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The Effectiveness of Energy Recovery Ventilation (ERV) to Improve the Indoor Air Quality

Research Article

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Author Details

*Chun-Yu Tsai, Hsiu-Ju Cheng, Ling-Hang Hsu, Chen-Kang Huang**

Department of Biomechatronics Engineering, National Taiwan University, Taipei 106, Taiwan

*Corresponding author

Chen- Kang Huang, Department of Biomechatronics Engineering, National Taiwan University, Taipei 106, Taiwan

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Abstract

This study aims to achieve air cleaning by utilizing the energy recovery ventilation (ERV) to introduce outdoor fresh air into the conditioned space to reduce indoor CO_2 and particulate matter concentrations and recover energy simultaneously. The CO_2 and particulate matter concentrations were measured to observe the difference after turning on the ERV. It was found that the ERV led to reduce the CO_2 concentration significantly. With the ERV activated, the concentration of CO_2 reached below the standard level less than 100 minutes, reaching a minimum of 420ppm; while the concentration of $PM_{2.5}$ remains between 6- 10μg/m^3. An additional air duct facilitating ERV drawing air from stagnant area was helpful. By installing additional air duct, the problem of some poor circulation area was solved, and the concentration of CO_2 was confirmed to decrease to a minimum of 525ppm. The ERV was proved as a good and easy way to enhance indoor air cleaning.

Keywords: Energy Recovery Ventilation, ERV, Indoor Air Quality, CO_2 Concentration, Particulate Matter Concentrations

Introduction

Under the impact of global warming, the heat from solar radiation is increasingly trapped, much like being inside a greenhouse, making it difficult to dissipate. This has caused the overall environmental temperature to rise continuously. This worsening situation has led humans to spend more time indoors in air-conditioned environments. Additionally, the recent severe outbreak of the novel coronavirus disease (COVID-19) has forced us to undergo isolation in dedicated rooms when infected or exposed to individuals who have contracted the virus. The situation highlights the necessity for indoor environments to continuously provide excellent air quality for extended periods. In the context of air conditioning and ventilation systems in healthcare facilities, pathogens introduced by patients during their hospital stay have a high likelihood of spreading through the air conditioning system, potentially infecting other patients or staff on different floors [1]. Kim et al. [2] studied the transmission of pollutants associated with the Middle East Respiratory Syndrome Coronavirus (MERS-Cove) in isolation wards. They found that despite daily cleaning and simple disinfection of patient rooms, many environmental samples still contained MERS-CoV. The study revealed that the virus could survive in the air for up to six days, explaining why MERS-CoV spreads so easily within healthcare systems. Memarzadeh and Xu [3] investigated the role of air changes per hour (ACH) in air transmission infections using Computational Fluid Dynamics (CFD) analysis. Memarzadeh and Xu examined airflow mechanisms, particle trajectories, and proposed control strategies to reduce airborne infections. While increasing ACH diluted pollutant concentrations, it did not necessarily improve ventilation efficiency. The key factor in controlling pollutant transmission was the airflow path between pollutants and exhaust points. When the path was undisturbed by airflow interference, pollutants were better controlled. The exposure concentrations under poor pathways at different ACH levels showed that, theoretically, higher air change rates (ACH) should result in lower exposure concentrations due to dilution. However, the study revealed that the performance of ACH = 12 was worse than that of ACH = 6, attributed to airflow disturbances along the pathways. In contrast, under optimal pathways, the exposure concentrations at different ACH levels demonstrated that as ACH increased, the exposure concentrations decreased. The result indicated that improving indoor ventilation required not only increasing ACH but also paying attention to optimizing the airflow pathways for better particle movement control.

In this study, utilizing an Energy Recovery Ventilation (ERV) system for mechanical ventilation are proposed. By inspecting the Air Change Rate (ACH), the experiments aimed to achieve indoor air purification while promoting energy efficiency and sustainability.

Materials and Methods

Test Space

This study aimed to evaluate the indoor air quality in a typical laboratory, normally 6 to 8 people working inside, with devices installed in the 8.58m x 7.80m x 3.25m space (Figure 1).

Energy Recovery Ventilators (ERV)

The ERV installed in test space is shown in Figure 2. It facilitated mechanical ventilation by passing fresh outdoor air and allowed air replacement and energy recovery while preventing larger molecular pollutants from passing through the filter. The device can handle airflow of up to 500CMH (Cubic Meters per Hour). The air changes per hour (ACH) is calculated as airflow (CMH) divided by the indoor environmental volume (m^3), resulting in a ventilation rate of 2.3 times per hour.

MAPSV6 air box

The MAPSV6 air box [4] was utilized to record indoor air quality history. It monitored various parameters, including temperature, humidity, $PM_{1.0}$, $PM_{2.5}$, PM_{10}, TVOC, and CO_2 concentration. Real-time data could be displayed on the screen located in the top left corner of the device. Additionally, users have the option to capture data through Python programming for further analysis or store data on an SD card, as shown in Figure 3.

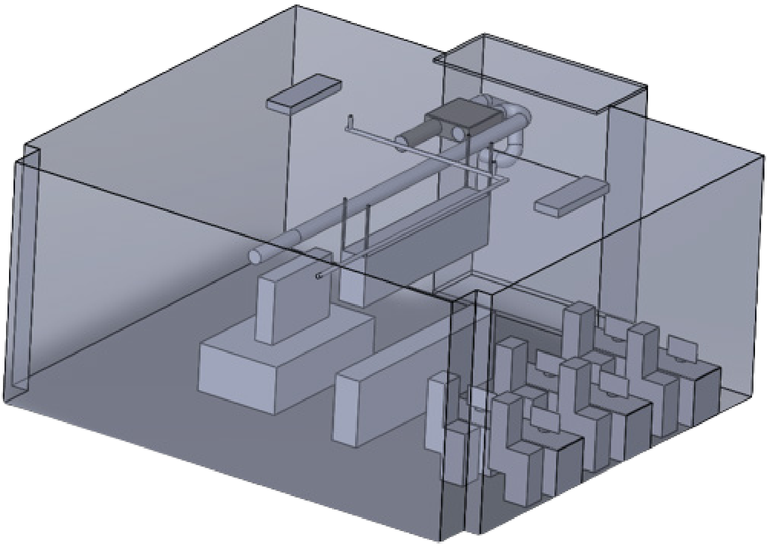

Figure 1: Test laboratory (from left to right in the image: main experiment area, central cabinet, and office area, equipped with two FCUs and one energy recovery ventilator at the top).

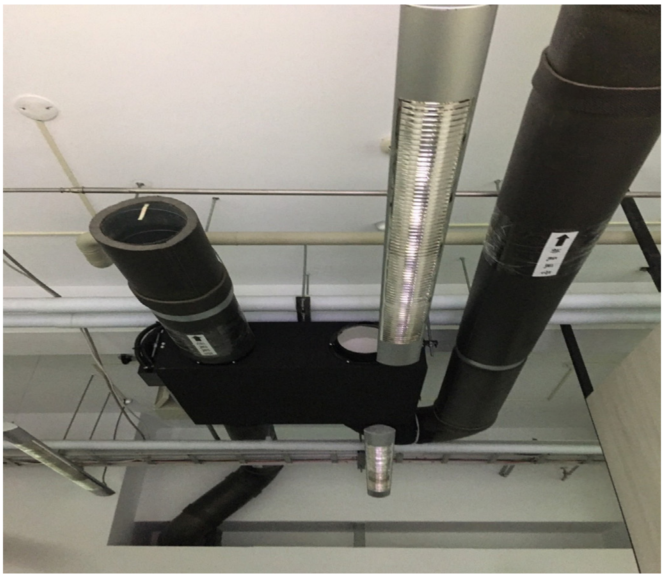

Figure 2: Photo of ERV tested in this study.

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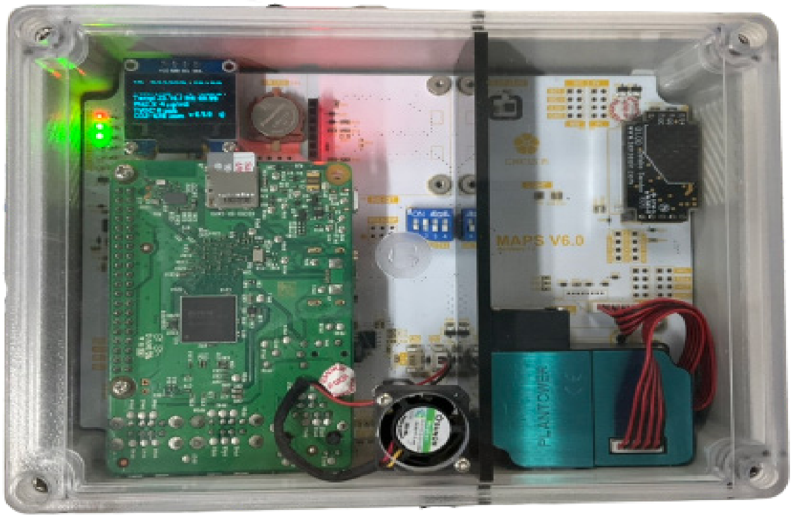

Figure 3: MAPSV6 air box.

Sampling of CO_2 and Particulate Matter Concentrations

Sampling was scheduled from 9:00AM to 5:00PM while the number of personnel was approximately consistent to 6. However, during the second week, there was an increase in the number of personnel to 8 people in the morning due to a laboratory event. For more details about the test space and corresponding descriptions, the literature [5] is suggested to be referred.

The analysis of particulate matter (PM) and CO_2 concentration can be divided into three parts.

a.MAPSV6 air box was uniformly placed on the central cabinet to collect data during two different scenarios: when the ERV was operating at its maximum fan speed and when it was turned off.

b.Two MAPSV6 air boxes were prepared, with one placed in the experimental area, and the other in the office area. Data were collected in both areas during two different scenarios: when the ERV was operating at its maximum fan speed and when it was turned off.

c.A MAPSV6 air box was placed in a location simulating a poorly ventilated area to collect indoor data before and after the installation of the additional air duct in the ventilation system.

Results and Discussion

Figure 4 shows the CO_2 concentrations (in ppm) observed by placing the MAPSV6 air box on the central cabinet. The horizontal axis represents time, and the vertical axis represents CO_2 concentration, and there were 6 people in the laboratory. During the morning period, activities were conducted indoors, and in the afternoon, some personnel left. The plot shows that from the morning until noon, the CO_2 concentration exceeded 600ppm, reaching as high as 800ppm, which is a level that may cause frequent dizziness and discomfort for humans. By comparing the data when the ERV was either on or off, it was evident that when the ERV was on, the CO_2 concentration reached below the standard 600ppm approximately 1 hour and 40 minutes earlier. Moreover, opening the ERV ultimately led to reducing the CO_2 concentration in the environment to 420ppm.

Figure 5 shows the $PM_{2.5}$ concentration under different conditions when the ERV being on and off. It can be observed that when the ERV was turned on, the $PM_{2.5}$ concentration decreased significantly. It started from a peak value of 15.0μg/m^3 and gradually decreased to 6.2μg/m^3, representing a reduction of 58.6%. On the other hand, when the ERV was turned off, the $PM_{2.5}$ concentration remained relatively high, fluctuating between 14 to 16μg/m^3.

Figure 6 illustrates the CO_2 concentration in the experimental area and the office area when the ERV was completely turned off. On the day when the ERV was off, and the MAPSV6 air box was placed in both the experimental and office areas, it can be observed that the CO_2 concentration reached its highest point, peaking at 1200ppm in the morning. This increase in CO_2 concentration was attributed to the presence of eight people in the laboratory during that time. Since the ERV was fully turned off, there was no fresh outdoor air introduced, resulting in the indoor CO_2 concentration remaining consistently above the discomforting level of 600ppm for an extended period.

Figure 7 shows the $PM_{2.5}$ concentration in the experimental area and the office area when the ERV was turned off, and the MAPSV6 air box was placed in both locations. Because of the turning off of the ERV, without providing air circulation and turbulence, the $PM_{2.5}$ concentrations in the environment, as shown in the figure, were consistently low, remaining below 3 μg/m^3 throughout the monitoring period.

Figure 8 shows that the CO_2 concentration in the experimental area and the office area when the ERV was fully turned on, and the MAPSV6 air box was placed in both locations. The figure shows that the time when CO_2 concentration exceeding 600 ppm was only around 130 minutes, indicating that the majority of the monitoring period experienced CO_2 concentrations below 600 ppm. This demonstrated that the ERV provided excellent indoor air quality by effectively reducing the CO_2 concentration.

Figure 9 shows the $PM_{2.5}$ concentration in the experimental area and the office area when the ERV was fully turned on, and the MAPSV6 air box was placed in both locations. From the figure, it is evident that the $PM_{2.5}$ concentration data in both the experimental and office areas exhibited similar patterns. This suggested that the airflow conditions were relatively uniform and consistent in both areas. The close resemblance in data performance indicated that increasing the fresh outdoor air by 500CMH through the ERV led to a more evenly distributed airflow throughout the indoor environment.

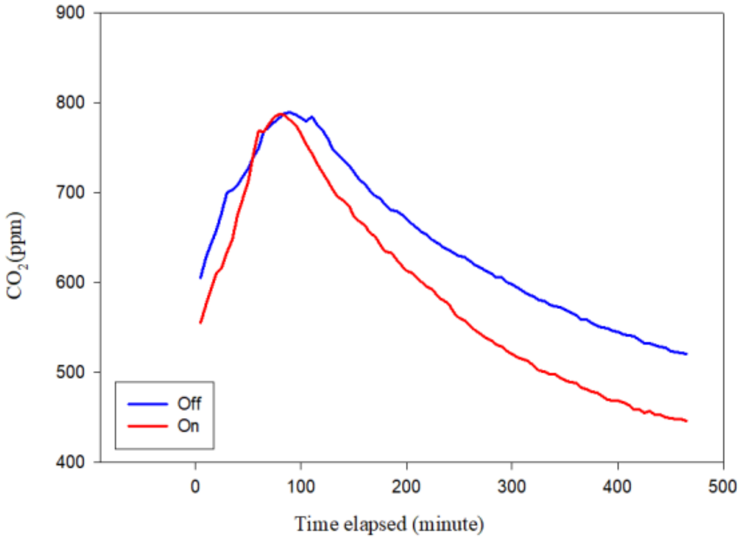

Figure 4: The variation of CO_2 concentration over time with the ERV turned on or off.

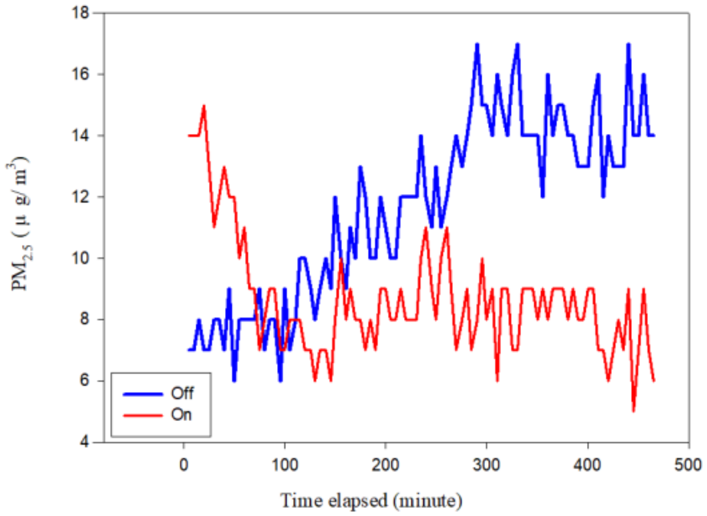

Figure 5: The variation of $PM_{2.5}$ concentration over time with the ERV turned on or off.

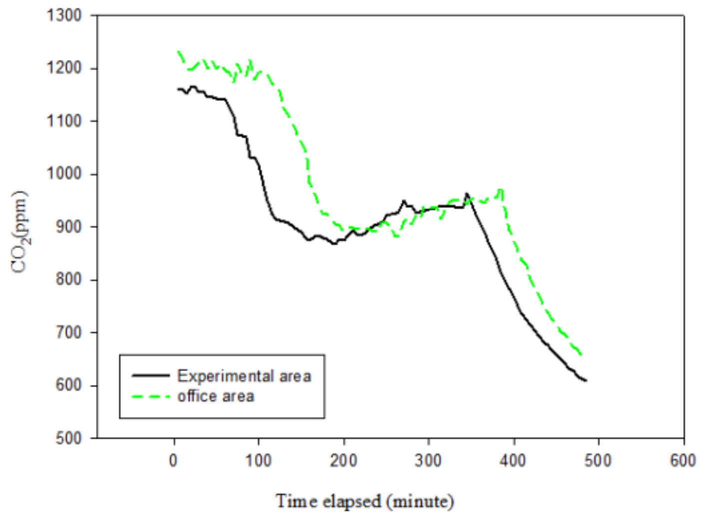

Figure 6: The variation of CO_2 concentration over time with the ERV turned off.

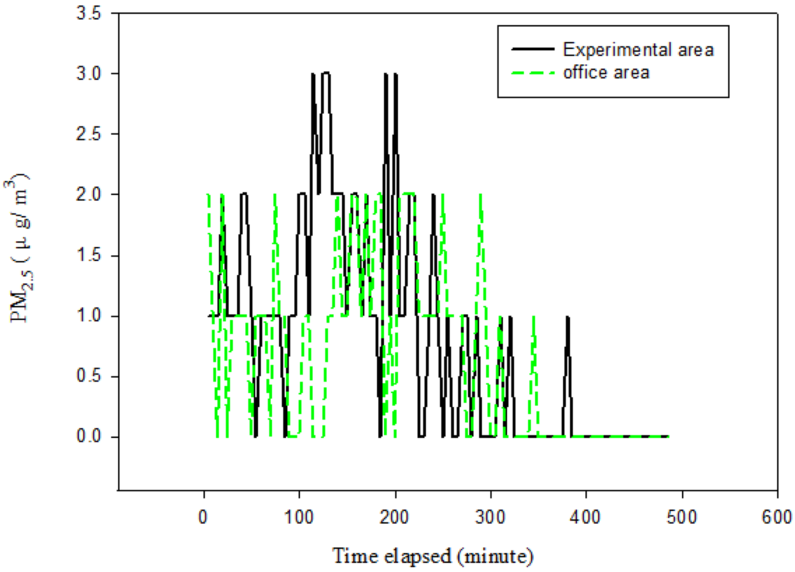

Figure 7: The variation of $PM_{2.5}$ concentration over time with the ERV turned off.

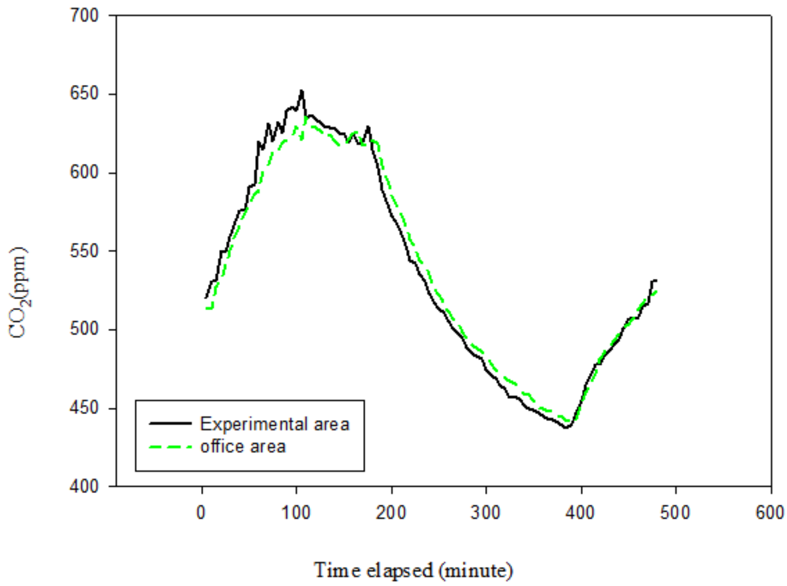

Figure 8: The variation of CO_2 concentration over time with the ERV turned on.

The Improvement by Installing an Additional Air Duct

Since personnel spent a significant amount of time in the office area, this location was specifically analyzed.

During the overall airflow observation of the laboratory, two issues were identified:

I.The return air inlet of the total heat exchanger on the ceiling did not have an additional duct extension, resulting in a short-circuit airflow phenomenon that negatively impacted overall air circulation.

II.The positions of the first two personnel in the office area had almost no detectable airflow. When particulate pollutants spread through the air, their movement paths tend to break at these points, causing particles to settle at the end of the path.

To address the issues of short-circuit airflow, uneven airflow distribution in the office area, and the risk of pollutant deposition, an additional air duct was designed to extend the return air inlet to the front of the office area. This allows contaminated indoor air to be effectively removed through this duct, as illustrated in Figures 10-12.

The MAPSV6 air quality monitor was placed at the front of the office to collect CO_2 concentration data. The results showed a significant decrease in CO_2 levels after the installation of the duct, with values remaining below 600ppm afternoon, as shown in Figure 13. Obviously, the problem of no flow or stagnant flow situation in the front section of experimental area is solved.

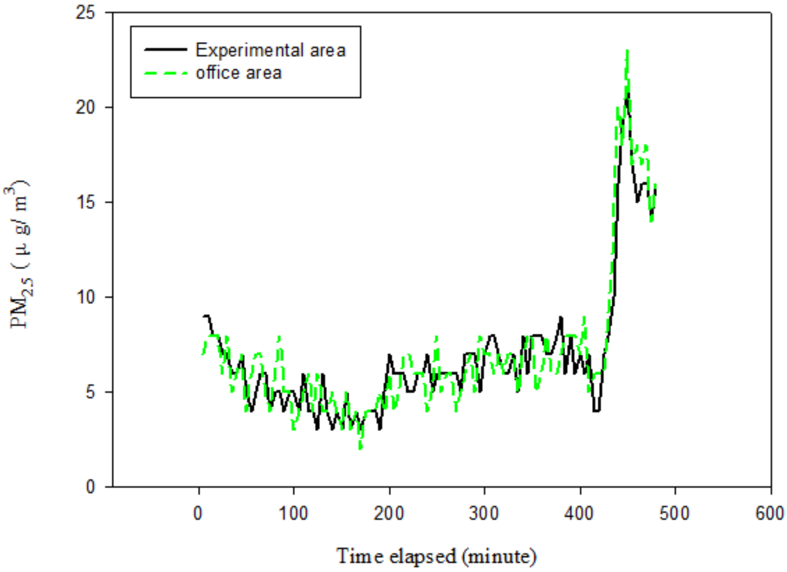

Figure 9: The variation of $PM_{2.5}$ concentration over time with the ERV turned on.

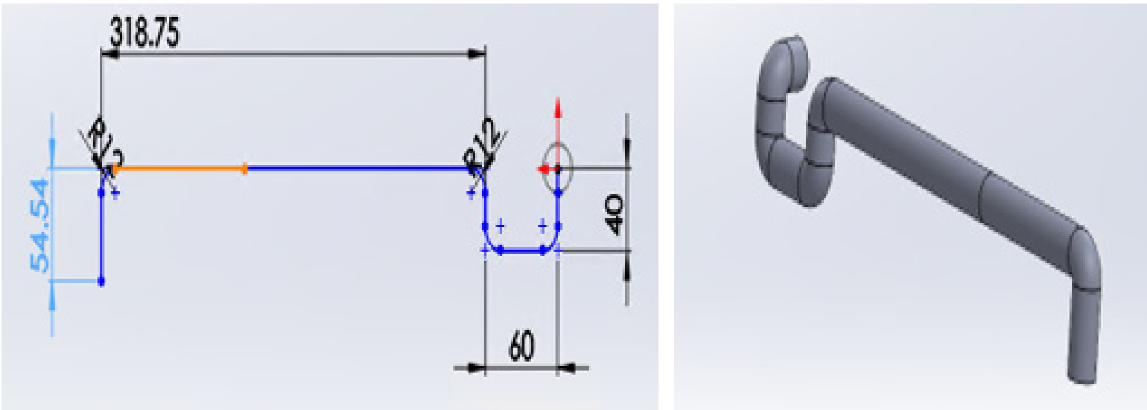

Figure 10: Additional air duct (unit: mm).

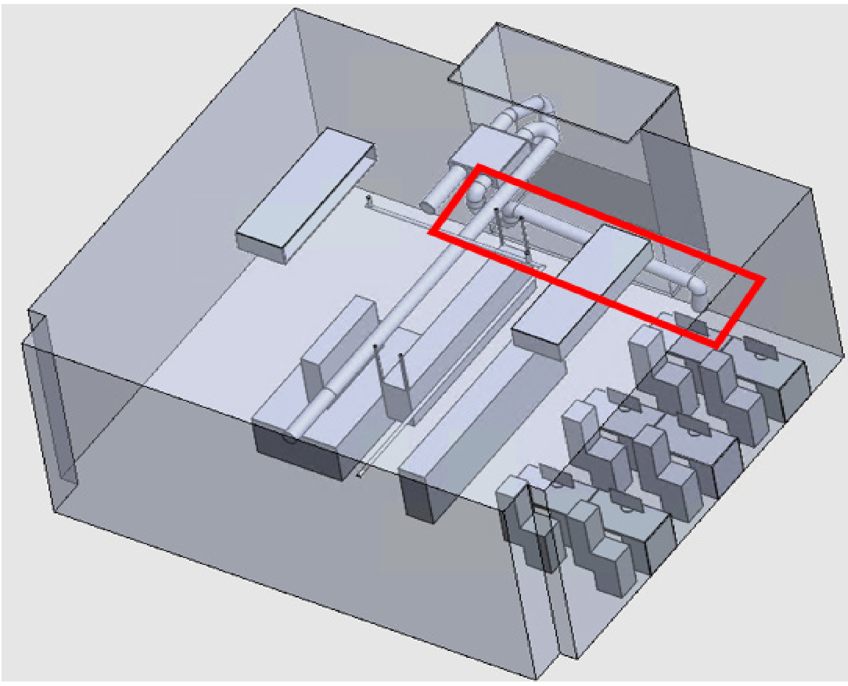

Figure 11: The schematic location of the additional air duct.

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Figure 12: Photo of the additional air duct installation.

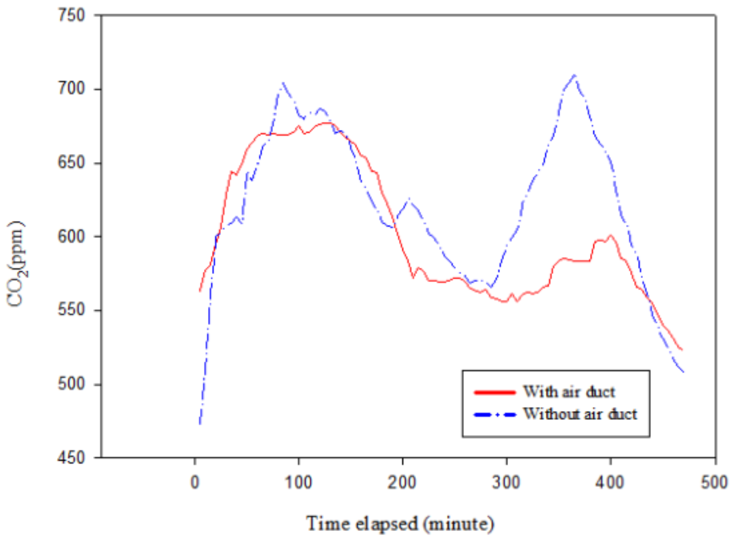

Figure 13: The CO_2 concentration comparison before and after the installation of additional air duct.

Conclusions

To improve indoor air quality, this study investigated the effectiveness of energy recovery ventilation (ERV) to determine the impact of the concentration of CO_2 and particulate matter. With the ERV activated, the concentration of CO_2 reaches below the standard level 100minutes earlier, reaching a minimum of 420 ppm; while the concentration of $PM_{2.5}$ remains between 6-10μg/m^3. Furthermore, the airflow was observed to address the issues of flow non-uniformity and short-circuit. By installing an external air duct, the problem of no flow situation in the front section of experimental area is solved, and the concentration of CO_2 is confirmed to decrease to a minimum of 525ppm.

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