# Development of Ambiance Air Recirculation Unit for Air Quality Monitoring in Lecture & Laboratory Rooms

Nelson S. Andres*, Angelo N. Rodriguez, Dan William C. Martinez, Cristina G. Rivera, Albert C. Tria, and Cunard Kristoper B. Magbag

***Abstract*—This study focuses on the purification and monitoring of indoor air pollution aided with UV light radiation intended for laboratory and lecture rooms in Bataan Peninsula State University. The developed air recirculation prototype utilizes Arduino integrated development environment (IDE) software with two air quality sensors namely, BME680 and PMS5003, which send signals to relay to control the purification and monitoring operations. As a monitoring device, the prototype is capable of displaying real time air quality measurements as well as pollutant concentrations. The measured data control the purification process which activates only at acceptable range of indoor air quality (IAQ) allowing the prototype to conserve energy. Two approaches on monitoring accuracy were done with respect to the distance of prototype sensors to the air quality tester. While for the effectiveness of purification process, a five-minute recalibration speed on smoke tests were conducted. This study aimed to help in reducing the intake of harmful air on the human body that causes cardiovascular diseases, respiratory problems and even viruses, more particularly in indoor environments like laboratory and lecture rooms.**

***Index Terms*—Ultra violet (UV) light, indoor air quality (IAQ), PMS5003, BME680, air filter, sensor**

## I. Introduction

Indoor air pollution can be traced to prehistoric times when humans first moved to temperate climates and it became necessary to construct shelters and use fire inside them for cooking, warmth and light. Fire led to exposure to high levels of pollution, as evidenced by the soot found in prehistoric caves [1]. Most people spend 84% of their day indoors and IAQ pollution has always been a major health concern, as people spend 84% of their day indoors. Household use of solid fuels is the most widespread source of indoor air pollution worldwide; solid fuels are extensively used for cooking and home heating in developing countries, especially in rural areas. The percentage of people using solid fuels varies widely among countries and regions, ranging from respectively 77%, 74%, and 74% in sub-Saharan Africa, South-East Asia, and the Western Pacific Region, to 36% in the Eastern Mediterranean Region, and 16% in Latin America and the Caribbean and in Central and Eastern Europe. In the majority of industrialized countries, solid fuel use falls below the <5% mark [2].

Sulfur dioxide, particulate matter, volatile organic compounds (VOCs), and carbon monoxide are some of the common contributors to high indoor air pollution. A person exposed to high indoor air pollution may directly affect human respiratory, cardiovascular systems, and sometimes cognitive function. Side effects may include sleepiness, lack of focus, irritation of the eyes, lung damage, and may even cause life-threatening effects. These effects may vary depending on the susceptibility of the subject, season or temperature, length, and intensity of exposure [3, 4]. Furthermore, pregnant women are also vulnerable to such risk when exposed to high level of ambient air pollutants. A number of studies indicate a significant association between air pollution exposure during pregnancy and preterm birth, congenital defects, and low birth weight [5].

Air pollution is one of the most critical issues as air quality and indoor air pollution are two of the world's biggest pollution challenges. The Philippines has earned the distinction of having the region's second biggest number of deaths due to indoor air pollution based on WHO (World Health Organization) which showed that close to 84 deaths per 100,000 Filipinos were recorded in 2016 due to indoor or household air pollution [6]. Air quality Index is used by organizations in order to calculate, forecast, and record the air pollution concentration in a specific location. The environmental protection agency (EPA) established the national standard for air quality index ranging from 0–500 in which each color category is based on the affected population depending on the air pollutant concentration. Thus, having an IAQ rating of 100 will only affect people with sensitivity to air pollution whereas having a 300 IAQ rating poses health risks to all people present in the vicinity. One method of enhancing air quality and lowering health hazards for building occupants is to use Ultraviolet Germicidal Irradiation (UVGI) in the HVAC (Heat, Ventilation, and Air Conditioning) system [7]. Utilizing UVGI will ensure that pollutants and viruses which escaped the filtration process are eradicated.

The IAQ in schools has been one of the major concerns among researchers, because children are more susceptible to air pollutants than adults, and children spend a significant amount of time in schools. Similarly, the IAQ in office buildings has also been of particular concern because it significantly affects the productivity of workers [8]. As schools nearly approach the reopening of classes and yet again revert back to face-to-face classes with additional compromises as an adjustment to the ongoing pandemic, classroom air ventilation and purification should be taken into consideration. A study showed that an educational

Manuscript received August 4, 2022; revised September 13, 2022; accepted September 21, 2022.

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doi: 10.18178/ijesd.2023.14.5.1449

institution located near urban roadways can incur high levels of air pollutants which are mainly associated with heavy outdoor activities alongside indoor activities [9–11]. Likewise, the Bataan Peninsula State University - Main Campus situated near urban roadways, is striving to create an effective air particle purification and monitoring device to comply to clean air provision on face-to-face classes. Hence, the study is aimed towards developing an in-door air-purifying and monitoring device for air quality to provide students and professors in laboratory and lecture rooms with clean breathing air.

## II. Air Recirculation Unit

The Ambiance Air Circulating Unit consists of pre-filter, intake fan, sensors, cabin filter, UV light and exhaust fan. The air that flows through automated air purifier produces a cleaner air quality. The purification runs or stops as it reaches the acceptable air quality range from the air samples. While UV light is added to the system to ensure that all air molecules are disinfected.

The Ambiance Air Recirculation Unit also serve as Air Quality Monitoring device. It consists of program that gathers real time data air quality index as well as particulate concentrations through PMS5003 sensors. It can detect a particle diameter down to 0.3 mm. The BME680 is a digital four-in-one sensor with gas, humidity, pressure, and temperature measurement. These data are then transmitted to UNO Rev3 microcontroller that allows the purification system to run or stop. The real time data gathered are also display in LCD/I2C.

TABLE I: AQI RANGE

| AQI Category | AQI Range (0–500) | PM10 | PM2.5 | Cleaned Pollutants (%) |
|---|---|---|---|---|
| Good | 0–50 | 0–50 | 0–30 | 100–90 |
| Satisfactory | 51–100 | 51–100 | 31–60 | 89–80 |
| Moderately Polluted | 101–200 | 101–250 | 61–90 | 79–60 |
| Poor | 201–300 | 251–350 | 91–120 | 59–40 |
| Very Poor | 301–400 | 351–430 | 121–250 | 39–20 |
| Severe | 401–500 | 430+ | 250+ | 19 |

Table I shows the adopted AQI category with corresponding AQI range and particulate matter concentration for PM10 and PM2.5. The pollutants are based on percentages as understand by the sensors. The table contains the conditions of the air purification process for its two-state function (on or off). The AQI category displayed depends on the sensed or measured parameters AQI range, PM10 and PM2.5. The AQI range is the basis for the purification operation; if AQI range is more than 100, the purification process continues and if the value is less than or equal to 100, then the purification process will stop.

Fig. 1 below shows the architectural purification system of the prototype as programmed in Arduino. The process starts when the relay receives signal from the sensors. If the sensor's signal is greater than 4mA, the AI module will send signal to the programming device. The programming device will check the status of the fan motor and UV light through the DI module. If the status of the fan motor and UV light are offline, the control module will turn them on to start the purification of air sucked by the exhaust fan. If the measured AQI reaches the 0–50 range, PM10 reaches 0–50 range and the PM2.5 reaches 0–30 range, means that the air quality is good and the air pollution poses little or no risk. At this category, the purification process stops but the monitoring of AQI, PM10 and PM2.5 continues. Monitoring an AQI of greater than 100, PM10 of greater than 100 and PM 2.5 of greater than 60, will trigger the purification process.

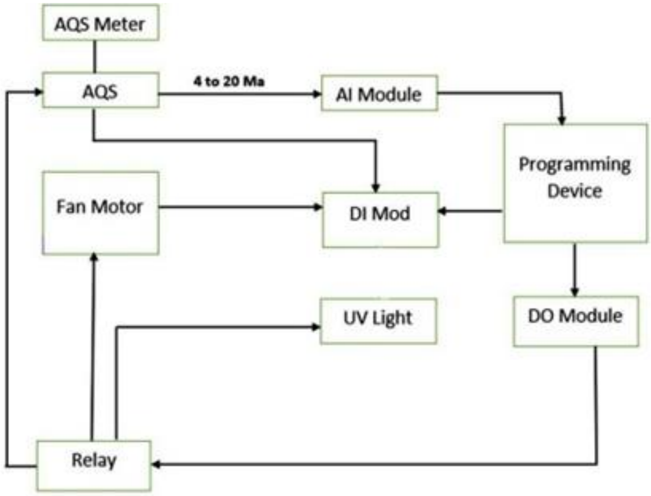


Fig. 1. System architecture.

## III. Results and Discussion

Accuracy, smoke, and comparative tests were conducted in order to prove the effectiveness and efficiency of the prototype in monitoring the air quality index of its surrounding as well as in purifying a 90 square meter classroom. The prototype was left operating until the air quality data were collected and each data collection occurred every 10-minute. This accuracy testing was done using a commercial air quality tester in order to prove that the data collected by the prototype is harmonized with that of commercial air quality tester in terms of the concentration of pollutants.

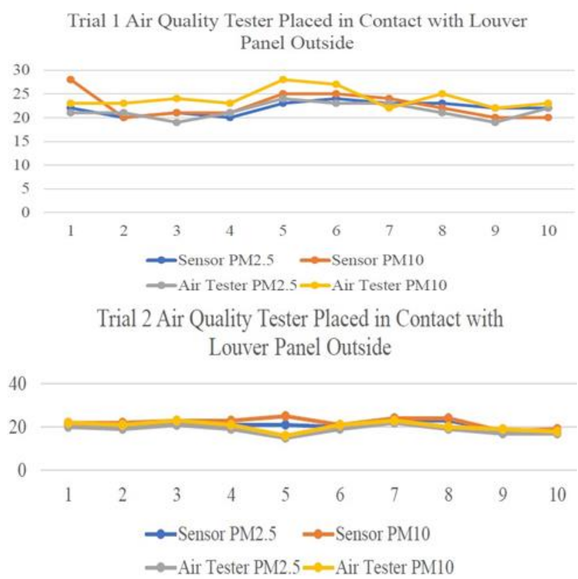


Fig. 2. Air quality tester placed in contact with louver panel outside.

It is shown in Fig. 2 that the pollutant concentration gathered by the prototype (PM10 and PM2.5 sensors) at a given time were almost similar with the pollutant concentration measured by the commercial air quality tester when it was placed outside the louver panel. This shows that the effectiveness of the device in detecting the air impurities of its surrounding.

While Fig. 3 depict the trials when the air quality tester was placed two meters far from the prototype. The air pollutants sensed by the prototype (PM2.5 sensor) and the commercial air quality tester in trial 1 and trial 2 have minimal discrepancy. These comparisons also demonstrate the accuracy of the prototype in terms of measuring air quality in indoor environment.


Fig. 3. Air quality tester placed 2m apart from the air circulating unit.

In different trials for the same classroom, the purification speed tests with a 5-min recalibration were also conducted and the results were shown in Fig. 3. These tests were initiated with windows and doors open for 5 min in which the prototype is put on standby. The prototype was operated on the 5th minute mark. The update on measurements of AQI and pollutant concentration is displayed in LCD every 30 s intervals. The purification process stops only when the displayed AQI and pollutant concentration reach the allowable range. From the listed data above, it is clear that the developed Air Recirculation Unit is capable of cleansing air pollution ranging from both “Poor” (Fig. 4) or “Very Poor” (Fig. 5) within 15 minutes of operation. The collected AQI data has an average of 18.24 AQI per minute based on the trials conducted.

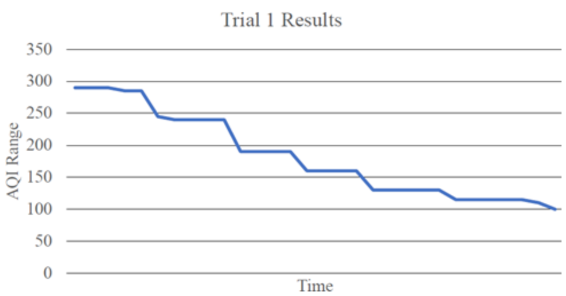


Fig. 4. Trial 1 of 5-minute recalibrated speed test purification.

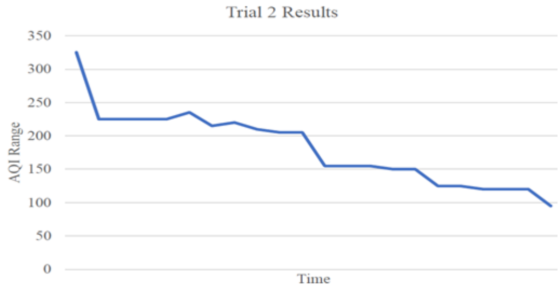


Fig. 5. Trial 2 of 5-minute recalibrated speed test purification.

After the accuracy tests, a smoke test was carried out in order to visually analyze the effectiveness of the prototype and to tangibly assess the function of the prototype in an environment. The test was achieved by burning 5 mosquito coils for 4.5 h inside the chamber with an area of 1.088 $m^3$ prior to starting the air purifier. Air Quality Index shown by the display was recorded every 10 min after the initial start of the air purifier and the time it took to visually clean the air was also recorded.

Start of Purification End of Purification after 1.5 hours

Fig. 6. Test for air purification.

As shown in Fig. 6, the prototype was able to cleanse the accumulated smoke produced by the mosquito coil in a span of one and a half hour. Rated with a high AQI, mosquito coil emissions can substantially exceed health-based air quality standards or guidelines and pose serious threat to human respiratory health [12].

Comparisons were made when the developed prototype was placed in a small closed room with two different trials in which qualitatively assess the performance with and without UV light filtration. The test follows the former smoke test in which the room was smoked for 30 min before turning on the air purifier. After the initial start of the prototype, records on AQI and particulate matter were collected every 5 min until the 30-min mark or until AQI reached a satisfactory level. Additionally, the air purifier was also set to consistently operate despite reaching satisfactory level for data gathering.

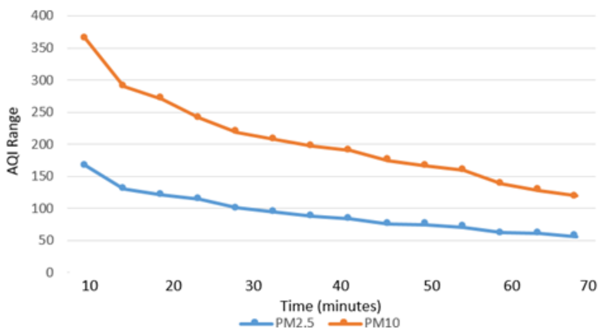


Fig. 7. AQI measurements inside sample closed room.

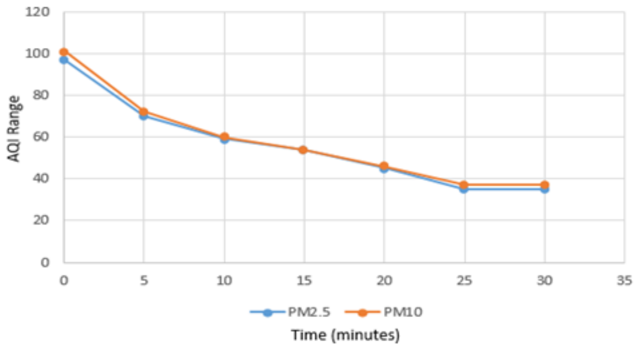


Fig. 8. AQI measurements during purification test without UV light.

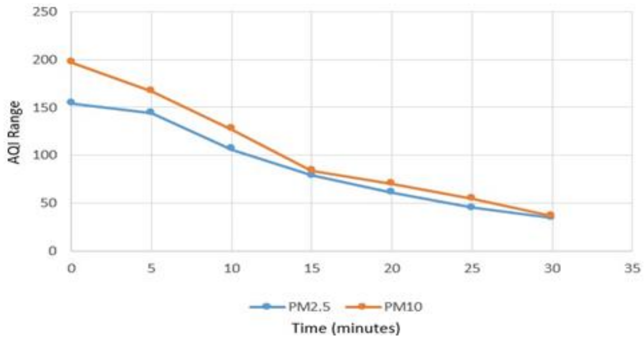


Fig. 9. AQI measurements during purification with UV light.

As shown in Figs. 7–9, particulate matter and AQI range did improve with UV light filters on as compared to without an operating UV light. Moreover, it is also evident that although the initial AQI of the test with UV light being turned on was higher than that of without UV filter, the purification time of both tests were identical. UV light is a known disinfectant for air, water, and nonporous surfaces and it has effectively been used for decades to reduce the spread of bacteria, such as tuberculosis. UV light may also be effective in inactivating the SARS-CoV-2 virus, which is the virus that causes the Coronavirus Disease 2019 (COVID-19). It has been shown to destroy the outer protein coating of the SARS-Coronavirus, which is a different virus from the current SARS-CoV-2 virus. The destruction ultimately leads to inactivation of the virus efficiently and safely inactivates airborne human coronaviruses [13]. However, the impact of UV light in terms of improving air quality did only of considerable extent due to UV light's functionality mainly leans with bacterial inactivation. Furthermore, having an air purifier active can reduce air pollutant as almost twice as fast as natural decay of pollutants.

## IV. Conclusion

This study was conducted to improve and monitor the air quality in lecture and laboratory rooms through the development of an Air Recirculation Unit utilizing real-time approximation of indoor air quality index and pollutant concentrations, whilst also attaining reduced power consumption. Furthermore, the use of UV light radiation allows the effective disintegration of S-layer protein lattices of most pathogens including SARS-CoV-2. The developed air recirculating unit performs function based on the AQI range and pollutant concentrations real time data collection. An LCD was provided to display the real-time air quality index and pollutant concentrations with a high reliability of 85%. In addition, the Air Recirculation Unit showed a considerable purification speed after allowing air exchange in classroom for 5 min. The Air Recirculation Unit was able to improve an AQI category from "poor" or "very poor" to satisfactory within 11 to 15 min. Furthermore, the prototype was found to be effective at detecting and purifying particulate matter ranging from 2.5µg to 10µg. Lastly, the Air Recirculation Unit has reduced the amount of pollutant in a closed room almost twice as fast as natural decay.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

The study was undertaken through the combined efforts of the authors. Nelson S. Andres, the principal author, led and initiated the whole research study; Angelo N. Rodriguez, configured the Arduino programs of the prototype; Dan William C. Martinez was assigned with the external design and 3D printing model of the prototype; Cristina G. Rivera contributed in writing the paper and conceptualization; Lastly, the testing and gathering data was conducted by Albert C. Tria and Cunard Kristoper B. Magbag. Finally, the authors had approved the outcome and final version of the manuscript.

## Acknowledgment

This research paper is an output of the BRIDGES (Building Research and Innovation Developmental Goals for Engineering State Universities and Colleges) program spearheaded by Batangas State University. BRIDGES is a collaborative project between Batangas State University and partner SUC's in the Philippines, in which BPSU is an active collaborator

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