2690.5± 776.5	1839± 431	
		Mean	898.77	1002.66	961.111	888.5	934.83	870.83	1769	2038.667	2670.83	2569.66	1900.3	
	PM2.5	8-10am	85.45 ±9.93	78.68±4.66	84.31±1.96	59.45 ±3	63.62± 0.875	61.1±3	125.88±6.74	81.81±12.38	49.02±0.875	41.43±6.59	59.35± 3.6	25µg/m³ (WHO,2006)
		10-12pm	106.11 ±1.49	83.23±1.37	77.18±3.96	60.5± 0.15	63.25± 0.7	67.12± 1.275	159.45±17.95	97.25±25.67	45±4.65	49.93±6.90	62.65± 4.8	
		12 - 2pm	73.96 ±2.28	83.1 ±4.80	75.36 ±3.36	61.82 ±0.97	61.82 ±0.075	63±0.6	139.21 ±6.25	100.65 ±13.55	51.25 ±0.8	52.85 ±4.41	65±4.6	
		Mean	88.5	81.67	78.95	60.59	62.9	63.74	141.51	93.23	48.42	48.07	62.33	
	PM10	8-10am	120.33 ±15	109.83± 6.30	121.61± 6.13	82.825±3.07	89.07± 1.52	83.82± 5.82	174.4±10.46	112.31±16.85	68.45±1.1	56.08±7.35	71.35± 2.4	50µg/m³ (WHO,2006)
		10-12pm	148.35 ±1.79	116.8±1.14	105.3±4.87	77.55 ±9.35	87.67± 1.87	91.32± 0.1	220.7±26.20	137.16±36.044	63.3±7.4	69.65±9.60	93.2±5.6	
		12 - 2pm	103.56 ±3.73	116.4±6.21	105.36± 4.19	86.22 ±2.12	76.12± 9.57	88.92± 1.55	190.34±13.54	138.58±15.52	66.85±5.4	73.58±7.92	97.45± 7.4	
		Mean	124.08	114.34	110.75	82.2	84.29	88.025	195.14	129.35	66.2	66.43	87.33	

4.3.1 New Model School

According to ASHRAE CO_2 concentration in indoor occupied spaces should be less than 1000ppm. 1000ppm concentration indicates that air exchange system of building is well enough. Since New Model School is a naturally ventilated the CO_2 concentration was not exceed the permissible limit. Though sometimes it exceed but most of the time it was in control. Averaged first, second and third floor concentration has been recorded 898.77ppm, 1002.66ppm and 961.11ppm. Floor 1 concentration was recorded three times of the day 846.33ppm, 982.33ppm and 867.6ppm respectively. The study suggests that according to ASHRAE and (Ferreira, Cardoso. 2014) first floor of this school was in acceptable level and healthy condition in school building (figure 4.1 and 4.2). CO_2 concentration on second floor and third floor of this school was most of the time exceeded but not significant in number. Second floor concentration was recorded 915.33ppm, 1014ppm and 1078.66ppm respectively.

Averaged concentration of CO_2 was recorded in third floor respectively 1057.33ppm, 1047.33 and 778.66ppm. From this study we can identify that first floor is healthier condition than the second and third floor. Another finding was from 10:00am to 12:00pm is more vulnerable time in this school because of its located aside beside busy roadside. Carriages are moving more in this two hours and concentrations of CO_2 relatively more than the others period of time. On that time first, second and third floor concentration was recorded 982.33ppm, 1014ppm and 1047.33ppm. More notable matter is fluctuation (±253.57, 424.11 and 467.13) of CO_2 concentration on that time was more than the other situation (figure 4.1 and 4.2).

According to WHO guidelines PM2.5 concentration on indoor building should be less than 25µg/m³. While, an open structured extreme roadside areas New Model School exceeded its recommended limits. Averaged concentrations on three floors have been recorded 88.5µg/m³, 81.67µg/m³ and 78.95µg/m³ respectively. First floors concentration of PM2.5 on three different times of the day was recorded 85.45±9.93µg/m³, 106.11±1.49µg/m³ and 73.96±2.28µg/m³ respectively. Second floors concentration was recorded 78.68±4.66µg/m³, 83.23±1.37µg/m³ and 83.1±4.80µg/m³. Third floor concentration was recorded respectively 84.31±1.96µg/m³, 77.18±3.96µg/m³ and 75.36±3.36µg/m³. Study suggests that average concentration of PM2.5 was recorded 3 to 4 time higher than the recommended limits in different floors of the building and different times of the day (figure 4.3 and 4.4). Since an open structured school and located extreme roadsides concentration was significantly higher in this building.

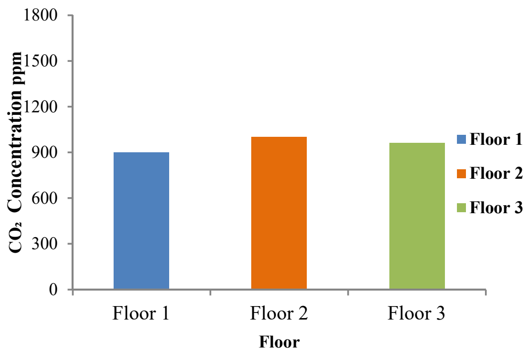


Figure 4.1 : CO_2 Concentration on Different Floor

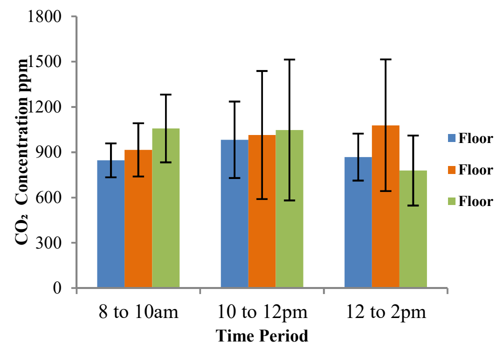


Figure 4.2: Floor Wise Concentration with Time

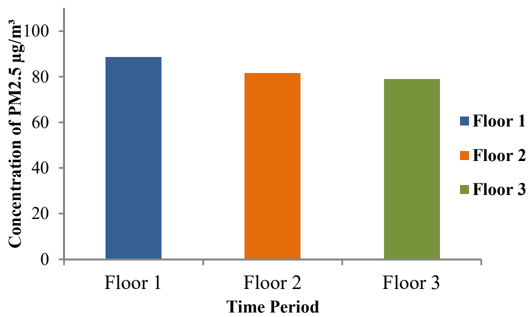


Figure 4.3: Floor Wise PM2.5 Concentration

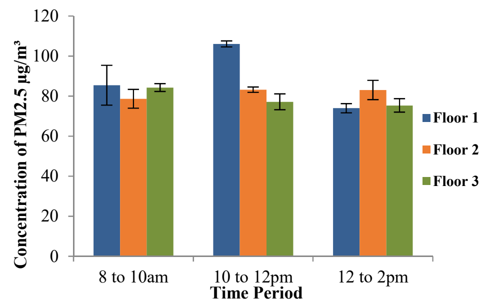


Figure 4.4: Floor Wise PM2.5 Concentration with Time

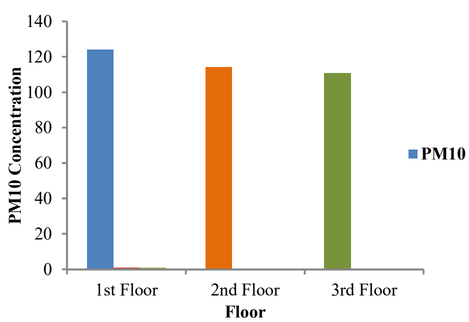


Figure 4.5: Floor Wise PM10 Concentration

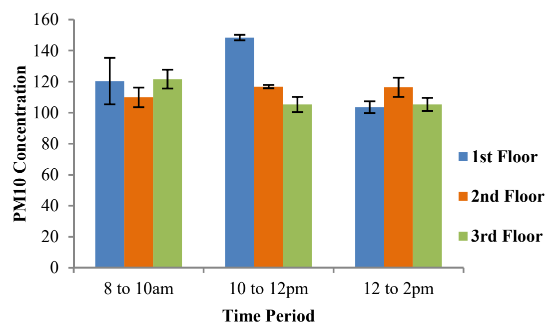


Figure 4.6: Floor Wise PM10 Concentration with Time

On the other hand, according to WHO guidelines PM10 concentration on indoor building should be less than 50µg/m³. While, an open structured extreme roadside areas New Model School exceeded its recommended limits. Averaged PM10 concentration was recoded in three floors 124.08µg/m³, 114.34µg/m³ and 110.75µg/m³. First floors concentration of PM10 on three different times of the day was recorded 120.33±15µg/m³, 148.35±1.79µg/m³ and 103.56±3.73µg/m³ respectively. Second floors concentration was recorded 109.83±6.30µg/m³, 116.8±1.14 µg /m³ and 116.4±6.21 µg /m³. Third floor concentration was recorded respectively 121.61±6.13µg/m^3, 105.3±4.87µg/$m^3$and 105.36±4.19µg/m^3. Study suggests that average concentration of PM10 was recorded 2 to 3 time higher than the recommended limits in different floor of the building and different times of the day (figure 4.5 and 4.6). Though fluctuation was not too much but concentration was too much high in this building. Maximum averaged concentration was recorded 148.35±1.79µg/m^3 in first floor which was 3 times more or less higher than the WHO recommended values (figure 4.5 and 4.6).

Because of being naturally ventilated school PM can easily enter the building. Since the building was located beside the busy roadside areas which may have contributed to higher concentration of PM. Because of high traffic in Dhaka city and enormous number of fuel burnt which makes more particulate matter in the roadside areas. As we know, in summer season huge number of dust create in Dhaka city because of dry season and lack of watering in the road which may have also contributed to higher concentration of PM in the roadside areas school.

4.3.2 Kakoli High School

Kakoli High School a residential areas another naturally ventilated school and sufficient tree covers surrounding its premises. According to ASHRAE and (Ferreira, Cardoso. 2014) CO_2 should not exceed 1000ppm in indoor occupied buildings. Averaged first, second and third floor concentration has been recorded 888.5ppm, 934.83ppm and 870.83ppm. The CO_2 concentration result of this school is satisfactory (figure 4.7 and 4.8). Floor 1 concentration was recorded 853ppm, 854.5ppm and 958ppm. Floor 2 was recorded 887.5ppm, 872ppm and 1045ppm respectively. Third floor was recorded 799ppm, 972pppm and 841.5ppm. Study suggests that CO_2 concentrations in all the three floor of the school was in acceptable limit most of the time during the study period. Fluctuation of CO_2 concentration was not high during the different times of the day. There is no significance difference among the three floors. Though averaged concentration on second floor in 12:00 to 2:00pm was relatively higher but the fluctuation was not too much (figure 4.7 and 4.8). However, the averaged CO_2 concentration in this school is well within the recommended limit. Though this school is located in residential areas but the concentration of PM2.5 was not recorded lower during the study period. Averaged concentrations of PM2.5 in three floors have been recorded 60.591µg/m^3, 62.9µg/m^3 and 63.74µg/m^3 respectively. Concentration on first floor was recorded 59.45±3µg/m^3, 60.5±0.15µg/m^3 and 61.82±0.975µg/m^3 respectively. Second floor concentration was recorded 63.62±0.875µg/m^3, 63.25±0.7µg/m^3 and 61.82±0.075 µg/$m^3$and third floor concentration of PM2.5 was 61.1±3µg/m³, 67.12±1.275µg/m³ and 63±0.6µg/m³. According to WHO guidelines PM2.5 concentration was recorded almost more than 2 times of acceptable level (figure 4.9 and 4.10). As a residential areas school and carriage are not moving more like roadside the concentration of PM2.5 was not fluctuating too much (figure 4.9 and 4.10). But the concentration was too much to make it severely unhealthy condition.

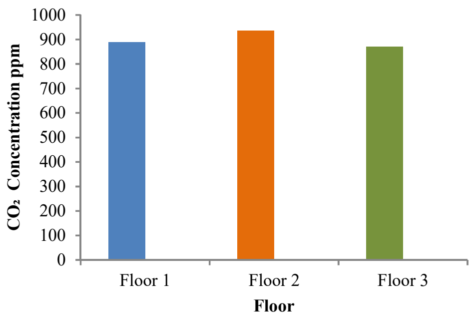


Figure 4.7: Floor Wise CO_2 Concentration

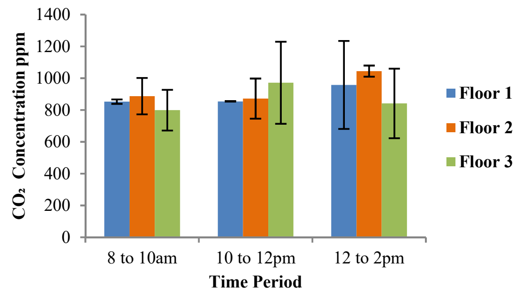


Figure 4.8: Floor Wise CO_2 Concentration with Time

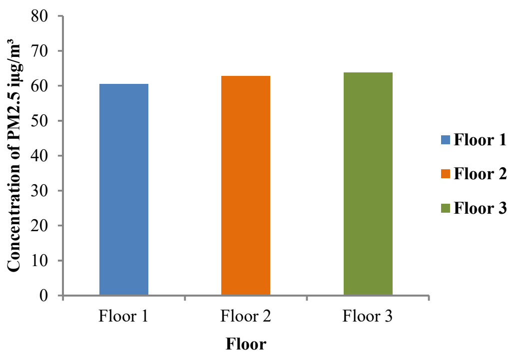


Figure 4.9: Floor Wise PM2.5 Concentration

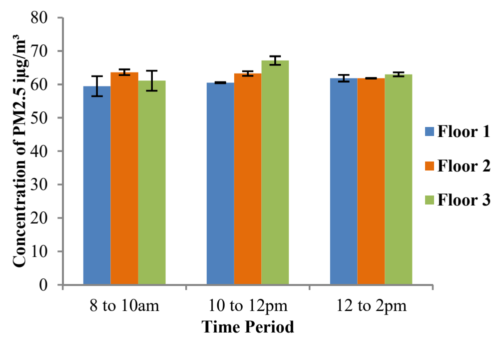


Figure 4.10: Floor Wise PM2.5 Concentration with Time

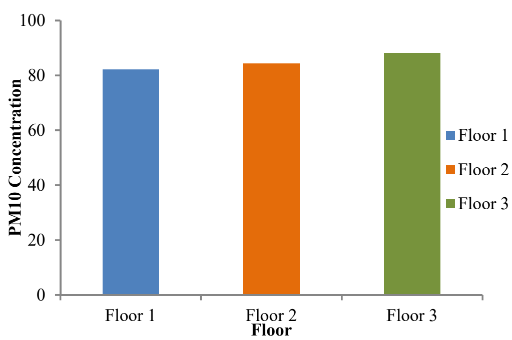


Figure 4.11: Floor Wise PM10 Concentration

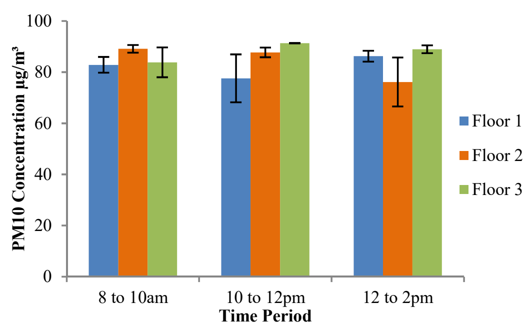


Figure 4.12: Floor Wise PM10 Concentration with Time

On the other hand, averaged PM10 concentration was recorded in three floors respectively 82.2µg/m³, 84.29µg/m³ and 88.025µg/m³. PM10 concentration on first floor was recorded

82.825±3.07µg/m^3, 77.55±9.35µg/$m^3$and 86.22±2.12µg/m^3 respectively. Second floor concentration was recorded 89.07±1.52µg/m^3, 87.67±1.87µg/m^3 and 76.12±9.57µg/m^3 and third floor concentration of PM10 was 83.82±5.82µg/m^3, 91.32±0.1µg/$m^3$and 88.92±1.55µg/m^3. According to WHO guidelines PM10 concentration was recorded higher than the acceptable level on every floor (figure 4.11 and 4.12).

As a residential areas school and carriage are not moving more like roadside the concentration of PM10 was not fluctuating too much (figure 4.11 and 4.12). But the concentration was too much to indicate it severely unhealthy condition.

4.3.3 Daffodil International School

Roadside areas close structured school and more vulnerable school than the other two open structured schools. Daffodil International School is a close structured and located near busy roadside areas in Dhanmondi. During the study period, measurement was conducted in third and fifth floor. Concentration of CO_2 in Daffodil school was recorded significantly higher (figure 4.13 and 4.14). Data measurement was taken in third and fifth floor which averaged concentration has been recorded 1769ppm and 2038.66ppm. Concentration was found in different times of the day on third floor respectively 1844.33ppm, 1730.66ppm and 1732ppm. Concentration of CO_2 was recorded in fifth floor 2282.33ppm, 2209.66ppm and 1624ppm respectively. According to ASHRAE this schools classrooms condition is unhealthy (figure 4.13 and 4.14). Ductless air conditioning systems make this school classroom more polluted. Ductless air conditioning system reduces the air circulation system of the building. Since this school has not enough ventilation system, concentration of CO_2 was recorded significantly higher. Study suggests that CO_2 concentration and fluctuation on fifth floor was significantly higher than the third floor (figure 4.13 and 4.14). However, both this floor is in unhealthy condition.

Averaged PM2.5 concentration was recorded in third and fifth floor 141.51µg/m^3 and 93.23µg/m^3. Concentration of PM2.5 in third floor was measured in three different times of the day respectively 125.88±6.74µg/m^3, 159.45±17.95 µg/m^3 and 139.21±6.25 µg/m^3. According to WHO guidelines PM2.5 concentration on indoor occupied building should be less than 25µg/m^3 but the concentration on third floor of Daffodil school found more than 5 to 6 times higher than the acceptable level (figure 4.15 and 4.16). In third floor highest averaged PM2.5 concentrations was recorded 159.45±17.95 µg/m^3 on 10:00am to 12:00pm which was more than 6times higher than the WHO guidelines and fluctuation of PM2.5 was too much high. On fifth floor, concentration was recorded 81.8±12.38µg/m³, 97.25±25.67µg/m³ and 100.65±13.55µg/m³ respectively.

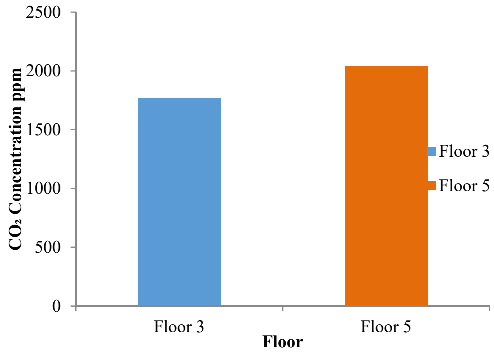


Figure 4.13: Floor Wise CO_2 Concentration

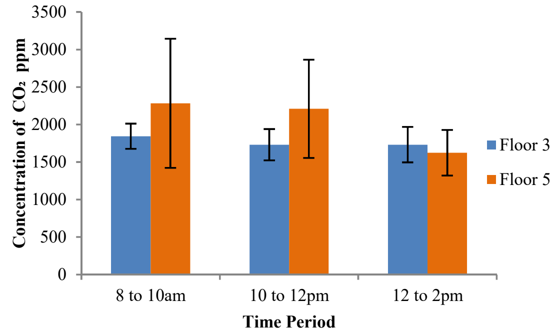


Figure 4.14: Floor Wise CO_2 Concentration with Time

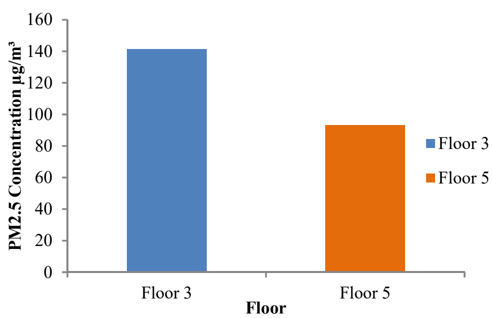


Figure 4.15: Floor Wise PM2.5 Concentration

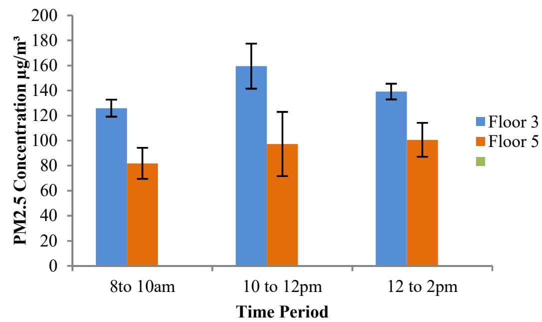


Figure 4.16: Floor Wise PM2.5 Concentration with Time

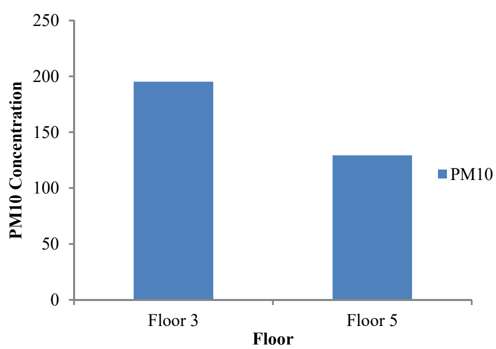


Figure 4.17: Floor Wise PM10 Concentration

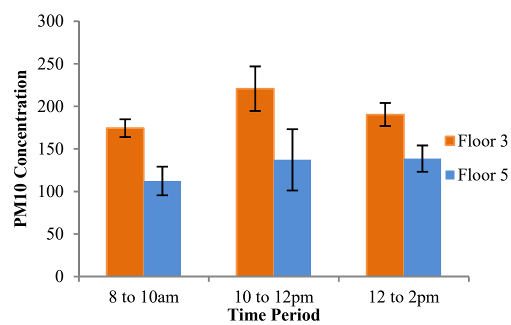


Figure 4.18: Floor Wise PM10 Concentration with Time

Though, concentrations were recorded lower than the third floor but it had also crossed the WHO guidelines and more than 3 to 4 times higher than the limit (figure 4.15 and 4.16).

However, third and fifth floor averaged PM10 concentration was recorded 195.14µg/m³ and 129.35µg/m³. Concentration of PM10 in third floor was measured in three different times of the day respectively 174.4±10.46µg/m³, 220.7±26.20µg/m³ and 190.34±13.54µg/m³.

According to WHO guidelines PM10 concentration on indoor occupied building should be less than 50µg/m³ but the concentration on third floor of Daffodil school found more or less than 3 to 4 times higher than the acceptable level (figure 4.17 and 4.18). In third floor highest averaged PM10 concentrations was recorded 220.7±26.20µg/m³ on 10:00am to 12:00pm which was more than 4 times higher than the WHO guidelines and fluctuation of PM10 was too much high. On fifth floor, concentration was recorded 112.31±16.85µg/m³, 137.16±36.044µg/m³ and 138.58±15.52µg/m³ respectively. Though, concentrations were recorded lower than the third floor but it had also crossed the WHO guidelines and more than 2 times higher than the limit (figure 4.17 and 4.18). As we know particulate matter consists of liquids and solids particle in the air and it can be carried out long distance through air and end up in ground and water (Meng et al., 2007). Near roadside areas PM comes from motor carriages and dust particles. As we know Dhaka is a city of traffic and that's the one reason why high concentration found in Daffodil school. Though, concentration should be less in close structured building but lack of air circulation system causing high concentration in this building. Because, once particulate matter enter the classroom it cannot free from rooms and it stay in rooms which causing high concentration. One important thing found that fluctuation was higher during the 10:00am to 12:00pm in both third and fifth floor (figure 4.15, 4.16, 4.17 and 4.18). Study suggests that, this schools health condition of students is the most vulnerable on the basis of PM.

4.3.4 Stamford International School

Stamford International School is residential areas close structured school and not has enough ventilation system which causing higher CO_2 concentration. Measurement was taken in first, second and third floor during the study period. Averaged CO_2 concentration on three floors has been recorded 2670.83ppm, 2569.66ppm and 1900.33ppm. Concentration of CO_2 in three different times of the day in first floor was 2673.5ppm, 2596ppm and 2743ppm respectively. Concentration on second floor was 2529.5ppm, 2489ppm and 2690.5ppm. Concentration on third floor was 2487ppm, 1375ppm and 1839ppm. Study suggests that all three floor of this school classrooms CO_2 concentration was significantly higher (figure 4.1 and 4.20). Fluctuation of concentration was much higher in the first and second floor. Though concentration on third floor was relatively lower but many more time of this floor class was not taken. Study also suggests that this school is the most vulnerable school on the basis of CO_2 concentration among other schools.

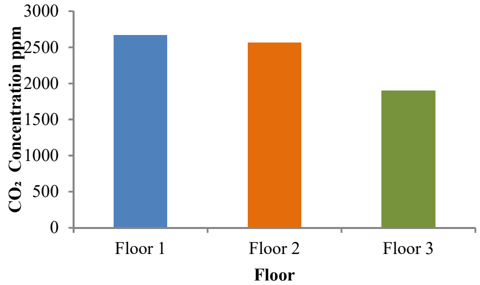


Figure 4.9: Floor Wise CO_2 Concentration

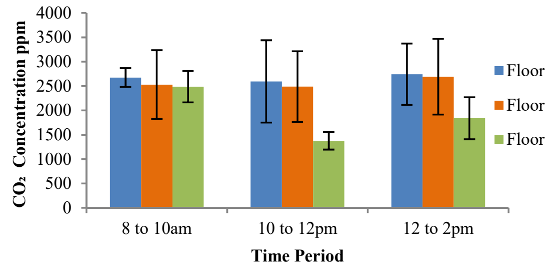


Figure 4.10: Floor Wise CO_2 Concentration with Time

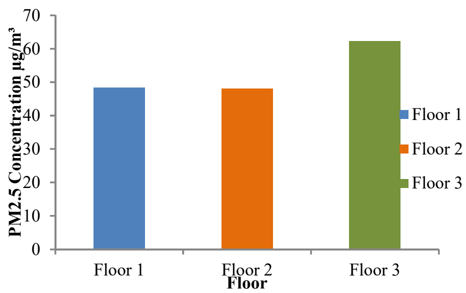


Figure 4.21: Floor Wise PM2.5 Concentration

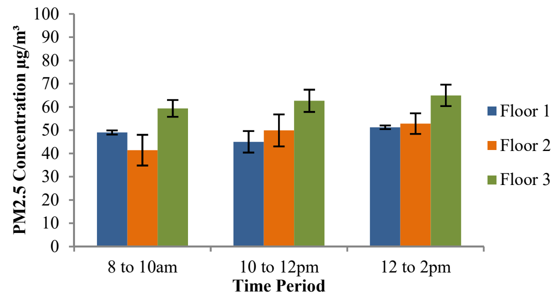


Figure 4.22: Floor Wise PM2.5 Concentration with Time

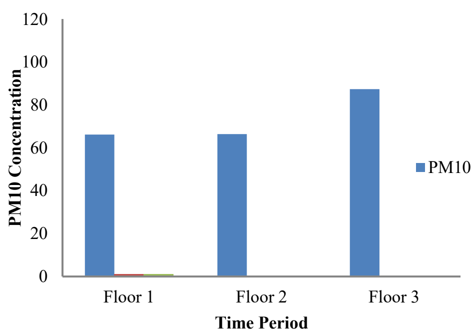


Figure 4.23: Floor Wise PM10 Concentration

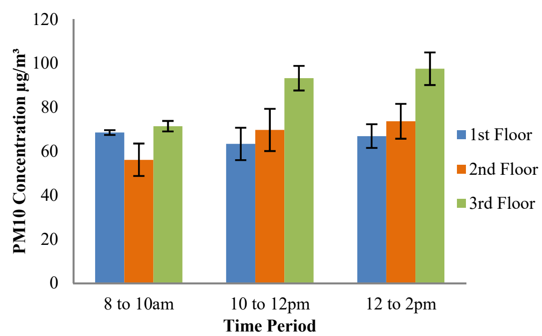


Figure 4.24: Floor Wise PM10 Concentration with Time

There was no classroom found in this building that concentration less than 1000ppm. The average concentration of each floor in a sampling period reached more than about 2.5 times than the maximum recommendation value according to ASHRAE and (Ferreira, Cardoso. 2014) (figure 4.19 and 4.20). The lowest value was recorded in third floor on 10:00am to 12:00pm which time classes was not regularly held on this floor. Ductless air conditioning system of this school classroom reduces the air circulation system and makes it more polluted.

Concentration of averaged PM2.5 on three floors was recorded 48.42µg/m³, 48.07µg/m³ and 62.33µg/m³. Concentration of PM2.5 was recorded on first floor 49.02±0.875µg/m³, 45±4.65µg/m³ and 51.25±0.8µg/m³ in different times of the day. Concentration on second floor was recorded 41.43±6.59µg/m³, 49.93±6.90µg/m³ and 52.85±4.41µg/m³ respectively. Concentration on third floor was recorded 59.35±3.6µg/m³, 62.65±4.8µg/m³ and 65±4.6µg/m³ respectively. Concentration of PM2.5 on all three floors found more or less 2 times higher than the WHO guidelines (WHO, 2006) (figure 4.21 and 4.22). Though concentration on first and second floors was relatively lower than the third floor but concentration breaks the WHO guidelines (figure 4.21 and 4.22). In this building fluctuation and concentration of PM2.5 was not higher like the Daffodil school. Study suggests that, this buildings PM2.5 concentration is lower than the other three schools in the study. Among other schools on the study, this schools health condition is much better though this concentration don't recommend as healthier condition.

However, three floors averaged PM10 concentration was recorded 66.2µg/m³, 66.43µg/m³ and 87.33µg/m³. Concentration of PM10 on first floor was recorded 68.45±1.1µg/m³, 63.3±7.4µg/m³ and 66.85±5.4µg/m³ in different times of the day. Concentration on second floor was recorded 56.08±7.35µg/m³, 69.65±9.60µg/m³ and 73.58±7.92µg/m³ respectively. Concentration on third floor was recorded 71.35±2.4µg/m³, 93.2±5.6µg/m³ and 97.45±7.4µg/m³ respectively. Concentration of PM10 on all three floors found higher than the WHO guidelines (WHO, 2006) (figure 4.23 and 4.24). Though concentration on first and second floors was relatively lower than the third floor but concentration breaks the WHO guidelines. In this building fluctuation and concentration of PM10 was not higher like the Daffodil school. Study suggests that, this buildings PM10 concentration is lower than the other three schools in the study. Among other schools on the study, this schools health condition is much better though this concentration don't recommend as healthier condition.

4.4 Particulate Matter Concentration Difference between Rainy and Normal Day

There is a huge differences found in concentration of PM2.5 on a rainy day and normal day. 2first April 2018 in Dhaka city, it was little raining in early morning. During this day data was collected from Kakoli high school. Because of little rain there found a significant lower concentration of PM2.5 than a normal day. After rain, the days three time concentration was recorded 37.15µg/m³, 40.33µg/m³ and 44.766µg/m³ respectively. While in a normal sunny day PM2.5 concentration was recorded 85.633µg/m³, 86.916µg/m³ and 80.93µg/m³ respectively. In a normal sunny day PM2.5 concentration was more than 2 times higher than the after raining day concentration (figure 4.25). Another important issue in a study that after sunrise and day progressing on a rainy days the concentration was increasing gradually.

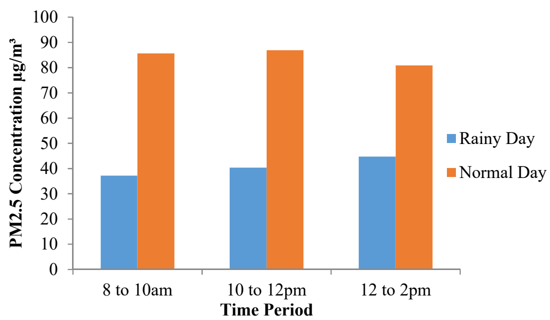


Figure 4.25:PM2.5 Concentration in a Rainy and Normal Day

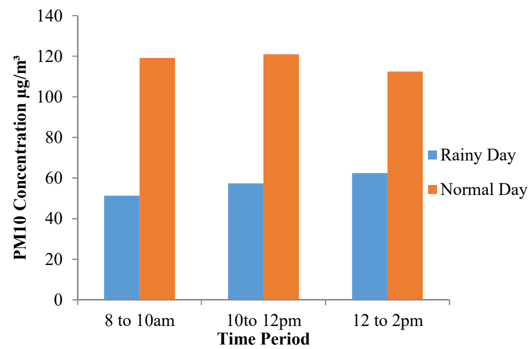


Figure 4.26: PM10 Concentration on a Rainy and Normal Day

Concentration of PM10 was recorded in a rainy day on Kakoli School respectively 51.3µg/m³, 57.45 µg/m³ and 62.45 µg/m³ (figure 4.26). On that day, 20 to 25 minute raining after 8:00am. In a normal day concentration was recorded 119.18µg/m³, 120.95µg/m³ and 112.516µg/m³ respectively. In a normal day concentration was significantly higher than the after raining day concentration and it was two times higher than the rainy day concentration (figure 4.26). Because of little rain dust particle become wet and this particle couldn't move which turned the rainy day concentration lower. Immediate after rain, concentration was found 51.3µg/m³ which was nearly acceptable level according to WHO guidelines. Than in 10:00am to 12:00pm concentration was recorded 57.45µg/m³ which was much higher than the morning concentration. While, 12:00pm to 2:00pm concentration was recorded 62.45µg/m³ which was exceeded previous two concentrations record. As the day progressing in a rainy day, the concentration was increasing gradually. Because of little rain dust particle and other particle become wet and couldn't move and as the day progressing particles become dry and concentration was increasing gradually.

Chapter 5 Conclusion

5.0 Conclusion

Students spend most of the time in the indoor environment in a day and a major period of time they spend in their school buildings. So it is very important to maintain environmental quality in the school classroom for the purpose of making more productive students. In this study, in extreme summer season CO_2, PM2.5 and PM10 concentrations were mainly monitored along with HCHO, temperature and relative humidity in the four schools on the basis of roadside areas, residential areas open structured and close structured. Among the indoor air pollutants monitored CO_2 and PM concentrations were found more significant. Since there were no significant indoor sources for emission human activity is responsible for this higher concentration of CO_2. CO_2 concentration was higher in the close structured schools classrooms because of CO_2 from classrooms occupants and lack of ventilation system. PM concentration was higher in the roadside schools classrooms because of particle emission from outdoor traffic, construction activity and dust from roadsides or open areas. Though in roadside and residential areas school either open structured or close structured PM2.5 and PM10 concentrations exceeded the acceptable limit in the all classrooms according to WHO guidelines. This research indicates that there is a need of regular air circulation in close structured building for improving air quality. This excessive CO_2, PM2.5 and PM10 concentrations can definitely negatively affect the health of students and degrade the performance of students as well as teachers too. So the output of this study point out that better management strategy for monitoring and controlling indoor air pollution in the school classrooms.

Chapter 6 References

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Photo 1: Data Measurement in Kakoli High School

Photo 2: Data Measurement in Stamford International School

Photo 3: Data Measurement in New Model Bi- Lateral High School

Photo 4: Data Measurement in Daffodil International School

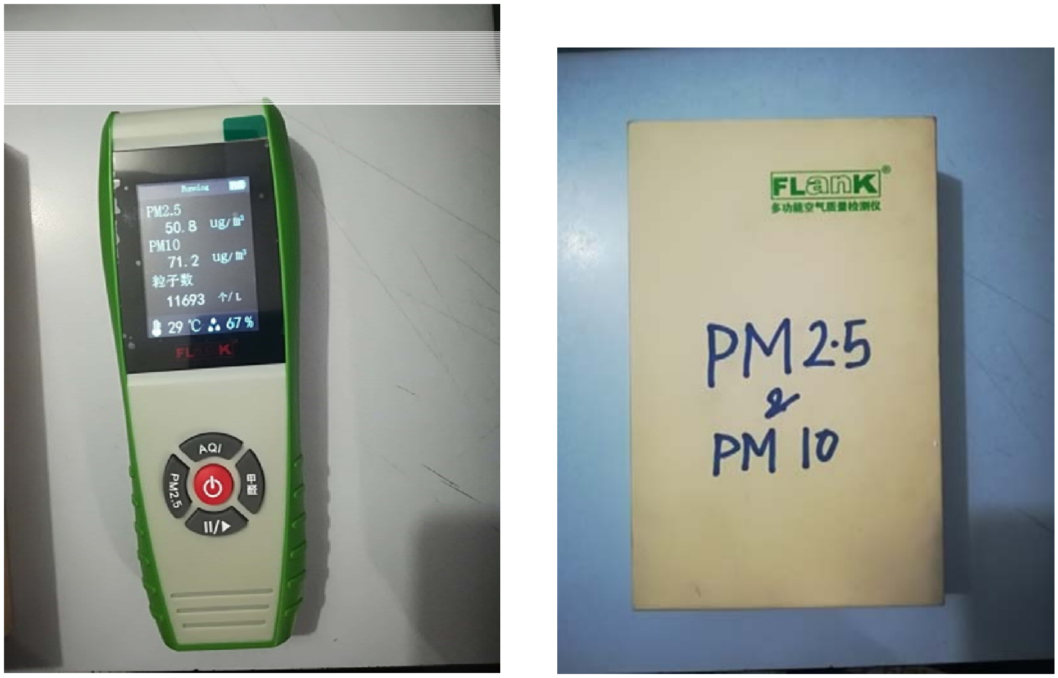

Photo 5: Flank Meter

Photo 6: Combo Indoor Air Quality Meter