

RENSAIR

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CASE STUDY

Real-world trial confirms efficacy of Rensair in-vehicle air purifiers

INDEPENDENT TRIAL CONDUCTED BY

Delos[™]
Innovate Well

rensair.com

PARTICIPANTS

The participants in this independent, real-world indoor air quality trial were:

ORGANISER



Delos is a global wellness leader with a mission to enhance health and well-being in the spaces where we live, work and play.

Built on ground-breaking collaboration between experts across building and health sciences, Delos develops products, programs and solutions that transform our environments into vehicles for health, well-being, performance and resilience.

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AIR PURIFICATION

RENSAIR

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Rensair is a specialist in portable air purification, using HEPA filtration and germicidal UVC light to trap and destroy harmful particulate matter.

Offering a full consultative service, Rensair solutions have been widely installed in the healthcare sector, governmental buildings, schools, retail and office spaces around the world.

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Rensair provided Rensair AirBubbl air purifiers for this trial, which was conducted independently by Delos. The results were subsequently shared with Rensair for this write-up.

ABSTRACT

Air purification test case in a taxi

Humans are exposed to a large variety of airborne pollutants inside a vehicle, namely Particulate Matter (PM) and noxious gases, which cause significant health effects. These pollutants are sourced either directly inside the vehicle or can infiltrate from polluted air outside the vehicle.

The Covid pandemic highlighted the importance of air quality inside all vehicles to prevent airborne disease transmission, but in-car filtration rarely meets the specifications to remove airborne pathogens, while travelling in vehicles with open windows leads to increased human exposure to traffic pollution.

A solution is to continuously filter the air within the vehicle using simple to retrofit air purifiers, which remove both particulate matter and noxious gases, and also allow a vehicle to travel with closed windows. However, there is limited research on the effectiveness of air purifiers in reducing the levels of pollutants in vehicle cabins.

This study, conducted by Delos using a car installed with Rensair AirBubbl air purifiers and air quality sensors, set out to determine the effectiveness of air purifiers in reducing air pollution while also mitigating airborne disease transmission risk.

The data from this trial demonstrated the performance of Rensair's AirBubbl air purifiers in reducing in-cabin pollution. The results showed a 59% and 54% reduction in Particulate Matter in simulations of light and dense traffic conditions respectively.

The outcome corroborates other independent tests carried out on the Rensair AirBubbl which demonstrate its effectiveness in reducing PM and noxious gases in enclosed indoor spaces.

INTRODUCTION

Humans are exposed to a large variety of airborne pollutants inside vehicles that cause significant health effects. These include:

- Particulate Matter (PM) - including fuel particulates, brake and tyre matter, as well as airborne pathogens (viruses and bacteria); and
- Dangerous gases, including Volatile Organic Compounds (VOCs) and Carbon Monoxide (CO), which can come from interior car materials and finishes, tobacco/e-cigarette smoke, fuel and exhaust fume leakage.

These pollutants are sourced either directly inside the vehicle or can infiltrate from outside polluted air.¹ Research clearly demonstrates the negative health effects associated with in-vehicle cabin exposure to air pollutants and pathogens, making it an important public health concern.

People spend a significant amount of time in vehicles. Americans, for example, spend on average about 6 percent (equivalent to 79 minutes) of their time in a vehicle.² Public transport and taxi drivers, whose vehicle is also their workplace, spend a considerably longer amount of time exposed to airborne pollutants, as do commuters travelling long distances in cars, taxis, buses and trains.

Numerous factors affect pollution levels in vehicles, all of which need to be taken into account when considering strategies to reduce in-cabin concentration of air pollutants:

- The number of passengers and their health/behaviour
- The type, age and condition of the vehicle
- HVAC settings and air exchange rates

- Driving conditions
- Traffic volume and driving routes
- Travel distance and vehicle speed.

While modern vehicles are commonly equipped with cabin air filters that remove airborne particles, their removal efficiency for ultrafine particles (UFPs) is low.³ Furthermore, significant variations in filtration efficiencies (50–90% at a particle size range of 0.3–0.5 µm) are reported for different filters.⁴ And crucially, built-in car air filtration systems are typically not effective in removing gas pollutants such as VOCs and CO.

Covid highlighted the importance of air quality inside all vehicles to prevent airborne disease transmission. During the pandemic, strategies to improve air quality in taxis and for-hire vehicles largely included opening windows, wearing masks and limiting passenger numbers. While these strategies combine to reduce infection transmission, for example by diluting the concentration of potentially infectious pathogens inside the cabin, research is lacking on the potential negative effects of these measures, for example in increasing in-cabin air pollution intake from open windows in heavy traffic.

An alternative solution is to continuously filter the air within the vehicle using air purifiers, removing both Particulate Matter and noxious gases. However there is limited research on the effectiveness of air purifiers in reducing the levels of pollutants in vehicle cabins.

PILOT STUDY AND METHODOLOGY

To better understand how air and airborne particles move within the confines of a vehicle, and to gauge how portable air purifiers perform within those spaces, a pilot study was undertaken by Delos using a taxi in different simulated traffic situations.

The study was conducted in a test taxi (2019 Toyota Camry), representative of vehicles used by Swan Taxis, a subsidiary of ComfortDelGro Corporation Australia (CDC). The experiments were conducted in Melbourne, Australia in October 2021. During the trials, the taxi was in a stationary condition inside a warehouse with the engine running in idle mode.

An artificial smoke source was placed outside the taxi to simulate a polluted outdoor environment (e.g. a highway) and to test the efficiency of an air purifier in reducing high levels of pollutants that infiltrated the vehicle.

One driver and three passengers (one in the front and two in the back passenger seats) were present in the taxi during the tests, with both the windows and the vehicle doors closed.

The internal car HVAC (Heating, Ventilation, Air Conditioning) system was varied to evaluate the efficacy of the air purifiers in cleaning the air in different HVAC conditions. Two HVAC modes were tested: recirculation mode, where no outside air was introduced to the vehicle, and outdoor air mode, where outside air was drawn into the vehicle and existing air was expelled from the vehicle.

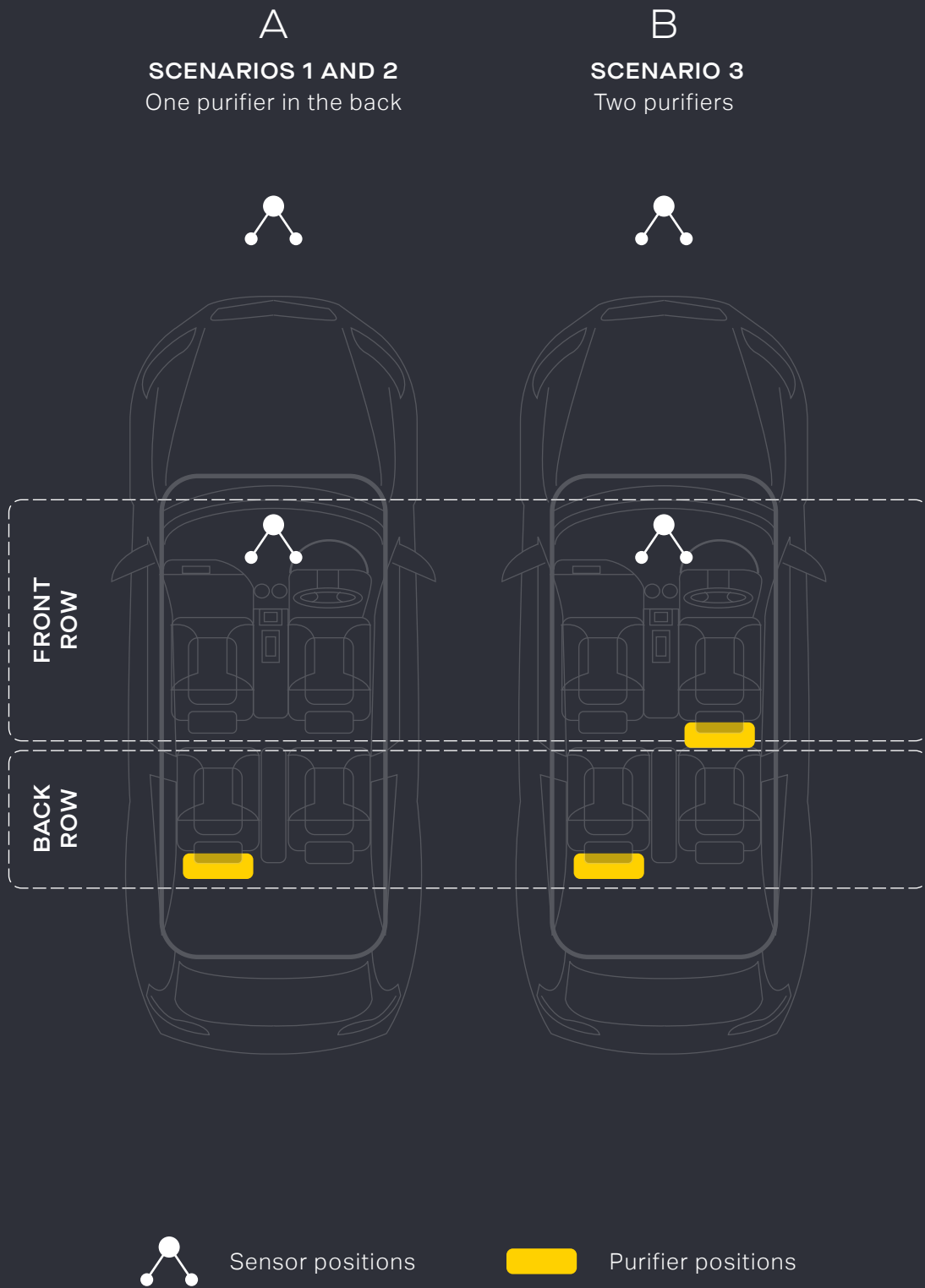
Two AirBubbl in-car air purifiers manufactured by Rensair were used. The purifiers were installed inside the vehicle cabin: one behind the driver's headrest and one behind the back passenger's headrest as indicated in Figure 1. These air purifiers feature two modes of operation: normal mode and boost mode. The normal mode of operation was used in scenarios 1 and 2, and the boost mode was used in scenario 3.

Concentrations of pollutants were rigorously monitored every 5 seconds both inside and outside of the taxi, including registering levels of Particulate Matter (PM_{2.5}) and Carbon Dioxide (CO₂):

- PM₁, PM_{2.5} and PM₁₀ mass concentrations (µg/m³) were measured using the TSI DustTrak DRX aerosol monitor model 8533.
- CO₂ and CO concentrations (ppm), temperature (°C), and relative humidity (%) were measured using the GrayWolf DirectSense II monitor.
- Total Volatile Organic Compound (TVOC) concentration (ppb) was monitored using the ppbRAE 3000 monitor model PGM-7340.

To record in-vehicle air quality data, the sensors were placed on the dashboard in front of the driver's seat. To record outdoor air quality data, the sensors were placed on a tripod 3 metres in front of the vehicle (to avoid the impact from pollutants generated by the car exhaust). The placement of the air purifiers and sensors is shown in Figure 1.

FIGURE 1. PORTABLE AIR PURIFIERS AND SENSORS PLACEMENT



HVAC SETTINGS AND THE THREE SCENARIOS TESTED:

When the HVAC system was set to recirculation mode, CO₂ concentration readings quickly accumulated inside the vehicle's cabin due to human respiration. Drowsiness is considered a potential risk for traffic accidents. Indeed, exposure to high Carbon Dioxide (CO₂) levels in vehicles may result in unpleasant feeling, fatigue, drowsiness or lethargy among drivers and passengers.⁵ This significantly limits the amount of time an HVAC system should be used in recirculation mode.

On the other hand, setting the vehicle's HVAC system to outdoor air mode potentially introduces outdoor pollution into the cabin.

Therefore this study aimed also to test whether it was possible to reduce PM2.5 levels and maintain low CO₂ levels by combining the use of portable air purifiers with the outdoor air mode setting of the vehicle's HVAC system.

SCENARIO 1

Scenario 1 had one air purifier placed on the back passenger's headrest and used the vehicle's HVAC system on recirculation mode (where no outdoor air was provided and only in-vehicle air was recirculated within the vehicle cabin). The air purifier was not used for the first 30 minutes of the experiment and only turned on for the remaining 30 minutes of the experiment, operating on the normal mode. As noted previously, Scenario 1 is unlikely to occur in real life as the buildup of CO₂ would lead to the occupants quickly becoming drowsy, which would be a dangerous environment.

SCENARIO 2

Scenario 2 had one air purifier placed on the back passenger's headrest and set the vehicle's HVAC system to outdoor air mode (where outdoor air is drawn into the vehicle and circulated within the vehicle cabin). The air purifier was not used for the first 30 minutes of the experiment and only turned on for the remaining 30 minutes of the experiment, operating on the normal mode. This scenario would be similar to a vehicle travelling in light traffic conditions.

SCENARIO 3

Scenario 3 included an artificial pollutant source (burning incense smoke), which was introduced outside the taxi to test the air purifiers' effectiveness in reducing high concentrations of pollutants within the vehicle cabin. This scenario would be similar to the vehicle travelling in a dense traffic environment. One air purifier was placed on the back of the driver's headrest and one on the backseat passenger's headrest. The vehicle's HVAC system was set to outdoor air mode (where outdoor air is drawn into the vehicle and circulated within the vehicle cabin). The two air purifiers were not used for the first 15 minutes of the experiment and then both air purifiers were switched on and set to boost mode for the last 15 minutes of the experiment.

Each scenario was repeated twice under the same conditions on the same day. Table 1, on the next page summarises the conditions of each scenario.

TABLE 1. DIFFERENT SCENARIOS

SCENARIO	Scenario 1		Scenario 2		Scenario 3	
DURATION	30 minutes	30 minutes	30 minutes	30 minutes	15 minutes	15 minutes
AIR PURIFIERS STATUS	Off	On	Off	On	Off	On
NUMBER AND LOCATION OF THE AIR PURIFIERS	1 back	1 back	1 back	1 back	1 front 1 back	1 front 1 back
AIR PURIFIERS MODE	Normal	Normal	Normal	Normal	Boost	Boost
HVAC MODE	Recirculation	Recirculation	Outdoor Air	Outdoor Air	Outdoor Air	Outdoor Air
ENGINE STATUS	Running	Running	Running	Running	Running	Running
WINDOWS /DOORS	Closed	Closed	Closed	Closed	Closed	Closed
OCCUPANTS	1 driver 3 passengers	1 driver 3 passengers	1 driver 3 passengers	1 driver 3 passengers	1 driver 3 passengers	1 driver 3 passengers
ARTIFICIAL POLLUTANT	No	No	No	No	Yes	Yes

Results

SCENARIO 1

CHART 1. INDOOR AND OUTDOOR CONCENTRATIONS OF PM2.5 IN SCENARIO 1 WITH THE HVAC SYSTEM IN RECIRCULATION MODE

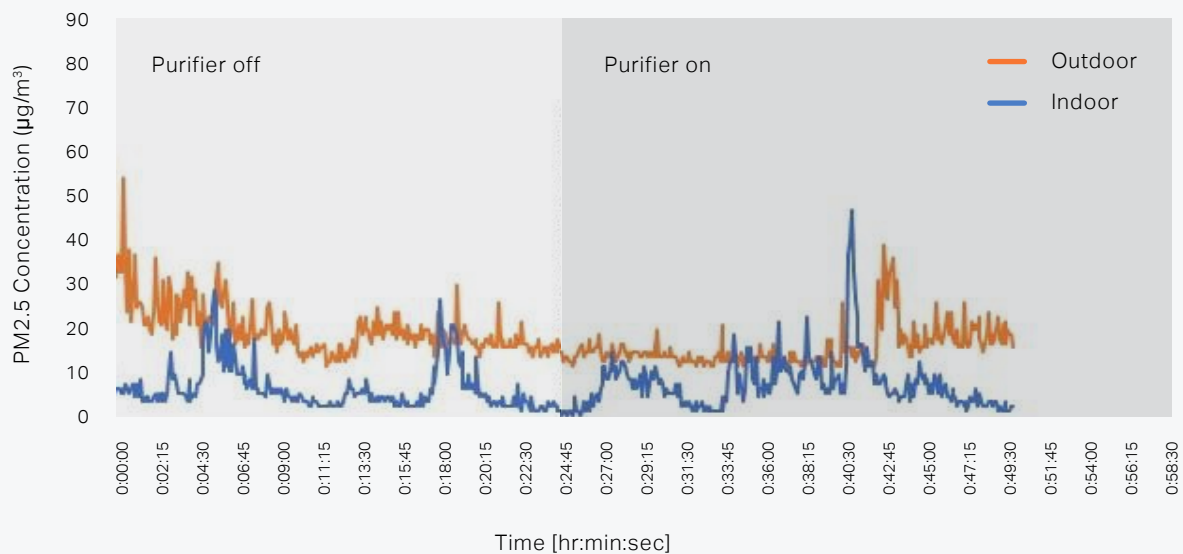


Chart 1 illustrates the indoor and outdoor mass concentrations of PM2.5 for Scenario 1, where the in-vehicle air was recirculated.

The average PM2.5 concentration without the use of the air purifier was $7\mu\text{g}/\text{m}^3$. The average concentration was very similar after turning the purifier on. It is likely that the lack of change in average PM2.5 concentration was because the PM2.5 concentration was already very low when the air purifier was switched on.

Furthermore it should be remembered that the CO₂ readings in this scenario were very high as the HVAC was in

recirculation mode and oxygenated air was not introduced into the cabin. Thus the advantage of the low readings is counteracted by the risk of creating a dangerous driving environment with the likelihood of driver drowsiness if the vehicle is driven for anything but a short amount of time.

It is important to note that while the readings in Scenario 1, without the air purifier switched on, were low, high average exposure to PM2.5 in vehicles is common in a wide range of countries, including Indonesia ($87\text{--}119\mu\text{g}/\text{m}^3$), Turkey ($30.6\text{--}120.4\mu\text{g}/\text{m}^3$), China ($54.5\text{--}71.6\mu\text{g}/\text{m}^3$), Canada ($8.6\text{--}71.9\mu\text{g}/\text{m}^3$), and USA ($12\text{--}35\mu\text{g}/\text{m}^3$).⁶

SCENARIO 2

CHART 2. INDOOR AND OUTDOOR CONCENTRATIONS OF PM2.5 IN SCENARIO 2 WITH THE HVAC SYSTEM SET TO OUTDOOR AIR MODE

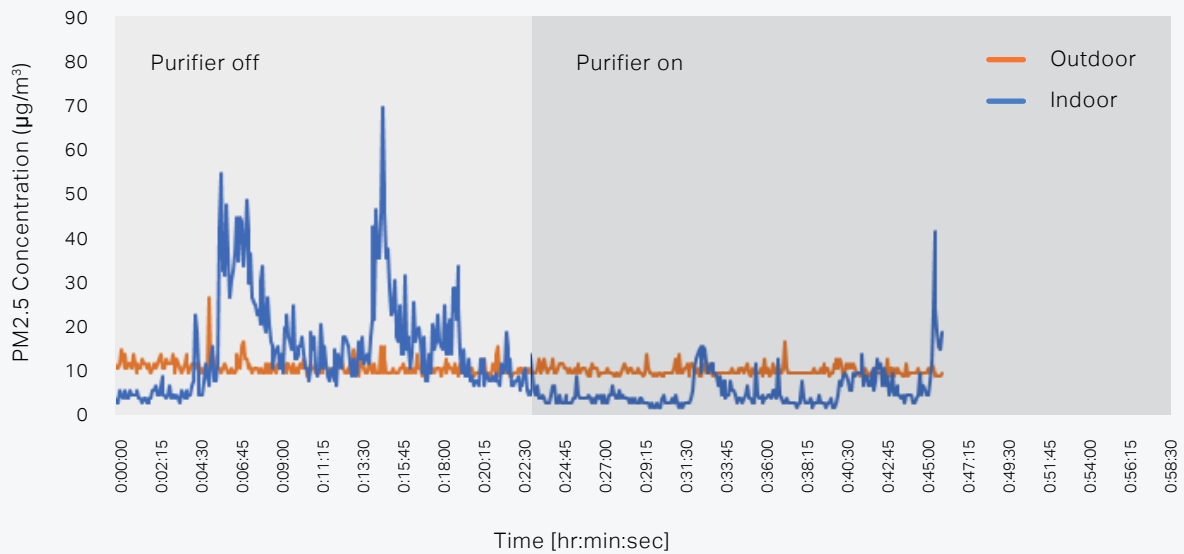
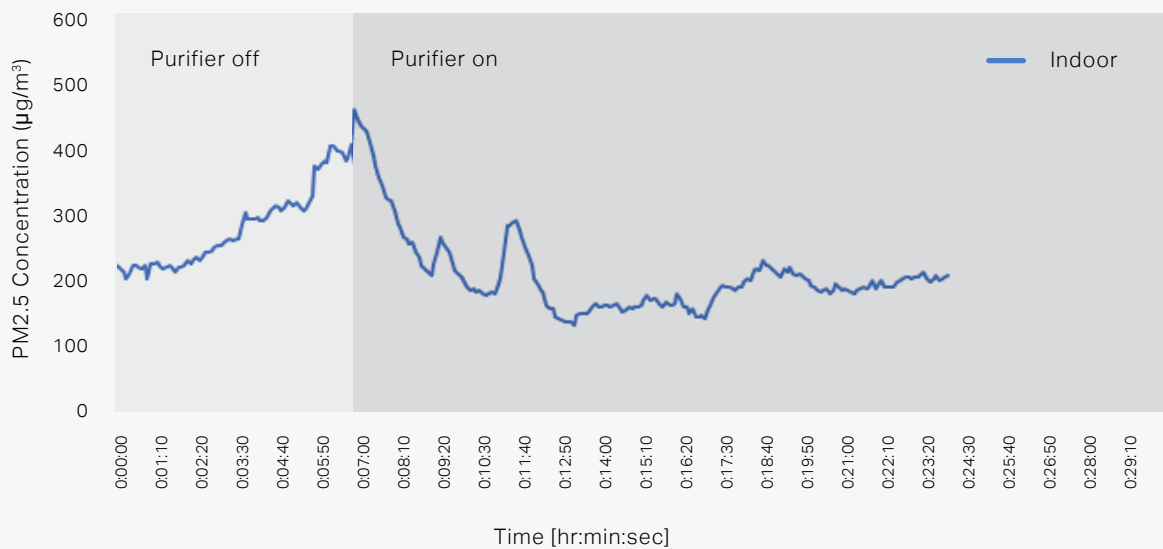


Chart 2 reports the indoor and outdoor mass concentration data of PM2.5 for scenario 2, where the in-vehicle HVAC system was set to outdoor air mode, drawing in outside air into the vehicle.

In the first 23 minutes of the experiment, when the air purifier was not in operation, the PM2.5 concentration averaged 17µg/m³. After the purifier was turned on, the PM2.5 concentration decreased to an average of 7µg/m³, a 59% reduction in PM2.5 concentration inside the vehicle.

SCENARIO 3

CHART 3. INDOOR CONCENTRATIONS OF PM2.5 IN SCENARIO 3, WITH THE HVAC SYSTEM SET TO OUTDOOR AIR MODE AND INCENSE BURNING OUTSIDE THE TAXI



In scenario 3 an artificial pollutant source was introduced by burning incense outside the taxi to simulate a highly polluted urban environment. The pollutants generated by the incense entered the taxi's cabin when the HVAC system was set to outdoor air mode.

Chart 3 shows the indoor mass concentration of PM2.5 for scenario 3. In this scenario, the HVAC was set to outdoor air mode, allowing the artificial pollutants generated outside the taxi to enter the taxi's cabin.

In the first period of the experiment, when the two purifiers were not utilized, the indoor PM2.5 levels started to increase and reached 438 µg/m³. After the two air purifiers were turned on and set to boost mode, the measured PM2.5 mass concentration inside the taxi's cabin decreased significantly to 200 µg/m³. This translates to a 54% reduction in PM2.5 levels after 16 minutes of air purifier use.

LIMITATIONS

It is important to note that this study was intended as a proof-of-concept to examine the effectiveness of air purifiers in personal vehicles. This study was conducted under stationary conditions. Given the complexity and number of variables that must be accounted for in real-world driving conditions, the findings are likely not representative of product performance with real-world use.

It should be noted that there were deviations from the protocol that affected the quantity of data collected for each scenario. As evident in the results section, for all three testing scenarios, the data collection timeframes were slightly less than the timeframes specified in the protocol. Fortunately, enough data was collected to demonstrate the effectiveness of the air purifiers in removing in-cabin PM2.5.

While this deviation did impact the quantity of data collected for each scenario, it did not affect the reliability of the data.

Additionally, in some scenarios, the HVAC mode was changed while the air purifiers were on. By simultaneously changing two independent variables (the HVAC mode and air purifier use), it was unable to attribute the reduction of in-cabin pollutants solely to air purifier use, thereby invalidating these results. Thus, these scenarios were omitted and the results were not reported.

Lastly, while the intention was to capture and measure infiltration of emission gasses such as NO₂ and SO₂, the monitoring equipment was not sufficiently sensitive to reliably measure the concentrations in the taxi cabin.

Conclusion

This study investigated the impact of using portable air purifiers on the in-cabin PM_{2.5} concentration inside a taxi.

Compared to when no air purification was used, there was a substantial reduction in PM_{2.5} levels inside the vehicle when Rensair AirBubbl air purifiers were utilized and the car HVAC system was drawing in outside air.

The study also demonstrated that when the taxi's HVAC system was set to recirculation mode, CO₂ concentrations quickly accumulated inside the vehicle's cabin, due to human respiration.

Using Rensair portable air purifiers with the vehicle's HVAC system set to outdoor air mode could be a potential strategy to reduce the levels of PM_{2.5}, without exposing the passengers to high levels of CO₂.

This study is only the first step in trying to understand the benefits of air purification in vehicles. Given the limited number of studies currently available on air purification in vehicles in real-world conditions, more research is needed.

REFERENCES

- ¹ Xu, B., Chen, X., & Xiong, J. (2018). Air quality inside motor vehicles' cabins: A review. *Indoor and Built Environment*, 27(4), 452–465. <https://doi.org/10.1177/1420326X16679217>
- ² Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., ... & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, 11(3), 231–252. <https://doi.org/10.1038/sj.jea.7500165>
- ³ Lee, E. S., & Zhu, Y. (2014). Application of a high-efficiency cabin air filter for simultaneous mitigation of ultrafine particle and carbon dioxide exposures inside passenger vehicles. *Environmental science & technology*, 48(4), 2328–2335. <https://doi.org/10.1021/es404952q>
- ⁴ Heo, K. J., Noh, J. W., Lee, B. U., Kim, Y., & Jung, J. H. (2019). Comparison of filtration performance of commercially available automotive cabin air filters against various airborne pollutants. *Building and Environment*, 161, 106272.
- ⁵ Ruey-YuChenaKin-FaiHobTa-YuanChangcGui-BingHongdChien-WeiLiueKai-JenChuang. In-vehicle carbon dioxide and adverse effects: An air filtration-based intervention study. <https://www.sciencedirect.com/science/article/abs/pii/S0048969720315606?via%3Dihub>
- ⁶ Maji, K. J., Namdeo, A., Hoban, D., Bell, M., Goodman, P., Nagendra, S. S., ... & Alshetty, D. (2021). Analysis of various transport modes to evaluate personal exposure to PM_{2.5} pollution in Delhi. *Atmospheric Pollution Research*, 12(2), 417–431. <https://doi.org/10.1016/j.apr.2020.12.003>

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