Investigating the efficiency of air filters in enclosed environments using a self-built low-cost Indoor Air Quality Monitoring System

ES014: EASTON SIM JIA RUI, YU YOUYOU, FANG JUNXUAN

MOTIVATION

- With **rising pollution levels** such as the haze which hit Singapore back in 2015 (CNA, 2019), disaster and pandemics such as **the Covid-19 outbreak** (WHO, 2023), **indoor air quality has worsened** while occupants find themselves in an **enclosed environment** such as offices and classrooms.
- This can cause **consequences** such as **lowered concentration** while studying in classrooms (Mendell & Heath, 2005), and risk of developing **respiratory syndromes** such as difficulty in breathing, asthma or even pneumonia in extreme cases.

- Given the severe gravity of the situation, we aim to **create** a **low-cost** and **easily scalable indoor air quality monitoring system** using easily-accessible and obtainable parts.
- Subsequently, we **investigated the efficiency of air filters** based on its **positioning** in a classroom, under different scenarios.
- Such technology is important as it makes monitoring indoor levels of air quality cheap and accessible, thereby improving the health and wellbeing of occupants in enclosed environments better.

Hypothesis

Our hypothesis is that **the efficiency of air filtering** is reliant and dependent on the **positioning** of the air filters.

Methodology

By constructing a low-cost and scalable monitoring system, we perform:

1. **Data collection** within a classroom in our school
2. **Mathematical modelling** using regression analysis and heat maps to visualise data
3. **Fluid dynamics stimulation** using Simcenter FLOEFD

1 Procedure and Experimentation

We carried out our experiment in a college classroom in our school, with the following procedures:

1. **3 air sensors** were placed in 3 different locations, which simulate the positions of students and teachers. The three units monitor air quality simultaneously.
2. After **ventilating** the room for 60 minutes, **incense** was burned to release **PM2.5 and PM10** until the readings level out across the room.
3. Air filters and/or the A/C were turned on while readings were taken in 30-second intervals until the level of PM dropped below **20 µg/m³**.

2 Result Analysis

- Figure 1: Our error margin of 5% demonstrates **high level of reproducibility** and **reliability** of our findings and our self-made monitoring system.
- Figure 2: The result of the particle concentration over time measured at point B, with the air filter placed at position 4, under different scenarios. The particle concentration is **normalised** using the equation $y_{norm}(t) = \frac{y(t)}{y(0)}$.
- In all cases, the particle concentration **decreased exponentially**. Hence, we adopt a **mathematical model** raised by researchers from Hanyang University (Lee et al., 2022):

$$y(t) = C + A \cdot exp(-Bx)$$

- **The result of curve fitting (B)** can be used to interpret the rate of decrease of concentration, i.e. **air cleaning efficiency**.
- Subsequently, a **multivariate regression** is used to **predict B using 5 other factors** including distance between the A/C and air filter, and whether the filter is elevated. We obtain the regression equation for PM10 and PM2.5 with coefficients as follows:

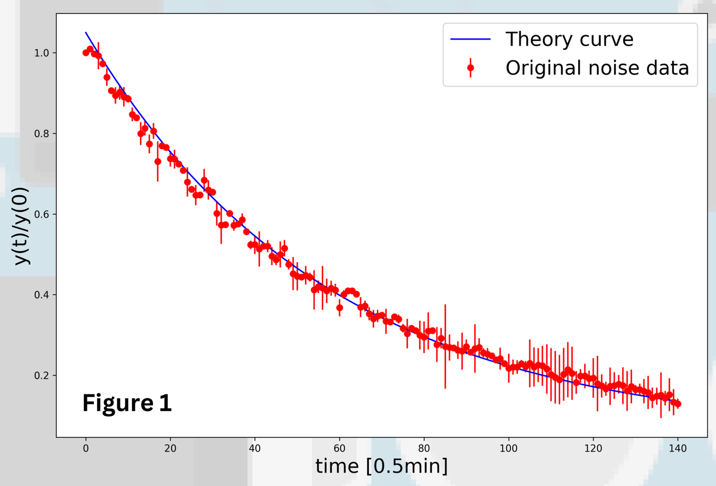


Figure 1

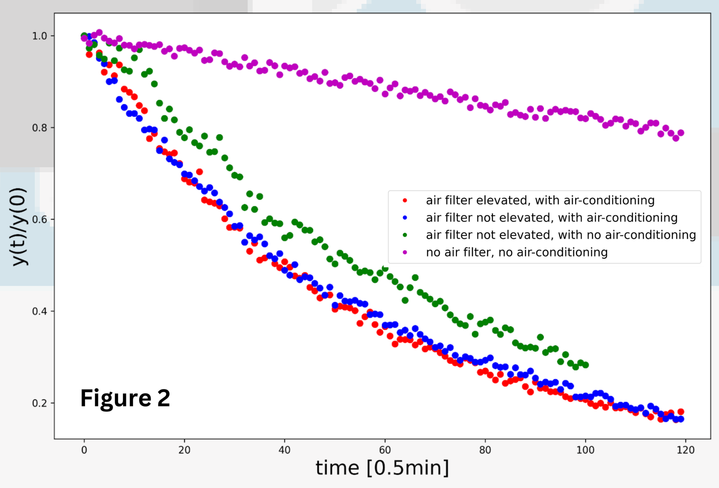


Figure 2

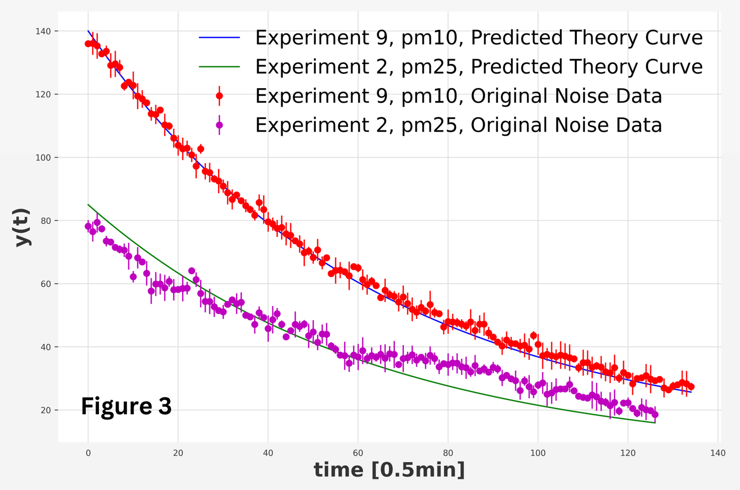
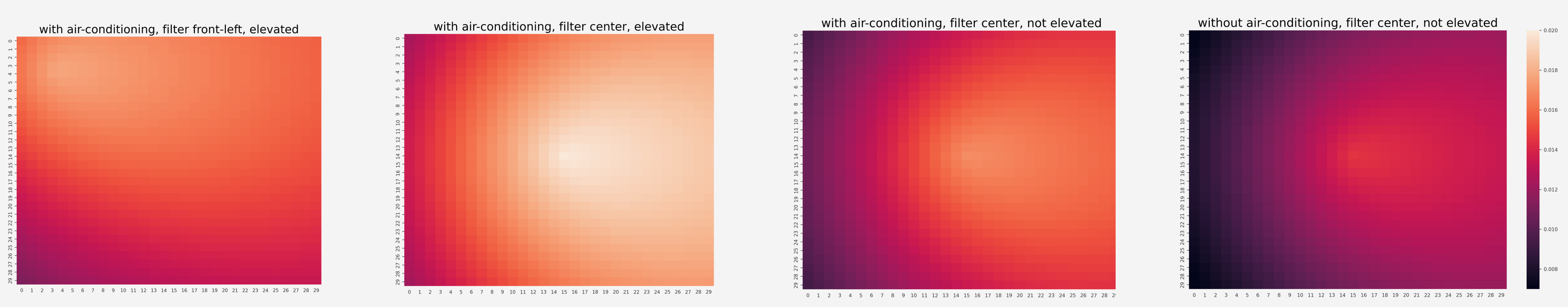


Figure 3

$$B_{PM10} = (-5.92 \times 10^{-5})f_1 + (-8.23 \times 10^{-4})f_2 + (-5.63 \times 10^{-4})f_3 + (2.96 \times 10^{-3})f_4 + (2.45 \times 10^{-3})f_5 + 0.0173$$

$$B_{PM2.5} = (-8.26 \times 10^{-4})f_1 + (-2.29 \times 10^{-4})f_2 + (-1.02 \times 10^{-3})f_3 + (3.0510 - 3)f_4 + (3.21 \times 10^{-3})f_5 + 0.0203$$

- Overall, we obtain a **validation percentage error** of **3.5%** for the PM10 model and **9.8%** for the PM2.5 model. A visualisation of the example is as shown in Figure 3. This indicates relatively good prediction accuracy.
- Hence, we obtain a visual representation of the air quality in a room. By applying our model to the entire classroom, we calculated the air cleansing efficiency at 900 positions. A lighter colour represents higher air cleansing efficiency, and better air quality.



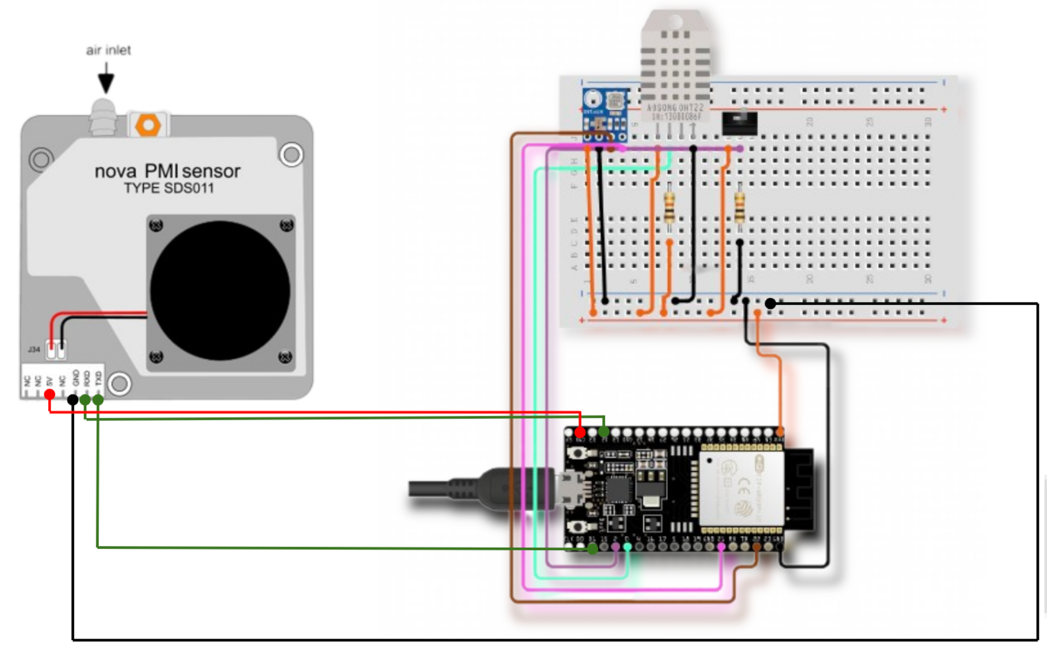
OBJECTIVE

By designing and building a **low-cost and scalable** air quality monitoring system, we wish to investigate the optimal positioning of air filters in classrooms that can achieve the **highest air cleaning efficiency**.

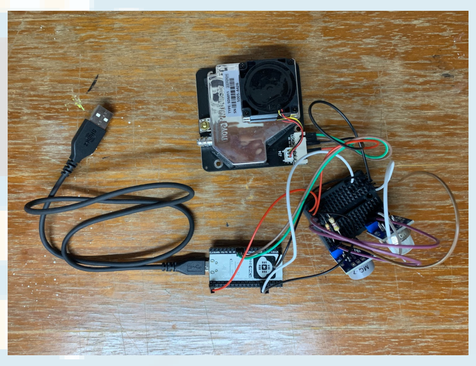
Construction of equipment

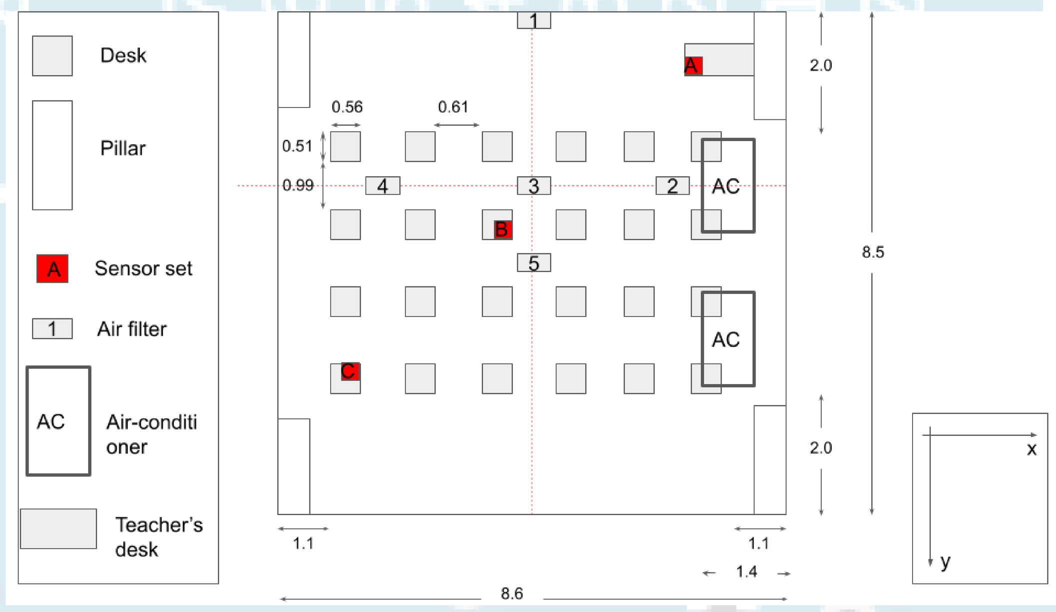
To create a low-cost and easily-assembled monitoring system, we chose the following parts:

- Nova SDS011 sensor (for measuring PM2.5 and PM10)
- ESP32 WiFi module
- BMP180 temperature and pressure sensor
- DHT11 humidity sensor



Three sets of our self-made sensors (as above) and one commercial air filter are setup in the classroom as depicted in the following diagram:





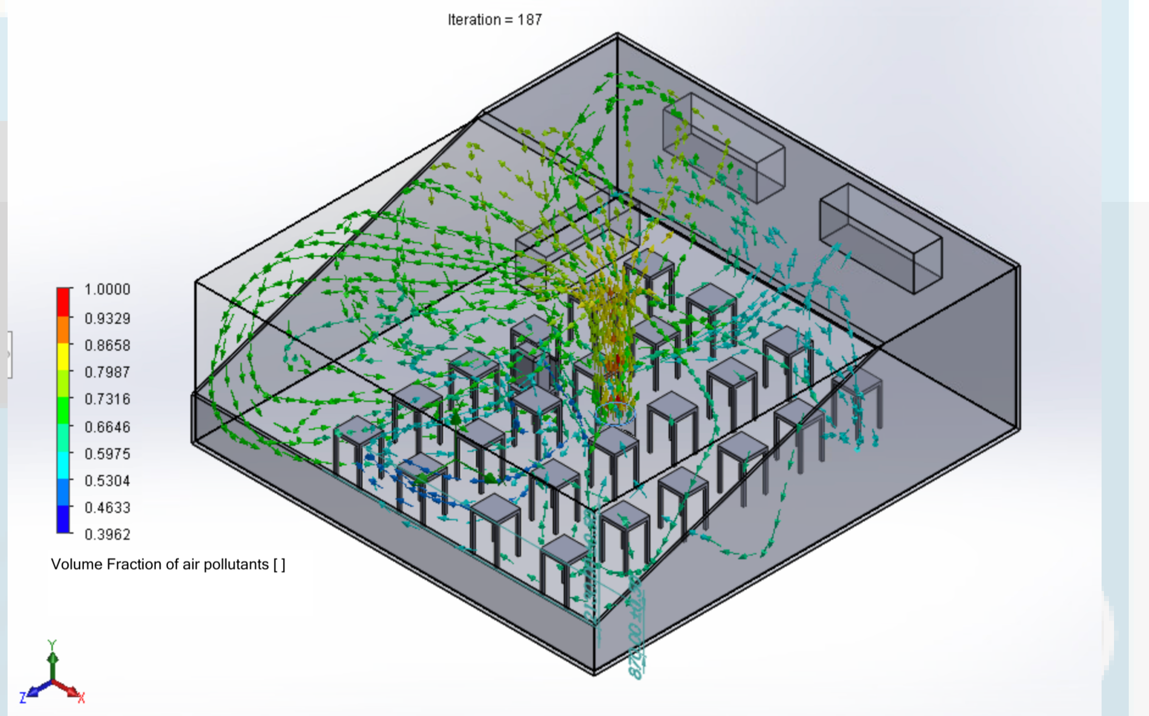
By using 3 of our self-made air sensors, we are able to **gather feedback and produce data simultaneously**, which makes our data collection very accurate and efficient.

3 Validation of results using CFD analysis and simulations using Simcenter FLOEFD

Computation fluid dynamics (CFD) uses modelling and governing equations to predict fluid flow (e.g. air pollutants). In this project, we used the simulator **Simcenter FLOEFD** to help us verify and compare results against our empirically collected data.

Inlets: general point at the center of the classroom

Outlets: A/Cs and air filter (since A/Cs have air filtering capabilities)



Upon testing against all experiments, we deduced that:

- Our simulations **matched empirical data** visually based on the direction of air flow.
- Comparing the values as seen on the sliding scale in the figure above, it matched predictions upon performing a chi-squared test on selected points on the simulations.

CONCLUSION AND FUTURE WORKS

We **verify our hypothesis** that when air filters are placed on elevated surfaces while A/Cs are turned on, it takes 40% less time when there is air conditioning and 20% less time when air filters are elevated, for the particle concentration at the centre to decrease below 30 µg/m³.

In the future, our prototype can be implemented in larger enclosed environments such as warehouses and factories at strategic locations.

The system can double up as **gas leak detection systems**: if there is an anomalous level of pollutant gases in a certain area of the room, then it means that that isolated region may have a gas leak.

With the cost of each unit being under $30, it is **cost-effective** and **easily scalable** for larger locations - a scaling of three to three-hundred units is easily achievable. These data can then be extrapolated by the occupants to determine which areas of the enclosed environment needs more filtration, hence enhancing efficiency of the air filtration systems of classrooms and offices.

REFERENCES AND LITERATURE

Lee, J., Park, S.-H., An, I.-H., Kim, Y.-W., & Yook, S.-J. (2022). Investigation of the Optimal Operating Position of an Air Cleaner in Terms of Indoor Air Quality in a Four-Bed Hospital Ward. Toxics, 10(7), 360. https://doi.org/10.3390/toxics10070360

Mendell, M. J., & Heath, G. A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air, 15(1), 27–52. https://doi.org/10.1111/j.1600-0668.2004.00320.x

World Health Organization. (n.d.). Who coronavirus (COVID-19) dashboard. World Health Organization. Retrieved February 5, 2023, from https://covid19.who.int/

Yong, C., & Menon, M. (2019, September 19). PSI hits unhealthy levels in Singapore for first time since 2016 as Haze Worsens. The Straits Times. Retrieved February 5, 2023, from https://www.straitstimes.com/singapore/hazy-conditions-persist-in-singapore-due-to-fires-in-sumatra