Assessment of Indoor Air Quality of Modernized Jeepney in Manila

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Abstract

People are aware that outdoor air pollution is harmful to their health, but indoor air pollution can also cause serious health complications. This study aims to determine the indoor air quality of modernized jeepneys to identify the best solutions to eliminate harmful emissions and provide comfort and good health for the occupants. The researchers conducted an IAQ assessment, including the following concentrations: carbon dioxide, carbon monoxide, PM_{10}, $PM_{2.5}$, formaldehyde, temperature, and relative humidity. In addition, a correlation of the parameters with the number of passengers and the cycle of opening-closing of the door were identified. A survey was conducted to explain the sampling results further. Based on the results, $PM_{2.5}$ and PM_{10} were the only contaminants that appeared to be within the standards. Temperature and carbon dioxide both have a relationship with the number of passengers. Carbon dioxide and $PM_{2.5}$ both have a relationship with the cycle of opening-closing of the door. The rest of the results and recommendations drawn based on these results are discussed in the latter part of this paper.

Keywords
Indoor air quality, modernized jeepney

1. Introduction

Jeepneys are part of every Filipino's daily life and serve as one of the primary means of transportation to the public. As time passes, the jeepneys that represented the Filipinos undergo modernization. Jeepneys are now equipped with an air conditioning system to comfort commuters (DOT, 2020). Along with the urbanization, rapid increase in the demand for infrastructures, and the increase of vehicles, commuters are exposed to health risks due to a significant amount of air pollutants. Traffic problems are not only resulting in economic losses but also causing health sickness to motorists and commuters. Vehicles stuck in traffic are also a great contributor to air pollution (CDC, 2016). The short- and long-term exposure to air pollutants can cause a range of adverse health effects on commuters (Wong et al., 2018). This IAQ management will involve controlling air pollutants and maintaining temperature and relative humidity within the acceptable standard.

The increase in the use of motor vehicles has resulted in a wide variety of dangers among the motorists and the commuters' health and environmental welfare. Poor indoor air quality could cause adverse effects among commuters (Chan, 2005). Most people know that outdoor air pollution is harmful to their health, but indoor air pollution can also cause detrimental health effects. There are not enough data provided regarding the level of pollutants in vehicle cabins. Consequently, there is an evident lack of priority towards actions about the proper maintenance of IAQ (Barnes et al.,

2018). This study aims to determine the quality of air for these modernized jeepneys to identify the best solutions to eliminate harmful emissions and provide comfort and good health for the occupants.

1.1 Objectives

The researchers assessed the indoor air quality of modernized jeepneys with the route of Munoz Market – Quiapo Church to provide and recommend engineering solutions and techniques in maintaining thermal comfort for the occupants. The specific objectives of the research are the following; to conduct an IAQ investigation that will show the levels of Carbon Dioxide (CO_2), Carbon Monoxide (CO), Particulate Matters (PM_{10} and $PM_{2.5}$), Formaldehyde (CH_2O), and the IAQ parameters (Temperature and Relative Humidity) inside the modernized jeepney; to determine whether the IAQ parameters in modernized jeepneys with route from Munoz Market – Quiapo Church are within the range of local and international IAQ standards; to determine whether there is a significant relationship between parameters and number of passengers as well as the cycle of the opening-closing door; and to provide engineering solutions and necessary recommendations for further improvement of modernized jeepney model based on the results, sited literature, and IAQ standards included in this study. A brief summary of the standards are showed in the following table 1.

Table 1. Summarize Table of Local and International IAQ Standards

Guidelines on Energy Conserving Designs of Buildings (DOE PH)		
Parameters		VALUES
Design Dry Bulb Temperature		25 °C
Design Relative Humidity		55 %
Maximum Dry Bulb Temperature		27 °C
Minimum Dry Bulb Temperature		23 °C
Maximum Relative Humidity		60 %
Minimum Relative Humidity		50 %
National Ambient Air Quality Guideline Values from RA 8749		
Parameters	Averaging Time	Values
Carbon Monoxide	8 Hours	10 ppm
Particulate Matter 2.5	24 Hours	50 ug/m^3
Particulate Matter 10	24 Hours	150 ug/m^3
ASHRAE 62.1 Standards/Guideline Values		
Pollutant	Averaging Time	Level
Particulate Matter 2.5	24 Hours	35 ug/m^3
Particulate Matter 10	24 Hours	150 ug/m^3
Carbon Dioxide	8 Hours	1000 ppm
Carbon Monoxide	8 Hours	9 ppm
GB/T 27630-2011 Guideline Value		
Pollutant	Averaging Time	Level
Formaldehyde	Eight (8) Hours	0.10 mg/m^3

2. Literature Review

2.1. Ventilation System

Ventilation is vital to ensure that the air within the vehicle is healthy enough for the people inside. It allows the contaminants from the external environment and those already inside the vehicle to be diluted and removed, allowing the outdoor air to come into and distribute within the cabin.

ASHRAE/ANSI 62.1 provided guidelines regarding the acceptable amount of outdoor air to match with and maintain the acceptable air quality inside the vehicle. These are specifically identified to acknowledge the allowable amount of inevitable, unnecessary, and harmful contaminants to keep everyone's safety inside a vehicle.

The derivation of ventilation rate from the number of occupants in the vehicle at any given time is shown in Equation 1. The recommended ventilation rate (cfm per person) is based on the given values of ASHRAE (2003) that shows the outdoor air requirements for the vehicle.

$$(1)\ \text{VCFM} = \text{NO} \times \text{N}$$

2.2. Correlation Coefficient

The correlation coefficient is used to determine the possible association and the strength of it of any variables (Schober et al., 2018) in which; in this study, the variables are the parameters, and the variables to be compared with are the cycle of opening-closing of the door and the number of passengers in the modernized jeepney. The computer correlation coefficient shall determine the type of relationship and the decision whether to reject the HO through this guideline; ±0.90 - ±1.00 - "Very Strong"; ±0.70 - ±0.89 - "Strong"; ±0.40 - ±0.69 - "Moderate"; ±0.10 - ±0.39 - "Weak"; ±0.00 - ±0.10 - "Negligible." The p-value should be computed as well, and if the p-value is less than or equal to the level of significance, which is 0.05, one shall reject the null hypothesis. The statistician used IBM® SPSS® Statistics version 23.0 for Pearson product-moment Correlation to quantitatively determine the significance of the possible association of the parameters and the two other recorded data.

3. Methods

3.1. Determination of Modernized Jeepney Company to Conduct the Study

The researchers conducted the study in a modernized air-conditioned jeepney (PM Jeepney) with the route which will start from Munoz Market – Quiapo Church. The operating hour of 6:00 a.m. to 7:00 p.m. is adjusted to comply with the government's general guidelines concerning general community quarantine. The modernized jeepneys, a class 2 public utility vehicle, can accommodate 23 passengers with a side-facing arrangement inside its cabin. The vehicle is structured using Isuzu QKR77 cab; its modifications were made by Almazora Motors Corporation, such as the chassis platform and rear body. Sanden Aircon Philippines complete its air-conditioning system.

3.2. Request for Company Approval for Conduction of the Study

The researchers provided a written request addressed to the company for the approval of the data gathering. The letter of recommendation shall include the purpose of the research, procedure of the sampling, equipment to be used, date of the actual sampling, and the names of the researchers.

3.3. Design of Data Gathering Protocol

The IAQ sampling was conducted during the first quarter of 2020 – 2021 in August. The researchers ensured that the sampling would be done during general community quarantine, which allows the operation of such public utility vehicles. The researchers monitored the sky condition every trip from the weather update on the PAGASA website online. All trials of the sampling procedure were conducted for three (3) consecutive days with a maximum duration of eight (8) hours per day in consideration of the 8-hour averaging time standard set by ASHRAE. Data logging has 5 minutes intervals from the start until the end of the journey. For additional information to enhance the data analysis, the research also recorded the number of times the door opens and closes, the status of the traffic per trip, weather during the trip, and the number of occupants.

3.4. Experimental Setup

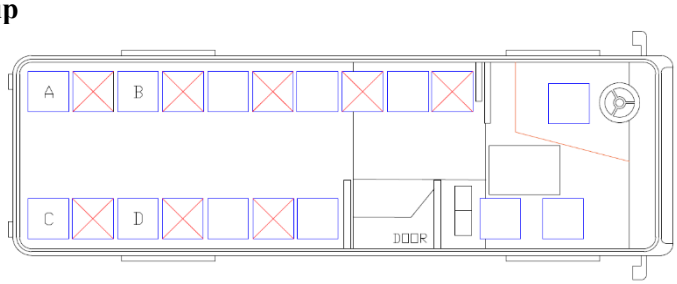

Figure 1. Sampling points location inside the modernized jeepney

Shown in Figure 1 are the four (4) placements of the sampling materials used in the study where; A is where the equipment used for $PM_{2.5}$ and PM_{10} were placed, B is where the number of passengers and cycle of closing-opening of the door were recorded, C is the location of the temperature and relative humidity measurement tools, and lastly, D is where the carbon monoxide and carbon dioxide were measured. These devices should not be placed within or directly at their breathing level to gather accurate data. Based on Chan (2005), the sampling points of the tools should be at the back part, and for CO and CO_2, these should be specifically close to the return louvers of the vehicle's ventilation

system. This rear seat location is also ideal for the seating configuration of Class 2 public utility vehicles since it allows the passenger to sit comfortably inside without being interrupted by the researchers during the assessment period.

3.5. Data Collection, Analysis, and Evaluation

This section includes the details of the sampling procedure done by the researchers to ensure that all the measurements are collected correctly and according to the guidelines. The collected quantitative data of the parameters are compared with the standards. The qualitative data of this study are from the survey answered by the commuters; through this, the researchers were able to draw a more comprehensive conclusion and recommendation for further improvement of the modernized jeepneys.

4. Results and Discussion

This includes all the results gathered during the 3-day assessment done inside the modernized jeepney. A line graph providing all the collected data and expected value per parameter will also be included to determine if the results are within the equipped standard. In addition, outlying data of all the measured parameters are also mentioned, the explanation for the possible factors affecting this irregularity are discussed in conclusion.

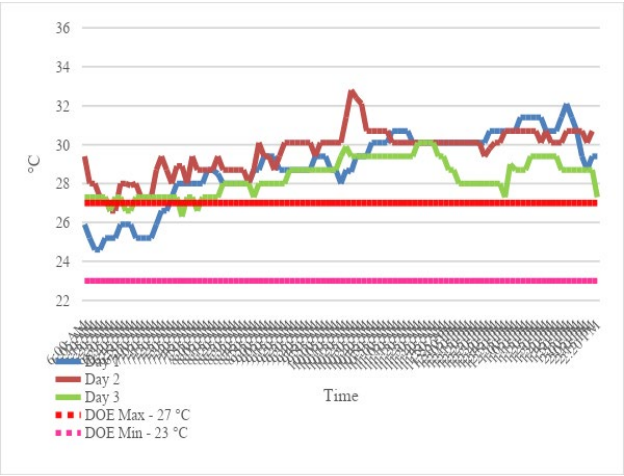

Figure 2. Comparison of temperature to DOE Guideline Values from Day 1 to Day 3

Figure 2 shows the time-weighted average of the gathered temperature levels throughout the 3-day assessment period. The obtained data are following; 28.8747 ℃, 29.609 ℃, and 30.6155 ℃ respectively. This result implies that the IAQ assessment for the temperature of the modernized jeepney is not acceptable based on the Department of Energy (DOE) Guideline Values (DOE, 2007).

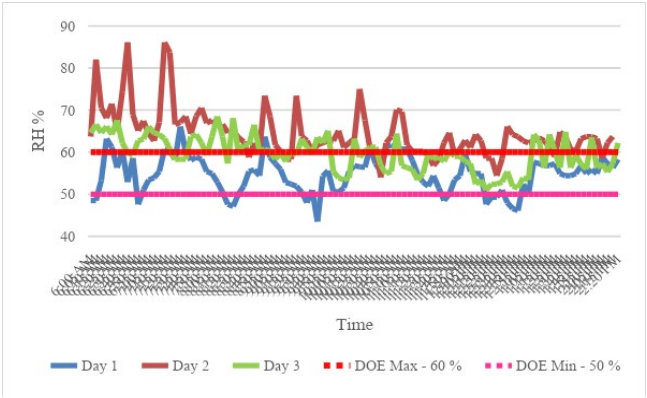

Figure 3. Comparison of relative humidity to DOE Guideline Values from Day 1 to Day 3

The computed TWA of the collected data of relative humidity percentage during the assessment period is 54.8202 %, 64.5316 %, and 59.7650 %, respectively. This shows that the assessment results of IAQ for relative humidity are not acceptable based on the guideline provided by DOE (2007) as shown in Figure 3.

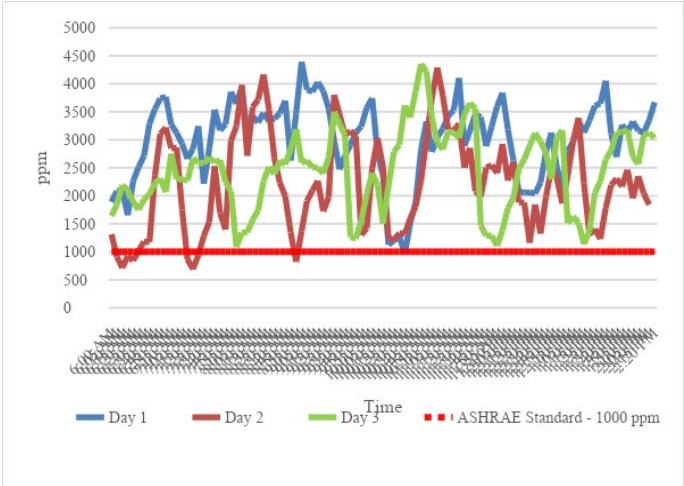

Figure 4. Comparison of Carbon Dioxide to ASHRAE 62.1 Standards/Guideline Values from Day 1 to Day 3

The TWA of the concentrations of carbon dioxide measured inside the modernized jeepney during the 3-day sampling is the following: 3030.3434 ppm, 2220.6224 ppm, and 2515.8640 ppm, respectively. This implies that the conducted IAQ assessment for carbon dioxide is not acceptable based on ASHRAE 62.1 standard as shown in Figure 4.

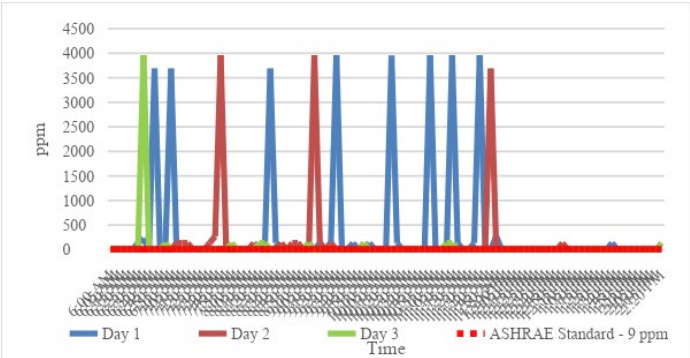

Figure 5. Comparison of Carbon Monoxide to ASHRAE 62.1 Standards/Guideline Values from Day 1 to Day 3

The TWA of the carbon monoxide concentrations gathered during the sampling period are the following: 335.8585 ppm, 136.3878 ppm, and 54.3398 ppm, respectively. These sets of results suggest that the assessment for carbon monoxide inside the modernized jeepney is not acceptable based on ASHRAE 62.1 standard as shown in Figure 5.

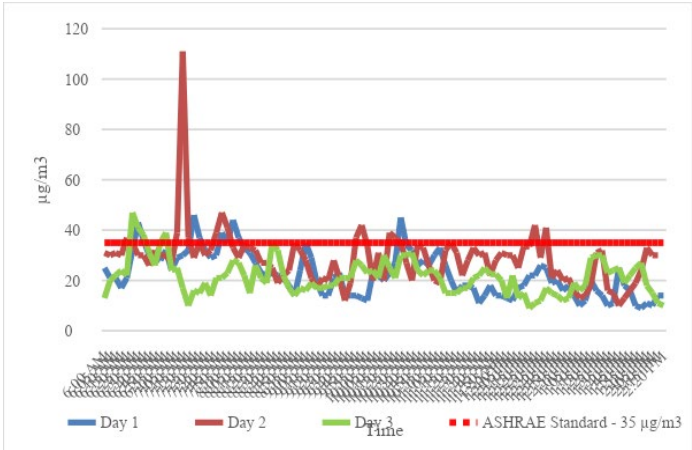

Figure 6. Comparison of Particulate Matter 2.5 to NAAQGV (RA 8749) and ASHRAE 62.1 Standards/Guideline Values from Day 1 to Day 3

The TWA of the particulate matter 2.5 concentrations collected inside the modernized jeepney during the sampling period are the following: 22.5354 µg/m3, 28.6531 µg/m3, and 21.0777 µg/m3, respectively. This shows that the IAQ assessment for particulate matter 2.5 in modernized jeepney is accepted based on the guideline values from NAAQGV and ASHRAE 62.1 as shown in Figure 6.

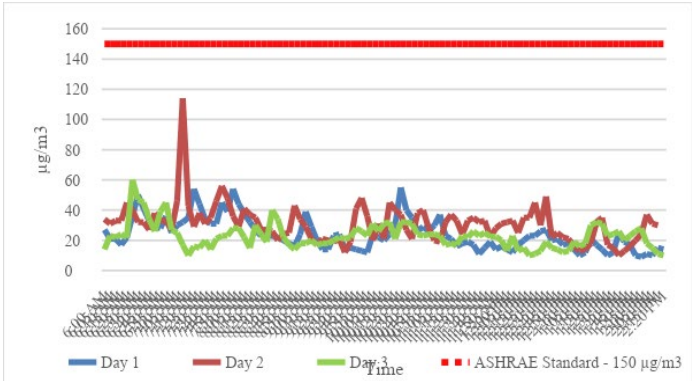

Figure 7. Comparison of Particulate Matter 10 to NAAQGV (RA 8749) and ASHRAE 62.1 Standards/Guideline Values from Day 1 to Day 3

The TWA of the PM10 concentrations measured inside the modernized jeepney during the 3-day sampling is as follows: 23.9899 µg/m3, 30.6531 µg/m3, and 22.436 µg/m3, respectively. This implies that the IAQ assessment for particulate matter 10 in modernized jeepneys is accepted based upon guideline values from NAAQGV and ASHRAE 62.1 as shown in Figure 7.

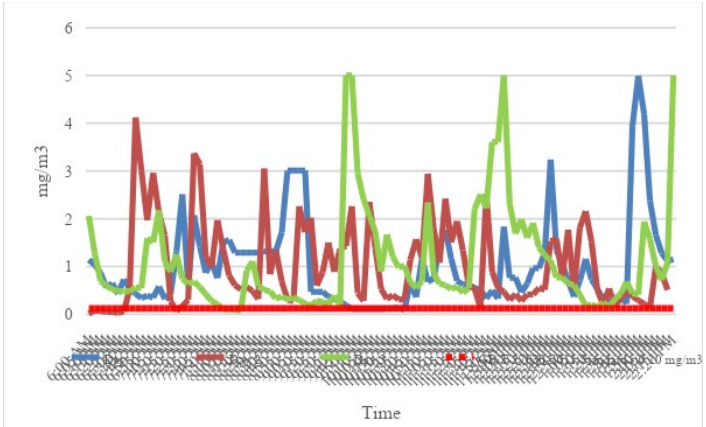

Figure 8. Comparison of Formaldehyde to GB/T 27630-2011 Guideline Value from Day 1 to Day 3

The time-weighted average of the gathered formaldehyde concentrations throughout the 3-day assessment period are following; 1.0124 mg/m^3, 1.0472 mg/m^3, and 1.0864 mg/m3. This result implies that the IAQ assessment for formaldehyde concentration of modernized jeepney is not acceptable based on GB/T 27630-2011 Guideline Value as shown in Figure 8.

4.1. Correlation of Number of Passenger / Cycle of Opening-Closing of Door and Parameters

The researchers determined whether the parameters and the numbers of passengers have a relationship and its strength. To acquire the quantitative details of this assessment, the researchers seek the help of a professional statistician who used a statistical tool, IBM® SPSS® Statistics version 23.0. The correlation coefficient and the p-value are considered to identify the relationship between the number of passengers and the parameters. The results are shown in Tables 2 and 3.

Table 2. Summarize Table for Correlation of Cycle of Opening-Closing of Door and Parameters

Parameters	Correlation Coefficient	P-Value	Decision	Remarks
Temp.	-0.410	0.478	Failed to Reject Ho	Not Significant
RH	0.110	0.055	Failed to Reject Ho	Not Significant
CO_2	0.253	0.000	Reject Ho	Significant
CO	0.010	0.859	Failed to Reject Ho	Not Significant
$PM_{2.5}$	0.007	0.908	Failed to Reject Ho	Not Significant
PM_{10}	0.009	0.879	Failed to Reject Ho	Not Significant
CH_2O	-0.038	0.505	Failed to Reject Ho	Not Significant

Table 3. Summarize Table for Correlation of Number of Passenger and Parameters

Parameters	Correlation Coefficient	P-Value	Decision	Remarks
Temp.	0.196	0.001	Reject Ho	Significant
RH	0.056	0.327	Failed to Reject Ho	Not Significant
CO_2	0.259	0.000	Reject Ho	Significant
CO	0.032	0.576	Failed to Reject Ho	Not Significant
$PM_{2.5}$	0.056	0.332	Failed to Reject Ho	Not Significant
PM_{10}	0.057	0.320	Failed to Reject Ho	Not Significant
CH_2O	-0.050	0.381	Failed to Reject Ho	Not Significant

4.2. Evaluation of Survey Results

There were 250 gathered responses varies through different demographics such as sex and age. It appears that most of the respondents are female and 25 to 34 years old. 19.6% of the respondents identified themselves as smokers, whereas 80.4% of the respondents are non-smoker.

In addition, 50.4% of the respondents say that they take a ride in a modernized jeepney for less than 30 minutes, 42.8% take it for 30 minutes to 1 hour, 6% take it for an hour to two, and lastly, 0.08% takes it for more than 2 hours. The majority of the respondents, which covers 59.4%, claim that they do not feel any discomfort while riding in a modernized jeepney; on the other hand, 40.6% say they do. Among the respondents, 58.4% emphasize that they do not think that riding in a modernized jeepney can increase the likelihood of these discomforts occurring, the 41.6% think so. Moreover, 92% percent of the respondents are in favor of the new 50% passenger capacity policy in a modernized jeepney; the other 8% claims that they are not in favor of it.

4.3. Infiltration and Exfiltration Analysis of Modernized Jeepney

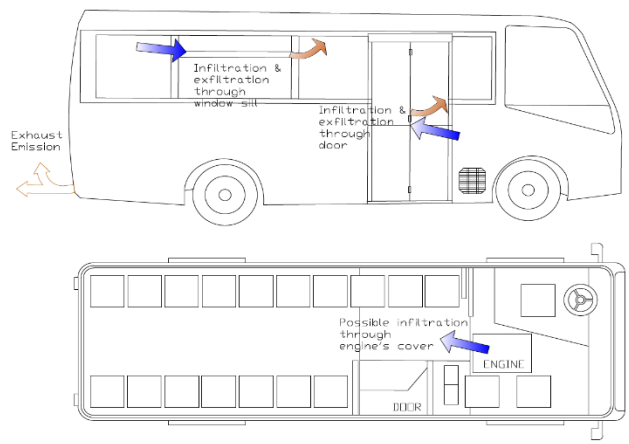

Figure 9. Possible infiltration and exfiltration inside the modernized jeepney

As shown in Figure 9, most of the time, infiltration and exfiltration in the modernized jeepney occur when the door is opened and closed. Even though it is already closed, it may still happen because of the small cracks and openings in the door or frame. The same thing applies with the vehicular windows; infiltration and exfiltration can occur through the windowsill. Inside the vehicle, infiltration can originate at the engine cover if the engine is not correctly sealed and covered.

4.4. Theoretical Engineering Solution for Ventilation System

Roof ventilation with reverse switch control for the fan blade direction (exhaust or intake) is ideal for installing the modernized jeepney. It needs a ventilation system for outdoor air and exhaust air. The researchers determined and designed a sound ventilation system to provide fresh air and dilute air pollutants. This includes the occupancy ventilation rate, air change per hour, and the number of fan/s required, based on the design consideration of ASHRAE 62.1, Ventilation for Acceptable Indoor Air Quality, to provide IAQ minimum ventilation rates that is acceptable to passengers.

The modernized jeepney has a total of 23 seating capacities (seated and standing) for passengers and an additional 2 for the driver and conductor, having a total of 25 for the number of occupants. The CO_2 generation rate of each occupant was based on the outdoor air requirements for ventilation of vehicles provided by ASHRAE, which is 15 cfm/person. CFM =375 CFM, ACH=28.8915 h-1, Nfan=1 fan.

4.5. Proposed Location of the Roof Vent in the Modernized Jeepney

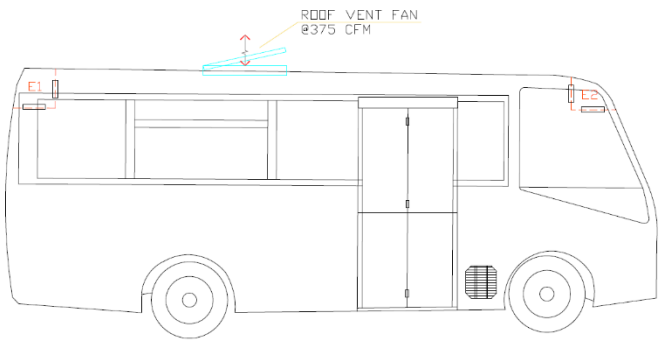

Figure 10. Proposed Roof Ventilation Fan Location

The researchers designed the proper placement of the vent in the roof of the modernized jeepney wherein the fan is between the two evaporators (front and rear A/C system) to maximize its functions, to provide fresh air to occupants and to dilute CO_2 and air contaminants. The proposed roof ventilation fan location is shown in Figure 10.

5. Conclusion

Based on the IAQ assessment, PM 2.5 and PM 10 were the indoor contaminants that appeared to be within the standards; the rest of the included parameters exceeded the guideline values. On the other hand, based on the statistical analysis, temperature and carbon dioxide have a significant relationship with passengers. Also, PM 2.5 and carbon dioxide have a substantial connection with the cycle of opening-closing doors.

Results revealed that the temperature level inside the modernized jeepneys involved in the study is higher than the baseline range. It may have been due to high heat gain since it was mostly partly sunny throughout sampling, which subsequently causes higher ambient temperature compared to the temperature inside the modernized jeepney. The concentration of relative humidity in modernized jeepneys exceeded that standard range; when this happens, it may trigger unnecessary fungi and mold formation that can cause harmful damage on both humans and the car. The concentration of carbon dioxide in the modernized jeepney involved in this study is not acceptable based on the standard comfort value. This may have been affected by various factors such as air exchange outside the vehicle, ventilation mechanism of the vehicle, travel route took during each ride and the movement of the commuters inside the vehicle. The carbon monoxide concentration gathered during the assessment was beyond the standard values; this may have been affected by the number of hours spent by the jeepney on traveling.

On the other hand, the concentrations of particulate matter 2.5 and particulate matter 10 are acceptable based on the standards. This may have been due to t6he controlled number of people inside the modernized jeepney and because the jeepney has a Euro IV engine. Lastly, it appears that the concentration of formaldehyde in the modernized jeepney involved in this study is also higher than the standard value. The formaldehyde concentrations are mainly due to the emissions coming from various interior materials found in the compartment, upholstery, ceiling, and other parts since formaldehyde is one of the components used in manufacturing these interior materials.

6. Recommendation

To regulate the in-cabin temperature of the modernized jeepney, the researchers endorse an air-conditioning system with a more flexible capacity since a load of passengers tends to vary throughout the route trip. Based on the results, the modernized jeepney has a high concentration of carbon dioxide, so it may benefit from having high-efficiency particle air (HEPA) filters or air cleaners to improve the CO_2 engagement inside the vehicle. The researchers suggest proper monitoring for any possible leakage in ducts and pipes; this may allow the gas from the exhaust to enter the vehicle if leakage occurs, and management of the modernized jeepney should also consider replacing air filters and regular, thorough cleaning to alleviate such undesirable results. The jeepney drivers should opt to close the door when traveling through polluted areas such as tunnels and congested zones. Through this, there will be an adequate control on the concentration of the PM2.5 and PM10 inside the modernized jeepney. To further improve and maintain this comfortable concentration of PM_{10}, modernized jeepney regulators may consider upgrading the air filters installed in

the vehicle and imposing a regular schedule for overall cleaning of the vehicle. Also, the driver and conductor of the jeepney should always make sure that the engine inside the vehicle is wholly sealed and adequately closed; this can also control the concentration of particulate matter 10. Lastly, for monitoring formaldehyde concentration, implementing source control can benefit modernized jeepney since it is an effective measure that focuses on monitoring and reducing emissions coming from the materials used in the vehicle's structure. In addition, the vehicle's interior materials should be pre-baked in an oven for 5 hours at 70 degrees Celsius to ensure that the amount of formaldehyde concentration of the modernized jeepney is safe for everyone inside it.

For the modernized jeepney in the study, installing a roof ventilating fan will serve as the fresh air intake for the vehicle to dilute a high concentration of Carbon Dioxide and unnecessary air contaminants that could lead to poor IAQ. HEPA Filters installed in the roof vent would reduce the air contaminants such as CO, $PM_{2.5,}$ and PM_{10} up to 99.5% entering the vehicle due to the possible infiltration through the new ventilation fan installed. It is recommended to turn on the newly installed roof ventilating fan using the remote every hour for 15 – 30 mins which are enough to replenish the needed fresh air for the passenger. The reversible switch for the exhaust fan would serve as an exit for fumes and unpleasant odor.

References

Barnes, Natasha, et. al. (2018). In-Cabin Air Quality during Driving and Engine Idling in Air-Conditioned Private Vehicles in Hong Kong. Hong Kong, China, MDPI

Chan, M.Y. (2005). Commuter's Exposure to Carbon Monoxide and Carbon Dioxide in Air-conditioned Buses in Hong Kong. Hong Kong, China, Indoor Built Environ.

Department of Transportation (2020). Protocol/ Guidelines for Public Transport Operations. Manila, Philippines.

Schober, P. et. al. (2018). Correlation Coefficients: Appropriate Use and Interpretation. Amsterdam, Netherlands, Wolters Kluwer Health, Inc.

Center for Disease Control and Prevention (2016). Carbon Monoxide Poisoning. Retrieved from https://ephtracking.cdc.gov/showCoRisk.action

Wong, L.T, et. al. (2011). In-cabin Exposure Levels of Carbon Monoxide, Carbon Dioxide and Airborne Particulate Matter in Air-Conditioned Buses of Hong Kong. Hong Kong, China.

ASHRAE (2003). Ventilation for Acceptable Indoor Air Quality. Retrieved from https://www.ashrae.org/File%20Library/Technical%20Resources/Standards%20and%20Guidelines/Standards%20Addenda/62-2001/62-2001_Addendum-n.pdf

Department of Energy, Philippines (2007). Guidelines on Energy Conserving Designs of Buildings. Retrieved from https://www.doe.gov.ph/sites/default/files/pdf/energy_efficiency/guidelines_energy_conserving_design_buildings_v2008.pdf