Performance Evaluation of Low-Cost Airborne Infection Isolation Room

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Abstract. *This study presents the performance of a low-cost airborne infection isolation room (AIIR). The system consists of an ante room, two AIIRs, a blower, two butterfly valves, an air conditioner, a controller, and a ventilation system. Pressure and temperature sensors were calibrated and installed in all rooms. The control was an in-house system, including Arduino Uno R3, ESP32, NI-USB 6009, and PLC FX5U. PID control was employed to regulate the pressure inside the AIIRs by adjusting the outlet air blower speed. The system was tested under various negative pressures, i.e. -2.5 to -10 Pa, and the effect of inlet opening was also investigated. The results showed that the system effectively controlled the pressure under all experimental conditions. The blower speed and room pressure were found to be related, with higher blower speeds required when all butterfly valves were open. The current of the motor increased with the valve set connected, and the highest current was observed when all butterfly valves were open. The air velocity generated by the blower suction varied with the room pressure, with a decrease in pressure leading to an increase in air velocity. However, for one room operation, the velocity difference was insignificant.*

Keywords:
Performance evaluation, low-cost controller, airborne infection isolation room, Covid-19

1. Introduction

From the outbreak of COVID-19, this pandemic has had a profound global impact. The pandemic has led to numerous confirmed cases and deaths worldwide, along with significant disruptions to daily life, economies, and healthcare systems [1]–[3]. Although situation seems to be better, coronavirus infection still remains over the whole world, because virus transmits easily along the air contained droplet nuclei [4]–[7] and ventilation systems in the confined space [8]–[11]. To control the spread of coronavirus and the new airborne infectious diseases, various solutions [12]–[14] have been implemented, including social distancing, mask-wearing, frequent handwashing, testing, contact tracing, quarantine, and the vaccination. For quarantine, the cost of quarantine can vary greatly depending on the country and region due to differences in government policies and regulations [15], [16]. Lee et al [17] demonstrate that the infectious virus deposition was reduced by 87-fold when the hood was operated. Bergeron et al [18] showed that the use of high flow air decontamination units can reduce 5 times of the peak contamination levels with faster removal rates greater than 33% compared with the traditional extractor in the infectious areas. Moreover, as the situation evolves and new guidelines are introduced, the cost may fluctuate over time. It is recommended to consult official government sources or relevant health authorities for precise information on the quarantine expenses in a specific location or context. The airborne infection isolation room is a major expense prepared by health organization of governments. To make the system available with low cost of construction, Sukarno et al [19] revealed that the heat pipe heat exchanger for pre-air cooling for the HVAC system of the airborne infection isolation room (AIIR) significantly reduces the energy consumption. In addition, Nuntapap et al [20] proposed an AIIR with an air control system. The control system was developed from commercial sensors and a proportional integral derivative (PID) control mechanism. PID is suitable for controlling engineering devices with wide range of application [21]–[23]. Prior to implementation, all sensors were calibrated for accurate system functioning. A user interface was created using LabVIEW. The key design parameter focused on achieving a pressure reduction capability of -2.5 Pa. Additionally, the study analyzed the airflow distribution within the AIIR at different outlet positions. The test results demonstrated that the PID-controlled system achieved the desired room pressure setpoints (at least -2.5 Pa) within 15 seconds and maintained stability. The outlet positioned at 10 cm height exhibited minimal air dispersion and turbulence, whereas the outlet at 60 cm height showed backflow and significant air dispersion. It is clear that with key parameters the low-cost system could be achieved. However, there is so far no performance test on this system.

Therefore, to assess that this system could be deployed with low cost operation, the objective of this work is to study performance of the low-cost airborne infection isolation room. The stability of control is also revealed.

2. Methodology

In this study, the low-cost airborne infection isolation room consists of ante room (room 1), two AIIRs (room 2 and 3), a blower, electrically controllable butterfly valves, an air conditioner, controller and ventilation system with air filter system as shown in Fig. 1 and Fig. 2. There were pressure and temperature sensors for all rooms. All sensors were well calibrated, shown in Fig. 3, and setup before tests. The electrically controllable butterfly valve was installed at pipe before inlet. An in-house control system of this work was developed by using a micro controller Arduino Uno R3 and ESP32 for automatic control, NI-USB 6009 for data interface, and PLC FX5U for air damper control. C++ was used for operating Arduino Uno R3 to receive signals from all sensors. GX-Work3 was a Lader program for PLC FX5U which connected with USB 6009. PLC was used to control air damper, air conditioner and lighting system. LabVIEW was crucial part of control. It was used to calculate and control all system using PID.

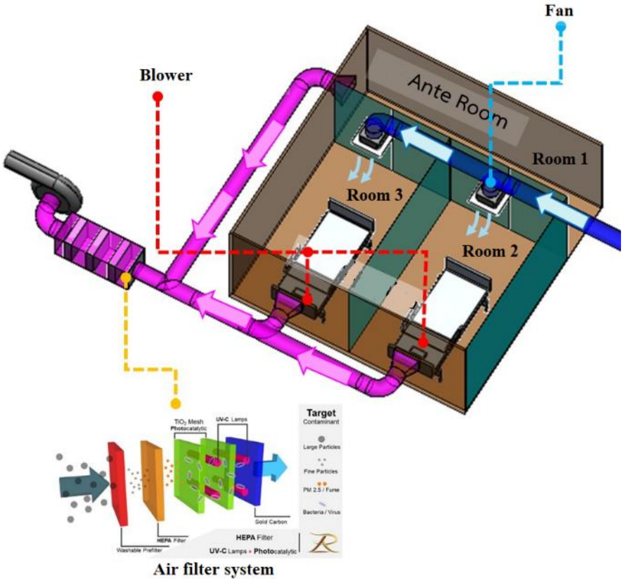
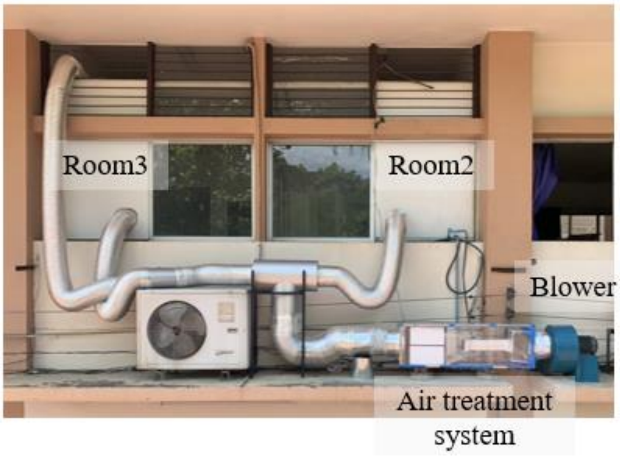


Fig. 1 Measurement and control system design.

(a) Front view of AIIR



(b) Back view of AIIR

Fig. 2 The low-cost airborne infection isolation room (AIIR).

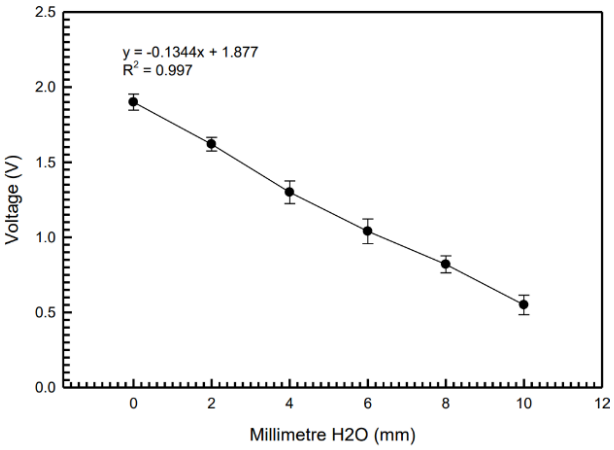
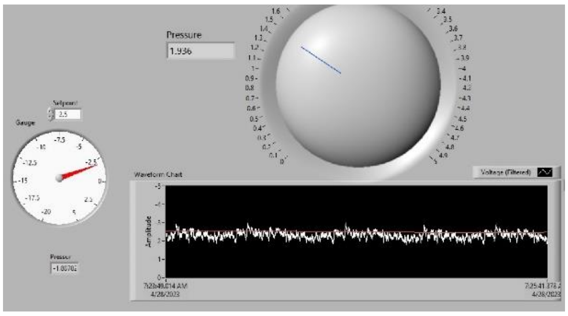


Fig. 3 Sensor calibration.

The control principle to regulate pressure inside AIIRs was used to adjust the speed of the outlet air blower while speed for the inlet air blower was kept constant. To achieve the required air exchange rate (over 12 air changes per hour) and maintain a negative pressure inside the room below 2.5 Pa, the outlet air blower was controlled based on Proportional integral derivative (PID) control using measured data from room 2 and 3 as shown in Fig. 4. More details of PID control are available in previous work [20].

Fig. 5 shows monitoring of measured air temperature from room 1 to 3.

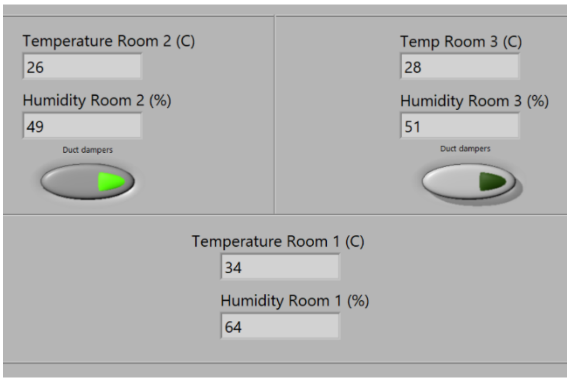
In this work, the performance of system were tested under various negative pressures of -2.5, -5 and -10 bar to assess the operation of fan, consumption of energy and velocity at outlet. In addition, effect of inlet opening was investigated. The system was tested in different situations, i.e. one room operation (room 2 or rooom 3 was selected) and full operation (all rooms were operated).



Pressure
1.936

Setpoint
2.5

Fig. 4 Example of pressure controlled at -2.5 Pa by PID control.



Temperature Room 2 (C)
26

Humidity Room 2 (%)
49

Temp Room 3 (C)
28

Humidity Room 3 (%)
51

Temperature Room 1 (C)
34

Humidity Room 1 (%)
64

Fig. 5 Dashboard of all room temperature monitoring.

3. Results and Discussion

Fig. 6 shows the operation of pressure controller at -2.5, -5, and -10 Pa within a time window of 3.5 seconds. The signal fluctuation for pressures of at -2.5, -5, and -10 Pa are ±0.6, 0.6, and 0.8, respectively. The fluctuation signal is higher at pressure of -10 Pa due to higher motor speed, causing pressure oscillation. However, the system can be able to control the pressure under all experimental conditions.

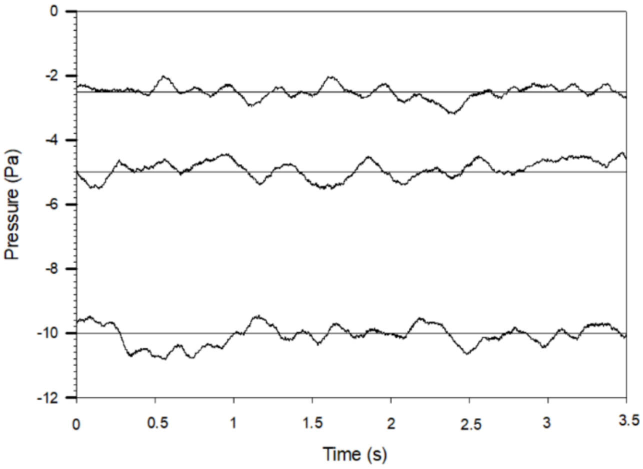


Fig. 6 Room pressures tested at -2.5, -5 and   -10 Pa using low-cost control system.

The relation of blower speed and room pressure is illustrated in Fig. 7. The blower speeds were measured for the operation of both rooms. When the designated pressure was maintained in each negative pressure, a higher blower speed was required when all butterfly valves are open. This is necessary to expel more air in order to maintain the desired room pressure as intended. In case of operating room 3, blower speed were higher because of higher friction due to longer pipe compared to room 2 as shown in Fig. 2.

As the room pressure decreases from -2.5 to -10 Pa, the blower speed increased significantly in all cases. This is because the higher blower speed corresponded to an increased flow rate, which effectively reduced the room pressure. However, in the case of all valves are open, the decrease in room pressure has a slightly lesser impact on the blower speed. This is due to the fact that the air can distribute equally through the outlets of each room.

Fig. 8 shows the measured current of motor during tests. It was found that at light load (only fan operating without the butterfly valve set), the current remained constant at 0.76 A because the motor had a low load, resulting in consistent current. When the valve set was connected, it was observed that the current increased. The highest current was detected when all butterfly valves were open. The condition where room 2 was open and room 3 was closed resulted in a lower flow rate compared to all other test conditions because the suction pipe was closest to the blower, resulting in a lower friction. Conversely, opening all rooms resulted in the highest current as the motor rotation speed was higher, allowing for a greater current.

Fig. 9 illustrates the air velocity generated by the blower suction for each room pressure. As expected, it was observed that the air velocity was changed by air flow rate corresponding to room pressure, where a decrease in pressure resulted in an increase in air velocity. However, for one room operation (room 2 or rooom 3 was selected), the velocity is insignificant difference.

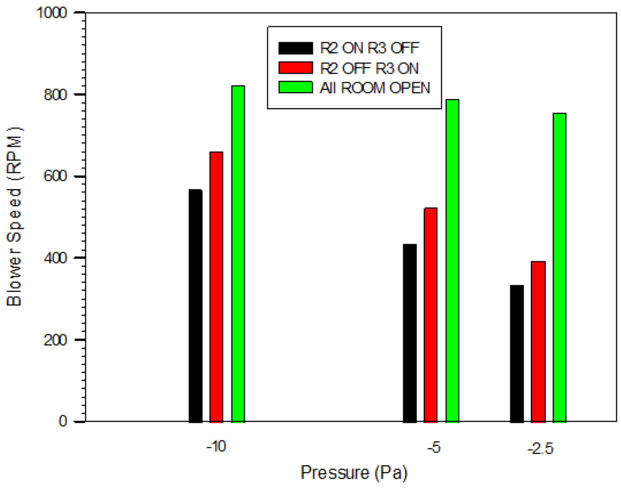


Fig. 7 Blower speed related with room pressure.

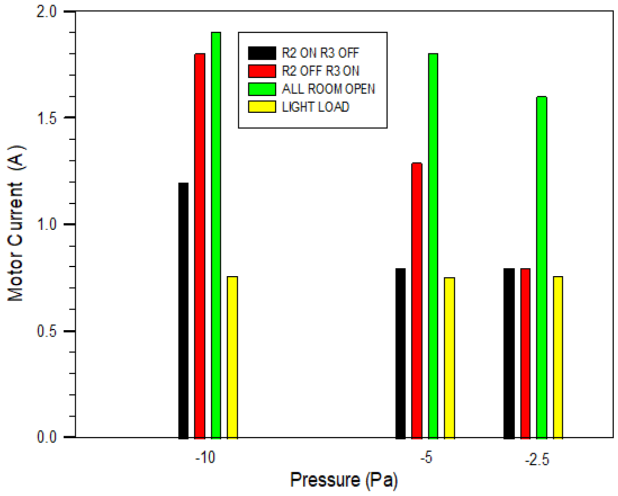


Fig. 8 Currents tested at room pressure of -2.5, -5 and -10 Pa.

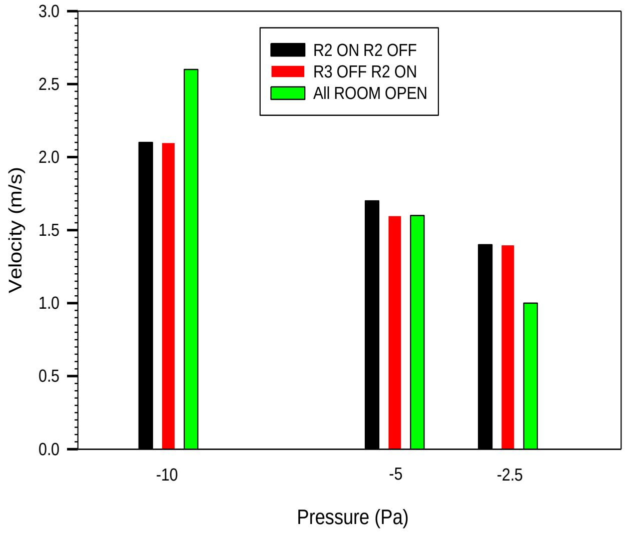


Fig. 9 Air velocity at outlet varied with room pressure.

4. Conclusions

This study examined the performance of an airborne infection isolation room (AIIR) equipped with a low-cost PID controller. All devices were available in the markets. Testing the system under different negative pressures ranging from -2.5 to -10 Pa with different inlet opening revealed that higher blower speeds were necessary when all butterfly valves were opened. The current of the motor increased with load and the highest current was observed when all butterfly valves were opened. The air velocity varied according to room pressure, whereby a decrease in pressure resulted in an increase in air velocity. Overall, the findings demonstrate the effective performance and control capabilities of the low-cost AIIR system.

Acknowledgements

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