Research on the Impacts of Building Height on the Concentration of Indoor Particulate Matter

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Abstract

Indoor particulate matter is an important indicator assessing indoor air quality (IAQ) around the world because the adverse health impacts of exposure to particles suspended in the air have been proved by several epidemiological studied. Recently, the indoor air quality and indoor particulate matter concentrations were increasingly emphasized. The objective of this study was to explore the impacts of building height on the indoor particulate matter concentration. Therefore, measurements of the concentration of fine particulate matter were simultaneously and continuously carried out in different floors of Atlas residence in winter in London through the low-cost instruments. In addition to this, the usage steps and working principles of instruments also were studied in this paper. The result showed that there was no obvious relationship between indoor particulate matter concentrations and building height according to $R^2$ coefficient. Although there were some deficiencies in this paper that should be improved in the future, the findings also can provide meaningful reference to further study on the factors affecting indoor particulate matter concentrations.

Keywords: indoor particulate matter concentrations; building height; indoor air quality;

1. Introduction

Air pollution caused by particulate matter (also referred to as PM or particle pollution) has been as one of the most seriously environmental problems around the world due to the rapid development of industrialization and urbanization (Han et al., 2014). In addition to this, many researches revealed that industrial activities caused by economic development, including energy production, road traffic and household combustion have been identified as main emission sources of multiple pollutants (Rovira et al., 2020; Prüss-Üstün et al., 2016). It is well known that there is closed relationship between air pollution and adverse effects on respiratory health (Ciccone et al., 1998). According to the world health organization (WHO) in 2012, the...
number of deaths from air pollution (PM and O₃) for both indoor and outdoor environments was approximately 6.5 million, accounting for 11.6% of all deaths in the world (WHO .2016a). Apart from this, Stanaway et al. (2018) also predicted that the number of deaths from air pollution may increase with time. Therefore, the health effects of air pollution have attracted attention from scientific community.

Recently, the health impact of outdoor air pollution has been widely studied and analysed and numerous researches have shown that most people believe that the risk of poor outdoor air quality is much higher than the risk of indoor pollution (Jones et al., 1999; Austin et al., 2002). However, with the improving health awareness, public concern over the health impacts of indoor air environment is also increasing. A result from the investigation of time distribution of American residents showed that individuals spent their most time (around 88%) of a day on indoor environment and less time (around 7%) on the vehicle. Only few time (around 5%) were spent on the outdoor environment (Robinson and Nelson, 1995). Therefore, the problem of people’s indoor-air quality is important and should be studied.

In this study, indoor measurements of PM₂.₅ and PM₁₀ were simultaneously carried out at the Atlas residence floors 28 and 7 from 28th January 2020 to 10th February 2020, using portable instrument, namely BME280-arduino. The purpose of present article was to explore the impact of building height on indoor particulate matter concentrations (PM₂.₅ and PM₁₀).

2.Methodology

2.1 Study area

In this paper, the measurements of PM were carried out in different floors (7 and 28) of Atlas residence located at the heart of London from the period between 28th January 2020 and 10th February 2020. Detailed information are given in Fig.1 according to website:https://www.kcl.ac.uk/study/accommodation/residences/atlas#ad-image-16.
Indoor particulate matter was as the primary monitoring object in this research due to its adverse effects on health conditions and it was described from the United States Environmental Protection Agency (EPA) as a complex mixture of solid or/and liquid particles suspended in the air such as PM$_{2.5}$ and PM$_{10}$. The main differences between these two suspended particles are size, shape and composition. For example, the PM$_{2.5}$ generally denotes that it includes all particular matter that have an aerodynamic diameter of 2.5 microns or smaller and the PM$_{10}$ can be also defined as the coarse particles with the aerodynamic diameter of 10 microns or smaller (Sun et al., 2006). Typically, the size of a human hair is about 35 times of 2.5 microns and the visual comparison are given in Fig.2 from irCELine (http://www.irceline.be/en/documentation/faq/what-is-pm10-and-pm2.5). According to WHO, the unit of concentration of these particles is micrograms (one-millionth of a gram) per cubic meter air or µg/m$^3$. 

2.2 Monitoring Objects
Figure 2 The size comparison between PM$_{2.5}$, PM$_{10}$ and human hair.

Apart from this, temperature is another object measured by sensor and the unit of it is Kelvin. The purpose of temperature measurement is to study the impact of indoor temperature change with a day on the indoor PM concentration.

2.3 Working principle of sensor

In this paper, the instrument measuring PM and temperature was mainly composed of Digital universal particle concentration sensor (PLANTOWER), BME280 sensor with Arduino, SD card and battery system. The photograph is given in Fig.3.
According to 2016 product data manual of PLANTOWER, PMS5003 used in present study is a kind of digital and universal particle concentration sensor. The main function of this sensor is to measure the concentration of particles in the air and then output them using digital interface. In addition to this, the main features of it are zero false alarm rate, real-time, correct data, minimum distinguishable particle diameter: 0.3 micro-meter, high anti-interference performance and optional direction of air inlet and outlet. Therefore, this sensor can be easily used into many instruments measuring suspended particles in the air to provide correct concentration data in time. Apart from this, the working principle of it is laser scattering. Firstly, scattering can be produced by using laser to radiate suspending particles in the air. Secondly, the certain degree of scattering light can be collected and then the curve of scattering light change with time can be obtained. In the end, microprocessor based on MIE theory can accurately calculate the diameter of equivalent particle and the number of particles with different size per unit volume through this curve. The details of the working process are given in Fig.4 from the website: https://www.aqmd.gov/docs/default-source/aq-spec/resources-page/plantower-pms5003-manual_v2-3.pdf.

![Functional block diagram of sensor](https://via.placeholder.com/150)

**Figure 4 Functional block diagram of sensor**

The measurement of indoor temperature was using BME280 Temperature, Humidity & Pressure Sensor with Arduino, which consists of extremely compact metal-lid LGA packages. According to Last Minute ENGINEERS (https://lastminuteengineers.com/bme280-arduino-tutorial/), the main functions of this precision sensor are to measure temperature ranging from -40°C to 85°C (±1.0°C accuracy), barometric pressure ranging from 300hPa to 1100hPa.
(±1hPa accuracy) and humidity ranging from 0 to 100% (±3% accuracy). In addition to this, the main feature of this sensor is that it has low power consumption. For example, the BME280 sensor consumes less than 1mA during measurement and only 5 μA during idle periods. Therefore, it is suitable to be used for continuously monitoring of indoor environment. Moreover, the working principle of it is based on proven sensing principles and then the temperature, humidity & pressure data can be obtained through issuing simple commands based on Adafruit BME280 Library. In this paper, read temperature function was used to read the temperature data from BEM280 module.

Moreover, the purpose of SD card is data storage and the working principles of it is that a small electrical current from the sensor moves electrons in the memory chip, which builds the correlation between the digital patterns stored on the chip and data.

As for the battery system in this study, the batteries were used for providing energy to continuous indoor monitoring during the period of two weeks.

2.4 Experiment design

In this paper, 7 and 28 floors of Atlas residence were selected as sampling place in order to explore the impact of the building height on indoor PM concentration. Generally, the room size is main factor affecting indoor air flow that plays an essential role in indoor fine particle concentration (Zhao et al., 2004). Therefore, indoor measurements of PM concentration were simultaneously carried out in the similar size rooms of Atlas residence (around 25 square meters). In addition to this, the measure instruments were installed on the south window of the bedroom. The main reason was that the particulate matter concentration measured in bedroom is relatively accuracy with less interference of human factors that include different usage and frequency of combustion activities such as burning of candles, use of fireplaces and cigarette smoking in these two rooms (Zhang and Morawska, 2002).

As for the measurement process, the calibration of two sensors was not able to carry out theoretically and the reason is that PM found indoors was resulted from skin, cooking, combustion activities and outdoor air flows, which is different with emission sources of outdoor PM (Howard-Reed and Polidori, 2006). However, the modified calibration was carried out in this research. Initially, two sensors were put together to measure the same environmental condition on January 28th 2020 and then the data from two sensors were plotted. If the result showed high R² coefficient, the calibration of sensors was completed. After simple calibration, the sensors began to measure the indoor particulate matter and temperature of two rooms (7 and 28 floors) on January 29th 2020. The measurements were carried out every fifteen minutes.
In the end, the measurements were finished on February 10th 2020 through turning off the instruments switch.

3. Analysis

The comparison between the data recorded from two sensors in the 28 floors room was made on 28th January 2020 in order to determine that comparison of data from two different sensors was accurate, rigorous and meaningful. The purpose of this step was to verify the validity of the data and the plotting result was given in Fig. 5.

![Figure 5 The data comparison of two sensors on 28th January 2020](image)

As can be seen from the Fig.5, the two sets of data from different instruments showed a high degree of similarity by R² coefficient = 0.9931, which was as the base of further comparison. In this paper, 24-hour concentration was used and there were two reasons. One of reasons was that 24-hour concentrations of Indoor PM$_{2.5}$ was one of international standards established by the United States Environmental Protection Agency. Therefore, the data were processed to 24-hour concentration, which was easily to compare quantitatively. In addition, minimizing impacts of human activities was another reason because different people have different life pattern during a day that may lead to temporary increase in PM concentration. The data of every 15 minutes was hard to analysis.
Figure 6 The comparison of PM$_{2.5}$ concentrations from two sensors from 29$^{th}$ January 2020 to 10$^{th}$ February 2020.

Fig.6 showed that 24-hour PM$_{2.5}$ concentrations from 7 and 28 floors were no significant difference and the $R^2$ coefficient (0.0571) also determined this result. According to Table 1, the averages of indoor PM$_{2.5}$ concentrations from two sensors over the period from 29$^{th}$ January 2020 to 10$^{th}$ February 2020 were similar, which were 11.7518 µg/m$^3$ of 28 floor room and 12.2010 µg/m$^3$ of 7 floor room.

Table 1 The average data of PM$_{2.5}$ concentration

<table>
<thead>
<tr>
<th>Data</th>
<th>Concentration of Room 1(µg/m$^3$)</th>
<th>Concentration of Room 2(µg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020.1.29</td>
<td>9.7052</td>
<td>11.4376</td>
</tr>
<tr>
<td>2020.1.30</td>
<td>11.5729</td>
<td>10.5812</td>
</tr>
<tr>
<td>2020.1.31</td>
<td>21.3229</td>
<td>12.6573</td>
</tr>
<tr>
<td>2020.2.1</td>
<td>6.4062</td>
<td>9.7863</td>
</tr>
<tr>
<td>2020.2.2</td>
<td>6.2758</td>
<td>10.8342</td>
</tr>
<tr>
<td>2020.2.3</td>
<td>12.6539</td>
<td>8.7642</td>
</tr>
<tr>
<td>2020.2.4</td>
<td>10.2643</td>
<td>10.7463</td>
</tr>
<tr>
<td>2020.2.5</td>
<td>9.4682</td>
<td>16.5487</td>
</tr>
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<td>2020.2.6</td>
<td>13.3682</td>
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<td>13.7135</td>
</tr>
<tr>
<td>2020.2.8</td>
<td>17.5638</td>
<td>11.4969</td>
</tr>
</tbody>
</table>
As can be seen from Fig. 7, 24-hour PM$_{10}$ concentrations showed similar result compared with PM$_{2.5}$. There was no obvious difference of concentrations between different floors and the $R^2$ coefficient was 0.0396. In addition, the overall average of PM$_{10}$ were 12.5163 µg/m$^3$ and 13.0323 µg/m$^3$ respectively.
Figure 8 The relationship between indoor temperature change with a day and indoor PM2.5 concentration

Fig 8 showed that there was no significant correlation between temperature change and indoor PM$_{2.5}$ concentration and the $R^2$ coefficient was 0.0696.

4. Discussion

4.1 Result analysis

This study revealed that building height was not the main factor affecting the concentration of Indoor particulate matter. In addition, the PM concentration of these two rooms was below 24-hour international standard ($35 \mu g/m^3$). Therefore, the reason for this result may be that the impacts of the building height cannot be reflected at low concentration. Moreover, this study also suggested that the concentration of indoor PM$_{2.5}$ was not changed with indoor temperature. However, this result was not accurate because air-conditioner was worked in indoor environment for a long time in winter of London. Most of data on indoor temperature from two rooms were ranged from 20 °C to 25 °C during a day, which could not be affected by the change of outdoor temperature.

4.2 Comparison with alternative instruments

As for monitoring of indoor fine particle concentration, the TSI SidePak AM520 is one of common alternative instruments. The main functions of this sensor are real-time mass concentration measurement and data logging. Moreover, the main advantages are that it is smaller than the PLANTOWER used in this study and is robust enough to survive rougher use
in industry (from FRONTLINE Safety: https://www.frontline-safety.co.uk/blog/hsi-sidepak-am520-what-are-the-features-and-benefits/). However, the main disadvantage is that it is not able to use in continuous monitoring because it needs to be recharged.

As to monitoring of indoor temperature, Q-Trak Indoor Air Quality model 7575 is one of common temperature monitors (Lee and Chang., 2000). In comparison with BEM280, the main advantages are Bluetooth communications for transferring data, RAKPRO™ data analysis software and more monitoring objects including CO₂ & CO from the website: https://tsi.com/products/indoor-air-quality-meters-instruments/indoor-air-quality-meters/q-trak-indoor-air-quality-monitor-7575/. However, the price of this sensor is more expensive compared with BEM280 and these two alternative instruments are not able to combine together.

4.3 Assessment and improvement

Recently, the low-cost equipment composed of BEM280 was used for meteorological monitoring (Carranco et al., 2017). The purpose of this research was to study the accuracy of the weather data collected by low-cost equipment. There were two advantages in this research. One was that the Bosch BME280 sensor was installed near by the HMP155 and PTB330 sensors located at Automatic Weather Stations (AWS), which resulted that the same data sources at the same time were measured by different sensors. In addition to this, another advantage was that the data coming from the Bosch sensors were corrected using an adjustment value and then the degree of accuracy of the low-cost sensor data were assessed through statistics caused by plotting data signals. These advantages played an essential role in the reliability and accuracy of the research analysis.

Therefore, there are some weaknesses in present research that need to be improved in the future. The conclusion of the paper lacks reliability compared with the Carranco’s study. In the future, the measurements should carry out in the unoccupied rooms, which can be as blank control group to eliminate interference from human activities. Moreover, the measurements should be carried out in different regions to reduce experimental contingency and the number of measurements should be increased.

5. Conclusions

In this paper, the impacts of building height on the concentration of indoor particulate matter in London from January 28, 2020 to February 10, 2020 have been analyzed using the low-cost instrument. Moreover, compositions, principles and usage of this instrument have been studied. The result is that building height cannot be the dominant factor affecting indoor PM
concentration. In addition, the deficiencies and further improvements also have been discussed in this paper, which may provide meaningful reference to the further research.

Acknowledgments

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