EXPERIMENTAL ANALYSIS OF INDOOR AIR QUALITY FOR HUMAN COMFORT IN VEHICLE CABIN

SITI NOR'AIN BINTI MOKHTAR

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2021

EXPERIMENTAL ANALYSIS OF INDOOR AIR QUALITY FOR HUMAN COMFORT IN VEHICLE CABIN

SITI NOR'AIN BINTI MOKHTAR

THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2021

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Siti Nor'Ain Bt Mokhtar

Matric No: KQK 190008

Name of Degree: Master of Mechanical Engineering

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Experiment Analysis of Indoor Air Quality for Human Comfort in Vehicle Cabin

Field of Study: Indoor Air Quality

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date: 29/09/2021

Subscribed and solemnly declared before,

Witness's Signature Date: 29/09/2021

Name:

Designation:

[EXPERIMENTAL ANALAYSIS OF INDOOR AIR QUALITY FOR HUMAN COMFORT IN VEHICLE CABIN]

ABSTRACT

In present time more people spend a relatively longer time inside their vehicles. However, the microenvironment of a vehicle cabin is vulnerable to exposure of air contaminants such as carbon dioxide, Carbon Dioxide (CO_2) and Particulate Matter PM_{10} originated from the surrounding and vehicle operation. Carbon Dioxide would cause acidosis, which is particularly harmful to the cells of the brain. Even at low-to-moderate, CO_2 (>800ppm) has been found to be associated with headache, fatigue, kidney failure and reduce cognitive ability in humans. Exposure to Particulate $Matter_{10}$ affects the lungs and heart, leading to health complication such as nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms. The purpose of this study is to assess and analyze the indoor air quality Indoor Air Quality (IAQ) of a car travelling the route between UTeM main campus and FTK campus. This experiment was conducted for Perodua Myvi and Honda Freed for 2 condition of time there is morning and evening. The assessment was conducted in a car as it was travelling along the designated route. Total route of 2 destination are16km. The 3M EVM (Environmental Monitor) was set up to measure the parameters such as temperature, carbon dioxide (CO_2), and particulate matter (PM_{10}). Additionally, the study regarding the number of passengers and vehicle operation (driving/idling) was also done. The average temperature for Perodua Myvi during morning was 26.9°C, while 27.0°C for evening which staying within the DOSH acceptable range, 26-27.0°C. Whereas the average temperature for Honda Freed during morning and evening was 27.3°C and 27.5°C respectively which exceed than Department of Safety and Health (OSH) acceptable range. The overall mean of CO_2 concentration for Perodua Myvi during morning for 2 and 5 passengers are 276 and 291 respectively. While during evening are 114 and 196 respectively. Honda Freed is gradually increase during evening up to 627 for 5 passengers compared with Perodua Myvi. In term of Particulate Matter, the experimental data for both cars during morning and evening are within acceptable range of 150µg/m^3 from United States Environmental Protection Agency (USEPA).

[EXPERIMENTAL ANALAYSIS OF INDOOR AIR QUALITY FOR HUMAN COMFORT IN VEHICLE CABIN]

ABSTRAK

Pada masa kini, lebih ramai masyarakat semakin kerap menghabiskan masa berada dalam kenderaan mereka. Walaubagaimanapun persekitaran mikro kabin kenderaan terdedah kepada pencemaran udara seperti karbon dioksida, CO_2, dan bahan zarah, PM_{10} yang berpunca daripada persekitaran dan operasi kenderaan itu sendiri. CO_2 akan menyebabkan asidosis, yang sangat berbahaya bagi sel-sel otak. Walaupun pada suhu rendah hingga sederhana, CO_2 (> 800ppm) boleh menyebabkan sakit kepala, keletihan, kegagalan buah pinggang dan mengurangkan kemampuan kognitif terhadap manusia. Pendedahan kepada PM_{10} mampu mempengaruhi paru-paru dan jantung yang akan menyebabkan komplikasi kesihatan seperti serangan jantung yang tidak membawa maut, degupan jantung yang tidak teratur, asma yang buruk, penurunan fungsi paru-paru dan peningkatan gejala pernafasan. Tujuan ujikaji ini dilakukan adalah untuk menilai dan menganalisis kualiti udara dalaman sesebuah kereta yang menempuh laluan antara kampus utama UTeM ke kampus FTK. Ujikali ini dilakukan terhadap Perodua Myvi dan Honda Freed iaitu pada 2 keadaan, pagi dan petang. Penilaian ini dijalankan di dalam kereta dan menempuh jarak laluan yang ditentukan. Jumlah jarak bagi 2 destinasi tersebut adalah 16km. EVM 3M (Monitor Lingkungan) digunakan untuk mengukur parameter seperti suhu, karbon dioksida (CO_2), dan bahan partikulat (PM_{10}). Selain itu, kajian mengenai jumlah penumpang dan jenis operasi kenderaan (memandu /kereta tidak dipantu) juga dilakukan. Suhu purata untuk Perodua Myvi pada waktu pagi adalah 26.9 ° C, sementara 27.0 ° C ketika waktu petang iaitu masih dalam lingkungan piawai DOSH iaitu 26-27.0 ° C. Manakala suhu purata untuk Honda Freed pada waktu pagi dan petang masing-masing adalah 27.3 ° C dan 27.5 ° C yang melebihi julat piawaian DOSH. Purata keseluruhan kepekatan CO_2 untuk Perodua Myvi pada waktu pagi untuk 2 dan 5 penumpang masing-masing adalah 276 dan 291. Sementara pada waktu petang masing-masing adalah 114 dan 196. Honda Freed secara beransur-ansur meningkat pada waktu petang hingga mencapai nilai 627 bagi 5 penumpang berbanding kereta Myvi. Dari segi bahan partikulat, data ujikaji bagi kedua-dua kereta pada waktu pagi dan petang berada dalam lingkungan 150µg / m3 yang masih diterima mengikut piawai USEPA.

ACKNOWLEDGEMENTS

First and Foremost, praises and thanks to the God, the Almighty for his showers of blessings throughout my research work to complete the research successfully. I would like to express my deep and sincere gratitude to my supervisor, Prof. Madya Ir. Dr. Nik Nazri Bin Nik Ghazali for giving me the opportunity to do Research Project Study and providing invaluable guidance and insights throughout this research. His dynamism, vision, sincerity and motivation have deeply inspired me. He has taught me the methodology to carry out the research and present the research works as clearly as possible. His guidance has helped immensely in making sure the study is properly researched and meet the standards for UM's Research Project study. It was a great privilege and honor to work and study under his guidance. I am extremely grateful for what he has offered me.

I am extending my heartful thanks to my lovely husband for his understanding, sacrifice and also guidance from the technical-side to make this research experiment and project successfully. I would also express my gratitude to Faculty of Mechanical and Manufacturing Engineering Technology (FTKMP, UTeM) for giving permission for the borrowing of tools to be used when experiment are been conducted. On the other hand, big thanks also address to my mother with always to support me on this Master's journey. Hope that all the effort will give a lot of benefit to be used in future.

TABLE OF CONTENTS

Abstract iii

Abstrak iv

Acknowledgements 1

Table of Contents 2

List of Figures 5

List of Tables...7

List of Symbols and Abbreviations 8

List of Appendices 10

CHAPTER 1: INTRODUCTION 11

1.1 Background of study 11

1.2 Problem Statement 12

1.3 Objective 13

1.4 Scope of study..14

CHAPTER 2: LITERATURE REVIEW 15

2.1 Indoor Air Quality 15

2.1.1 Sick Building Syndrome 15

2.2 Study on Vehicle Indoor Air Quality...16

2.2.1 Factors influencing Vehicle Indoor Air Quality......................................17

2.2.2 Indoor Air Quality Guideline 18

2.3 Air Pollutant...19

2.3.1 Carbon Dioxide (CO2) 20

2.3.2 Particulate Matter (PM10 and PM2.5) 20

2.4 Previous vehicle IAQ studies...22

2.4.1 Past findings 24

CHAPTER 3: METHODOLOGY 26

3.1 Introduction 26

3.2 Project Flow Chart 27

3.3 Scope of measurement 28

3.3.1 Location of study 28

3.3.2 Vehicle specification 29

3.4 Equipment 29

3.4.1 Instrument Setup 30

3.5 Data Collection 32

3.5.1 Sampling Procedures 33

3.5.2 Car activity monitoring 34

3.6 Data Quality 35

3.7 Data Analysis 36

3.7.1 Analysis of temperature, concentration of CO2 and PM10 36

3.8 Expected outcomes 37

CHAPTER 4: RESULT AND DISCUSSION 39

4.1 Introduction 39

4.2 Vehicle IAQ overview 39

4.2.1 IAQ analysis of the route between FTK and UTeM main campus 50

4.3 Factors influencing Indoor Air Quality 56

4.3.1 Number of passenger 56

4.3.2 Vehicle operation 57

4.4 Conclusion 62

4.5 Recommendation for future study 63

References 64

LIST OF FIGURES

Figure 3.1: Flow Chart 27

Figure 3.2: Selected route for study 29

Figure 3.3: Sensor Location of 3M EVM 30

Figure 3.4: 3M EVM Instrument placement of Perodua Myvi 31

Figure 3.5: 3M EVM Instrument placement of Honda Freed 32

Figure 3.6: Working method of EVM and Detection Management Software 33

Figure 3.7: PM10 Adjusting Impactor 35

Figure 3.8: Calibration of EVM using Zero/HEPA filter 36

Figure 4.1: Particulate Matter and CO_2 concentration of Myvi during morning (2 passengers) 42

Figure 4.2: Particulate Matter and CO_2 concentration of Myvi during morning (5 passengers) 43

Figure 4.3: Particulate Matter and CO_2 concentration of Freed during morning (2 passengers) 44

Figure 4.4: Particulate Matter and CO_2 concentration of Freed during morning (5 passengers) 45

Figure 4.5: Particulate Matter and CO_2 concentration of Myvi during evening (2 passengers) 46

Figure 4.6: Particulate Matter and CO_2 concentration of Myvi during evening (5 passengers) 47

Figure 4.7: Particulate Matter and CO_2 concentration of Freed during evening (2 passengers) 48

Figure 4.8: Particulate Matter and CO_2 concentration of Freed during evening (5 passengers) 49

Figure 4.9: Morning IAQ parameter (Temperature) 50

Figure 4.10: Evening IAQ parameter (Temperature) 50

Figure 4.11: Morning IAQ parameter (PM10) 51

Figure 4.12: Morning IAQ parameter (PM10) 51

Figure 4.13: Morning IAQ parameter (CO_2) 52

Figure 4.14: Evening IAQ parameter (CO_2) 52

Figure 4.15: Average Data of 2 Passengers 53

Figure 4.16: Average Data of 5 Passengers 53

Figure 4.17: Myvi 2 passengers (Idling) 57

Figure 4.18: Myvi 5 passengers (Idling) 57

Figure 4.19: Freed 2 passengers (Idling) 58

Figure 4.20: Freed 5 passengers (Idling) 58

Figure 4.21: CO_2 concentration (Vehicle Operation) 2 passengers 60

Figure 4.22: CO_2 concentration (Vehicle Operation) 5 passengers 60

Figure 4.23: PM_{10} (Vehicle Operation) 2 passengers 61

Figure 4.24: PM_{10} (Vehicle Operation) 5 passengers 61

LIST OF TABLES

Table 2. 1: List of indoor air contaminants and the acceptable limits 18

Table 2. 2: Acceptable range of specific physical parameters 19

Table 2.3: Past Studies of Bus Indoor Air Quality 22

Table 3. 1: Technical Specification Variables in Experiment.. 28

Table 3. 2: Experiment Equipment 30

Table 4.1: Summary of Experiment Result per session (Driving) 40

Table 4.2: Min and Max data of CO2 concentration 55

Table 4.3: Min and Max data of Particulate Matter, PM_{10}.. 55

Table 4.4: Comparison Data during Driving and Idling (Evening) 59

LIST OF SYMBOLS AND ABBREVIATIONS

UTeM	:	Universiti Teknikal Malaysia Melaka
FTK	:	Fakulti Teknologi Kejuruteraan
IAQ	:	Indoor air quality
VIAQ	:	Vehicle Indoor Air Quality
CO	:	Carbon monoxide
CO_2	:	Carbon dioxide
VOC	:	Volatile organic compound
PM	:	Particulate Matter
RH	:	Relative Humidity
OPFR	:	Organophosphate Flame Retardant
NBFR	:	Novel Brominated Flame Retardant
WHO	:	World Health Organization
DOSH	:	Department of Safety and Health
USEPA/EPA	:	United States Environmental Protection Agency
ASHRAE	:	American Society of Heating, Refrigerating and Air Conditioning
HEPA	:	High Efficiency Particulate Absorbing
SVOC	:	Semi-volatile organic compound
NO	:	Nitrogen Oxides
OA	:	Outside air
RC	:	Recirculate-air
ACF	:	Activated Carbon Filter
BC	:	Black Carbon

UFP	:	Ultrafine Particles
SBS	:	Sick Building Syndrome
DMS	:	Detection Management Software

LIST OF APPENDICES

APPENDIX A: Freed 2 passenger- idling 69

APPENDIX B: Freed 5 passenger- idling 70

APPENDIX C: Myvi 2 passenger- idling 71

APPENDIX D: Myvi 5 passenger- idling 72

APPENDIX E: Freed 2 passenger (morning)-EVM A 73

APPENDIX F: Freed 5 passenger (morning)-EVM A 74

APPENDIX G: Myvi 2 passenger (morning)-EVM A 75

APPENDIX H: Myvi 5 passenger (morning)-EVM A 76

APPENDIX I: Freed 2 passenger (evening)-EVM A 77

APPENDIX J: Freed 5 passenger (evening)-EVM A 78

APPENDIX K: Myvi 2 passenger (evening)-EVM A 79

APPENDIX L: Myvi 5 passenger (evening)-EVM A 80

INTRODUCTION

1.1 Background of study

Good indoor air quality (IAQ) is required for a healthy indoor work environment. Poor indoor air quality can cause a variety of short-term and long-term health problems. Health problems commonly associated with poor IAQ include allergic reactions, respiratory problems, eye irritation, sinusitis, bronchitis and pneumonia. IAQ problems occur in buildings that are served by a mechanical ventilating and air conditioning (MVAC) system including air-cooled split unit. IAQ problems can be due to indoor air pollutants or to inadequate ventilation. This study is focus on IAQ specifically in vehicles cabin. More people spend a relatively longer amount of time inside their vehicles, however, the attention been given researching vehicle interior air quality (VIAQ) is considerably less than compared to building indoor air quality (Underwriters Laboratories UL LLC, 2015). The microenvironment of a vehicle on the other hand is exposed to many sources of air contaminants, either from inside the cabin itself or outside fumes. According to (Xu et al., 2018), even with only spending 5.5% of time inside automobiles, the exposure to unhealthy concentration of emissions both from the components of vehicle's interior and the exhaust fumes which carried by the supply ventilation air are noticeably significant.

Over the year, the researchers have carried out analysis in order to obtain the data of how polluted a space is (or in some cases, the vehicle's cabin) by conducting indoor air quality (IAQ) study and analysis. By definition IAQ is the quality of air inside a building or enclosed structures. The Department of Safety and Health (DOSH) describes it as how the inside air can affect a person's health, comfort, and ability to do work. It includes and not limited to temperature, humidity, mould, bacteria, poor ventilation, and chemical exposure (DOSH, 2020). For vehicles, the indoor air pollutants are volatile organic compounds (VOCs), carbon oxides (COx), particulate matter (PM), Legacy and novel brominated flame retardant ((N)BFRs), organophosphate flame retardant (OPFRs), and conventional and electronic smoking, as listed in the journal article by (Zulauf et al., 2019). However the most commonly studied and discussed are carbon dioxide (CO_2), VOC, and particulate matter (PM_{10} and $PM_{2.5}$).

The contaminants contained within the space need to be at certain concentration in order to maintain good indoor air quality. These standards are provided by DOSH, USEPA, or ASHRAE, listing the air contaminants and their respective concentration values. If the concentration were to exceed the guideline, the chances for the indoor air to mortally effect the occupants can increase, resulting in health issues such as eye, throat, or nose irritation, dizziness. Long-term exposure can lead to fatigue, respiratory disease, heart disease or even cancer (Unites States Environmental Potection Agency, 2020).

1.2 Problem Statement

In Universiti Teknikal Malaysia (UTeM) one of the mode of transportation commonly used to transit is by using car. Cars serve as one of the preferred mode of commuting for majority of the Faculty of Engineering Technology (FTK) students living in the UTeM main campus and needed to get to the FTK campus for class. Typically, a student would spend a collective total of 15 to 30 minutes a day on their cars transiting between FTK campus and the main campus. Occasionally, the car is packed when they are carpooling, and sometimes left the car on idle either waiting for friends or due to traffic. Possibly leading to potential indoor air pollution inside the cabin.

Recent studies conducted focusing on indoor air quality (IAQ) for vehicle's interior have suggested the trend of carbon dioxide (CO_2) gas build-up resulting in high concentration during operation, potentially endangering the driver and passengers, example; (Kim, H., Yang, X., Ryu, S., & Yu, 2018), (Chiu et al., 2015). Similarly, particulate matter (PM_{10} and $PM_{2.5}$) are also observed such as the study conducted by

(Jang, 2018) which is linked to traffic and ambient air quality that similarly pose harmful effects on the commuters' health. The mentioned circumstances are likely experienced by UTeM students in a sense that a number of them transit on a daily basis using their car. It is also common for them to carpool which substantially increase the car passenger capacity, affecting the carbon dioxide level. The traffic condition of the route between the UTeM main campus and the FTK campus might also affect the car IAQ level especially fine particles. However there have been no study monitoring these parameters inside a car while using this route. Hence, data for indoor air quality inside the vehicle cabin would be beneficial to assess the exposure level of the student who carpool to FTK campus daily to understand the risk, including identifying which factors influencing the car air quality.

For this study, the purpose will be primarily to assess the IAQ of the car cabin for aforementioned carbon dioxide (CO_2) and particulate matter (PM_{10}) parameters during transit. Subsequently, study the effect number of passenger and car operation (driving and idling) has on CO_2 and PM_{10}. This experiment will carry out using 2 types of car namely Perodua Myvi and Honda Freed.

1.3 Objective

i. To access and analyze the cabin indoor air quality (CO_2 and PM_{10}) of car with compares to the IAQ standard by DOSH ad USEPA for Low and High passengers capacity.

ii. To analyze the difference between driving and idling of vehicle operation.

1.4 Scope of study

The assessment will be conducted in a car simulating student traveling between UTeM main campus and FTK campus. The measuring parameters measured for this study are carbon dioxide (CO_2), particulate matter (PM_{10}), and temperature. The testing was conducted in two sessions; morning and evening to simulate the normal time for travelling before class and back to the campus of the day. Each session was conducted by monitoring and recording the parameters as the car completing the trip using the route for 30 minutes to assess the level of IAQ during the morning and evening. This followed by testing the IAQ under controlled condition to study the effect of for passenger count and vehicle operation. The outside road driving testing were conducted at constant speed of 90-100 km/h with air tight condition and constant speed of air conditioner.

LITERATURE REVIEW

2.1 Indoor Air Quality

Indoor air quality (IAQ) refers to the quality of air inside a building that resulted to its habitants' state of health and comfort (Unites States Environmental Potection Agency, 2020). The air quality is able to give an understanding of how a person's health, comfort and performance are affected by the indoor air, through various chemicals, including gases (i.e., carbon monoxide, ozone, and radon), volatile organic compounds (VOCs), particulate matter (PM) and fibres, organic and inorganic contaminants, and biological particles such as bacteria, fungi, and pollen (Cincinelli & Martellini, 2017). The vast number of variables that impact IAQ and the effect they have of human health have prompted many study kind of study being conducted in order identify the IAQ level of common spaces, such as office building, conducted by (Al-Hemoud, 2018) and (Mandin et al., 2017), and residential homes, (Sun, Y., Hou, J., Cheng, R., Sheng, Y., Zhang, X., & Sundell, 2019). The study of IAQ is crucial because the effect of difference state of air quality is noticeable, not only by odours but also through health symptoms such as; irritations (eyes, nose, or throat), dry mucous membranes and skin, erythema (reddening or flushing of the face or skin), mental fatigue, airway infections (cough), hoarseness (wheezing), and nausea (dizziness), (Axelrad, 2009).

2.1.1 Sick Building Syndrome

Sick building syndrome (SBS) is the term used to describe the situation where the residence suffers from health complications and discomfort from being inside a particular building, (Akinwale et al., 2019). The American Association of A/C Engineers and Heating and Refrigeration Standards (ASHRAE) classifies a premise as "sick building" when at least 20% of the occupants exhibit symptoms and complains of discomfort for more than 2 weeks, and if the affected occupants does not show signs of discomfort when they are no longer inside the building, (Barbu et al., 2019). The symptoms attributed to SBS are acute signs of discomforts such as headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odours, (Environmental Protection Agency & Environments Division, 1991). It is believe that poor ventilation rates and ineffective air circulation to be the main culprit for SBS, where high number of indoor and outdoor pollutions (air contaminants; CO, CO_2, VOCs and particulates) being circulated throughout the building and negatively impact its IAQ (Passarelli, 2009).

2.2 Study on Vehicle Indoor Air Quality

Vehicle interior indoor air quality (VIAQ) is similar to building IAQ in aspect that both are the study of exposure of various kind of air pollutants (e.g. particulate matter (PM), volatile organic compound (VOC), semi-volatile organic compound (SVOC), carbon monoxide (CO), and nitrogen oxides (NO). The aforementioned pollutants can also be found inside a vehicle's cabin (Xu et al., 2018). In vehicle setting, they are originated from emission of different sources, typically from the vehicle itself and surrounding. Example being formaldehyde (used as adhesive for making vehicle dashboards) is originated from the material when it breaks down and causes emission to be released inside the vehicle, and Benzene, which is the by-products of vehicle combustion emission (Underwriters Laboratories UL LLC, 2015). Lastly, pollutants such as PM_{10} and $PM_{2.5}$ are often associated with ambient pollutions. Furthermore, the concentration air pollutants inside a vehicle can also reached up to double or triple the amount than that of other indoor environment because of the more confined space of the cabin. (Faber & Brodzik, 2017).

The claim of high in-cabin concentration level does reflects in a couple of recent IAQ studies. An assessment lead by (Barnes et al., 2018). An investigation is carried out for the in-cabin air quality of private vehicles in Hong Kong. Out of 51 tested vehicle, 24% exceeded the recommended level of TVOCs by the Hong Kong Environmental Protection Department. Meanwhile, 96% exceeded the recommended CO_2 level of 1000 (part per million) ppm; 16% >5000 ppm, with the exception of carbon monoxide (CO) level and microbial counts which are low (Barnes et al., 2018).

Another study on by (Kim, H., Yang, X., Ryu, S., & Yu, 2018) concluded that the CO2 concentrations can reached up to 5000 ppm and 6000 ppm when the number of car passengers increased, while the car was in recirculate-air (RC) mode. It is only when the car switched to outside air (OA) mode and takes in outside air, the concentration was around and below 1000 ppm, and significantly improved with the application of ACF filters.

2.2.1 Factors influencing Vehicle Indoor Air Quality

Based on the results of the previously mentioned studies have shown that the concentration of air pollutants inside vehicle can reach beyond what considered as the safe limit, however they are also not fixed and instead influenced by how the vehicle operates. Similar statement also made in study by (Pham et al., 2019) and includes the factors such as:

1. Outside ambient air quality
2. number of occupants
3. fan speed
4. vehicle speed
5. cabin volume
6. cabin filter efficiency

2.2.2 Indoor Air Quality Guideline

The study of IAQ uses guidelines established by WHO, ASHRAE, DOSH, or any authorized body specializing in environment, safety and health in order to determine the quality of air in a given space. The space is considered suitable for resident as long as the existing contaminants are under certain limits: carbon monoxide <10 ppm; respirable particle < 0.15 mg/m^3 (DOSH, 2020). The complete table provided by the Malaysia Department of Safety and Health (DOSH) listed as below:

Table 2. 1: List of indoor air contaminants and the acceptable limits

Indoor Air Contaminants	**Acceptable limits**		
	Ppm	**mg/m3**	**cfu/m3**
Chemical contaminants			
a) Carbon monoxide	3	-	-
b) Formaldehyde	10	-	-
c) Ozone	0.1	-	-
d) Respirable particulates	0.05	-	-
e) (e) Total volatile organic compounds (TVOC)	-	0.15	-
Biological contaminants			
a) Total bacterial counts	-	-	500*
b) (b) Total fungal counts	-	-	1000*
Ventilation performance indicator			
a) (a) Carbon dioxide	C1000	-	-

According to Industry Code of Practice on Indoor Air Quality 2010, by DOSH and Department of Human Resources, Malaysia, (DOSH, 2010), the acceptable range specific physical parameters are:

Table 2. 2: Acceptable range of specific physical parameters

Parameters	Acceptable range
Temperature	23 – 26^{o}C
Relative Humidity	40 – 70%
Air Movement	0.15 - 0.50 m/s

Meanwhile the United States Environment Protection Agency (USEPA) NAAQS set the level concentration for particulate matter, PM_{10} to be on the level of 150 µg/m^3 (24-hour mean not to be exceeded more than once per year, over 3 years). While $PM_{2.5}$ is to be within 35 µg/m^3 (24-hour mean, not to be exceeded more than once per year over a 3-year period). Though not directly applicable to the indoor environment, these levels provide a basis for understanding public health risk, assuming a long-duration, annual exposure.

2.3 Air Pollutant

Air contaminants present in indoor environment exist in various forms such as the previously mentioned formaldehyde, a type of volatile organic compound (VOC). There are many other pollutants present in the setting, including carbon monoxide (CO), other types of organic chemicals (e.g. benzene, and toluene), nitrogen oxides (NO). However, the most commonly studied type of pollutants in VIAQ are carbon dioxide, CO_2 and particulate matter (PM_{10}, $PM_{2.5}$) (Masyita et al., 2017) (Xu et al., 2018) (Ding et al., 2016).

2.3.1 Carbon Dioxide (CO_2)

The mean concentration of CO_2 in outdoor setting is around 400 ppm, and 800 ppm of concentration for indoor setting (Cha, 2019). In IAQ studies, it is often used as the indicator for adequate ventilation of a space, with general baseline value for acceptable level of CO2 is below <1000 ppm, (Abdullah et al., 2018).

It is evident that the CO_2 level inside vehicles can exceeds the 1000 ppm limit, and experience certain influx due to certain condition which allows for the emission of CO_2. The IAQ of train cabin by (Masyita et al., 2017) in Malaysia displays an unhealthy level of IAQ with the mean for CO_2 to be 1007 ±53.25 ppm and 1217 ± 112.84 ppm during travel and return journey respectively. Where slight concentration increase was experienced during the boarding of passengers and assumed to be caused by the increased number of passenger.

High level of CO_2 can have impact on the health for the occupants over a certain period of exposure. It is often associated with typical minor health symptoms such as drop in work performance and increased absence. If the level exceeds 600 ppm, the severity may resulted in headache, drowsiness, difficult in concentrating and dizziness (Chiu et al., 2015).

2.3.2 Particulate Matter (PM10 and PM2.5)

Another air contaminants present in cabin microenvironment are particulate matter and fine particulate matter (PM_{10}, $PM_{2.5}$). PM_{10} is particulate matter 10 micrometers or less in diameter, $PM_{2.5}$ is particulate matter 2.5 micrometers or less in diameter. $PM_{2.5}$ is generally described as fine particles. By way of comparison, a human hair is about 100 micrometres, roughly 40 fine particles could be placed on its width (Autralian Government Department of Agriculture, 2019).

The particles are either man-made or natural; the prior being the by-products of engine combustion, by-products of industrial activities, and pavement erosion by road traffic and abrasion of brakes and tyres. While the later are formed in the air through chemical reactions of gaseous pollutants released via traffic emission and industrial process, and are mostly found in fine PM (World Health Organisation, 2013).

PM_{10} typically originated as dust from construction sites, landfills and agriculture, wildfires and brush/waste burning, industrial sources, wind-blown dust from open lands, pollen and fragments of bacteria. Black carbon (BC), particulate matter with diameters less than 2.5 mm ($PM_{2.5}$), and ultrafine particles (UFP, particles with diameters < 100 nm) are considered as traffic-related pollutants, and research suggests that a significant fraction of a person's total daily exposure to black carbon and ultrafine particles occurs during commute periods (Ham et al., 2017). Coincidentally, fine particulate matter ($PM_{2.5}$) are typically higher in concentration during vehicle operation. Research by (Kokon, E. O., Yli-Tuomi, T., Turunen, A. W., Taimisto, P., Pennanen, A., Vouitsis, I., 2017), recorded the maximum mean of $PM_{2.5}$ concentration of 85 µg/m3 in Finland. In Portugal, an investigation found that the mean $PM_{2.5}$ concentrations were 56 µg/m3 on a bus and 51 µg/m3 in the metro during morning rush hour (Ramos et al., 2015).

Short and long exposure to high level of particulate matter may result in acute respiratory response such as inflammation, asthma, allergies, while not limited to long-term health effect such as lung cancer and cardiovascular disease (Ding et al., 2016).

2.4 Previous vehicle IAQ studies

For this study, the scope has been narrowed down for the type of air pollutants, the considered variables affecting the concentration of air pollutants, sampling method, and data analyzing method. Several past studies were pick as references on the aforementioned criteria to ensure that the overall execution of this investigation are doable and able to achieve the objectives.

Table 2.3: Past Studies of Bus Indoor Air Quality

No	Author	Summary	Method	Finding
1	Mohd Firdaus	- Determine exposure to the indoor air pollutant (PM_{10}, CO_2, CO) i. - To determine the respiratory health problem among long distance bus driver	- PM_{10}, CO_2 and CO measured in 4 hour average using Q-TRAK PLUS IAQ Monitor (model 8554, TSI Inc.) and DustTrack model 8520	- Mean concentration of PM_{10} and CO_2 has exceeded permissible value, CO did not exceed - CO2 level concentration is influenced by the number of passengers inside the bus
2	Yelim Jang	- Determine the factors associated with the internal bus $PM_{2.5}$ and CO_2 concentration	- $PM_{2.5}$ and CO_2 were measured using MicroPEM and CO_2 data logger - Conduct t-test to find significance between bus operation and concentration of $PM_{2.5}$ and CO_2	- $PM_{2.5}$ concentration peaked at traffic facilities; traffic light, crosswalks where the bus stops. - On-board CO_2 is significantly higher than during rush hour and long distance route.

Table 2.3: continued

No	Author	Summary	Method	Finding
3	Chun-Fu Chiu	- Monitor the CO_2 concentrations and temperatures of three 43-seater tour busses with high passenger capacity, over the course of 3 days, 2 nights school excursion.	- CO_2 data monitoring equipment, (Smart eHome Wireless Indoor Air Quality (IAQ) Monitoring System).	- CO_2 concentrations in tour bus cabins are significantly influenced by number of passengers on-board
4	Amaia Fernandez	- Chemically analyse the particulate matter (PM) inside commuting and tourist busses moving through the city of Barcelona, Spain	- Collect $PM_{2.5}$ samples from filters placed inside public bus moving through the city, and VOCs with in-situ pumping and adsorption into cartridges filled with graphitised BC adsorbents.	- Main source of particles inside bus cabin is from human emissions; textile fibre, skin flakes
5	Hanis Zakaria	- Determine and investigate indoor air quality and air change per hour (ACH) inside the car with different ventilation setting which are re-circulation (RC) and outside air (OA) mode.	- Finding the ACH to indicate the accumulation of CO_2 inside car cabin through mathematical formula and compare to the result from the devices	- Carbon dioxide concentration rise higher in recirculation than in outside air mode and air change per hour (ACH) can influence efficiency of carbon dioxide exchange out of the car.
6	A. Gajewski	- To study the concentration of CO_2 in bus	- Temperature, pressure, humidity and CO_2 were measured using instrument reading method for journey and return.	- Relative humidity, temperature, and concentration increased simultaneously during air recirculation

7	Siti Nor'ain	- To access and analyse the cabin indoor air quality (CO_2 and PM_{10}) of car and compares to the IAQ standard by DOSH and USEPA for minimum and maximum passenger. - To analyze the difference between driving and idling of vehicle operation.	- Monitor temperature, CO_2, and PM_{10} inside a car cabin while travelling between FTK Campus to UTeM main campus	- Vehicle speed influence the CO2 concentration inside the cabin, while PM10 is dependent on the ambient PM10 level. -

2.4.1 Past findings

One of the most commonly mentioned notes in the research journals are the variables that affects the concentration of CO_2, PM_{10} and $PM_{2.5}$. In study conducted by (Jang, 2018) for bus IAQ in Korea, the in-cabin $PM_{2.5}$ was concluded to be influenced by the ambient concentration where it is associated with traffic facilities. Similarly, in a study conducted in Barcelona by (Moreno et al., 2015), it is concluded that the exposure of $PM_{2.5}$ is associated with traffic emission. Depending on what mode of transport taken (subway or road vehicle), its chemistry varies.

Study conducted by (Chiu et al., 2015) for CO_2 in tour buses in Taiwan shows that the concentration on average is >1000 ppm and the daily "minute average of CO_2 concentration above >1000ppm" reaches above 55% for all of its 3 busses during their 3 days tour. It is stated that the concentrations were greater in the passenger compartment compared to the driver, and that there was concentration decrease during the passenger disembarking period which open the bus door.

The sampling methods in each research are varied in terms of instruments used and approach. However, most utilised instrument reading method. In order to take reading for the concentration around the bus driver, (O & Juliana, 2014) positioned the measuring device near to the driver's seat. Similarly, (Gajewski, 2013) placed the measuring probe in front of the bus, behind the driver on a seat, so the probe was below the passengers' heads. This is also similar to (Chiu et al., 2015) monitoring method that includes the placing of sensor beside the dashboard, and at the center of the emergency door in the passenger section. The sensors were placed at the approximate height of the seated passengers.

Following (Chiu et al., 2015) method, the data are analyzed through descriptive analysis to find the daily mean concentration of each air pollutants, and determine the minimum and maximum value for 2 experimental vehicles. Finally, the value is compared to the DOSH IAQ guideline and the percentage of exceeded value is to be calculated. For the secondary objective, the particulate matter and CO_2 concentration between driving and idling car operation was identifying.

METHODOLOGY

3.1 Introduction

This chapter explains in details on the various research methods and procedures adopted for realizing the objectives of the study. The sequence of the discussion begin with research design. A research design is a procedural plan adopted by the researcher to answer any research questions. Through, this research design the researcher proposed study design to use, method to collect data , types of analysis to be used and finally the way to report the findings. Other important things in research design include the rationale and justification for each decision that shapes the answer to the ‘how’ of the research journey (Rivas et al., 2017). This is necessary for the purpose of informing other researchers as guidance for analytical work in future researches regarding the same subject matter. For this research, the research design includes parameters such as equipment, measures for taking reading, and highlighting the steps needed to test the factors affecting indoor air quality (IAQ) assessments. The study requires an extensive data collection and processing effort. To achieve the objectives, the research design covers data collection, data classification, and data analysis.

The data collection process took over the course of 3-days, covering several variables; temperature, humidity, and the air pollutants (CO_2, PM_{10})**.** The weather condition for the whole testing experiment either during morning and evening of both cars, the weather condition is the same shiny weather with no rainy.

3.2 Project Flow Chart

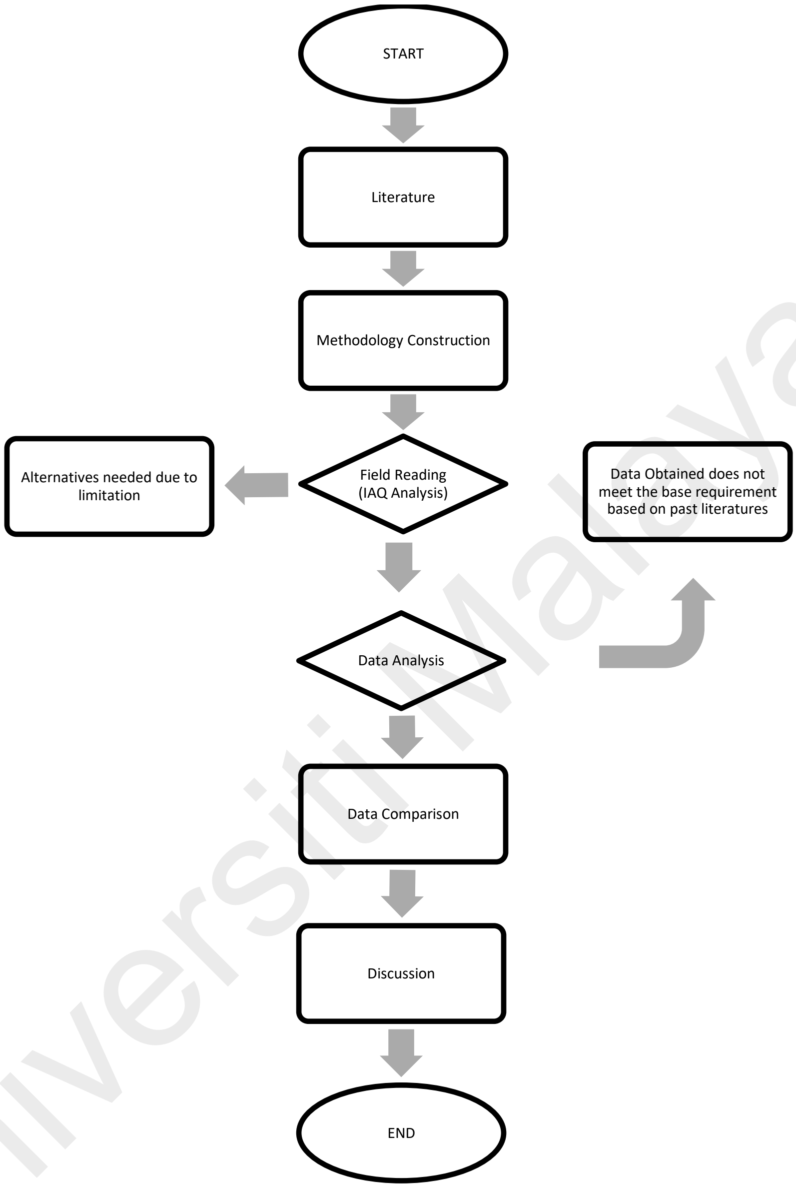


Figure 3. 1: Flow Chart

3.3 Scope of measurement

The scope has been set up in order to test the specific parameters and meet the two objectives by the end of this study. The scopes were to ensure that the field-assessments cover the important data collection before they are classified and analyzed further into the study. Refer **Table 3.1** for Technical Specification Variables in Experiment.

Table 3. 1: Technical Specification Variables in Experiment

Constant Variables	Specifications
Type of Car used	Perodua Myvi and Honda Freed
Car Volume	Perodua Myvi (138.6 m^3) and Honda Freed (191.4 m^3)
Car capacity	5 seaters & 7 seaters
No of passenger	2 and 5 (Low and High capacity)
No of EVM used (location placed)	2 (front and back)
Air tight condition	All doors and windows are completely closed until end of experiment
Car Speed	80-100km/h
Air- cooler Condition	Level 5
Air-conditioner blower speed	Maximum
Re-circulate (RC) Mode	Yes
Outside Air (OA) Mode	No

3.3.1 Location of study

To conduct the study, careful planning and preparation has been made regarding the location for the assessment to take place. For vehicle IAQ study, this translated to the transit route taken by the car. Since majority of the between-campus transit from the main campus takes place on a single route (refers Figure), it was selected as the designated route for this study. Both journeys made from UTeM main campus, Durian Tunggal to the FTK campus, Ayer Keroh, Melaka, covers roughly 16km in total travel distance. It is selected because it is the most used route when people are getting to FTK and returning to UTeM main campus.

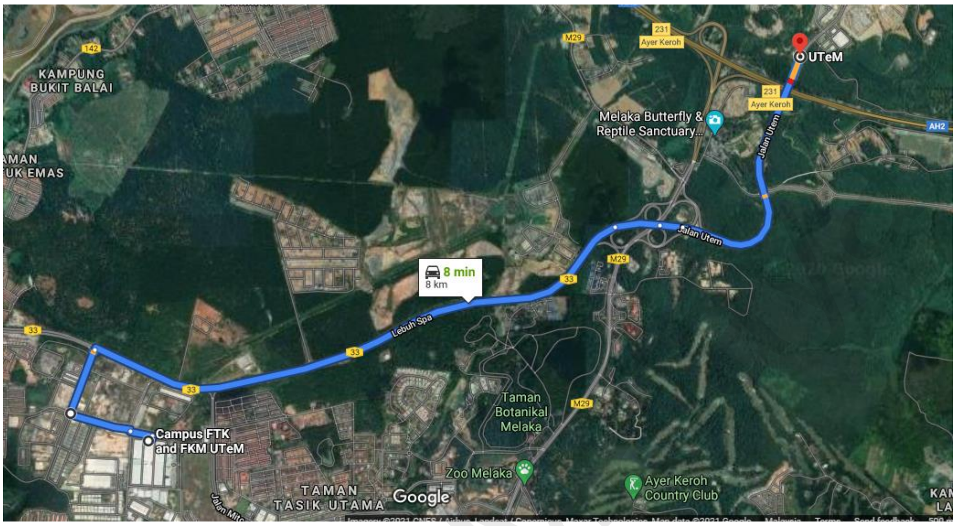


Figure 3. 2: Selected route for study

3.3.2 Vehicle specification

During this study, 2 types of vehicles are used which is 5-seater and 7-seater car. A few other variables were also kept constant throughout both sessions; the windows were closed until the test has been completed, car actuator was set to "recirculation" mode, while the blower speed dial and the temperature dial were kept the same for every testing

3.4 Equipment

The field-assessment requires the measurement of several IAQ parameters, namely; temperature, humidity, CO_2 and PM. The car was set up with one the following measuring instruments on a measuring platform. Refer **Table 3.2** for photo of equipment and **Figure 3. 3** for Sensor Location.

Table 3. 2: Experiment Equipment

	Equipment	Description
1.	3M EVM (Environmental Monitor) 	- Used to monitor for particulate matter (PM10 & PM2.5) and carbon dioxide (CO2) concentration inside the vehicle cabin - The monitor also reads and records the temperature and relative humidity (RH)

Figure 3. 3: Sensor Location of 3M EVM

3.4.1 Instrument Setup

A reading-station was set up at the back seat of the car, located within the middle portion of the backseat. 2nd location is in between driver and passenger. The placement was done so it is possible to take the reading for the all of the car's passenger, similar to the setup done by (Barnes et al., 2018). Instrument located at 2 points that we call Front and Back to see the different concentration between both location. 3M Environmental Monitor was place away from any window and cabin wall. The 3M Environmental Monitor was to run for a period of 30-minutes with 1-minute interval for a single trip. Lastly, the data collection unit for temperature read in degree Celsius, carbon dioxide (CO2) in unit PPM, and particulate matter (PM) were read in μg/m$^{3.}$ Refer **Figure 3.4** and **Figure 3.5** for Instrument Setup of 3M EVM for Perodua Myvi and Honda Freed respectively.

Figure 3. 4: 3M EVM Instrument placement of Perodua Myvi

https://paultan.org/2008/10/10/2008

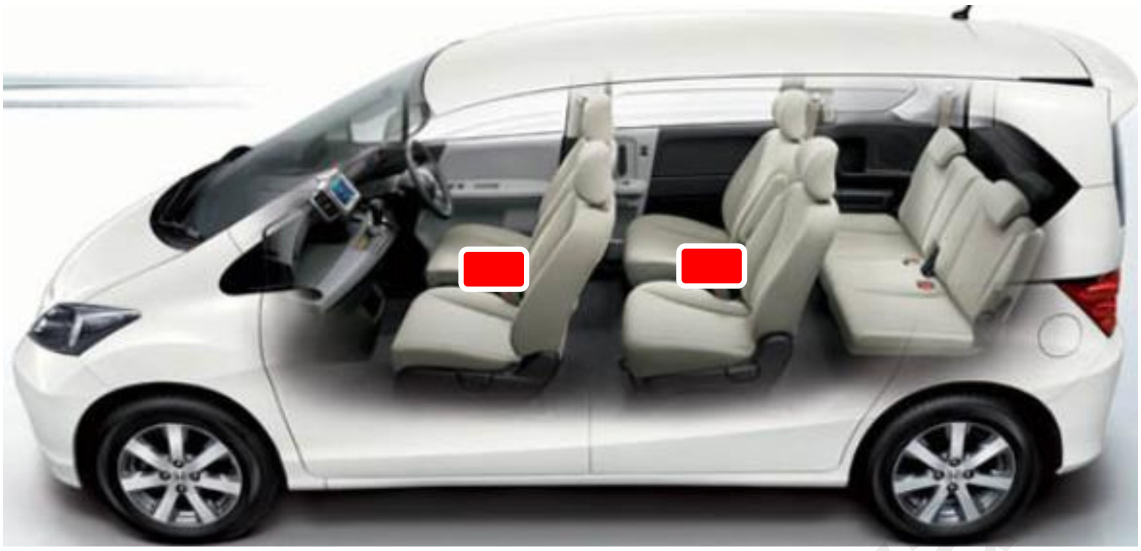


Figure 3. 5: 3M EVM Instrument placement of Honda Freed

http://freedcar.blogspot.com

3.5 Data Collection

The testing apparatus was set up inside the car using EVM to read the temperature, CO2, and PM_{10}. The car and air-conditioning was started for 5 minutes before the EVM was switched on and begin the real-time reading. The car were to complete 2 trips (looping from FTK to UTeM main campus) for a single session, this is to ensure the reading was done over 30-minutes while using the designated route. The first session was conducted using 5-seaters car which is Perodua Myvi with low-capacity passengers which only include the driver and researcher, while the second session was consist of high-capacity passengers with 5 occupants. The same testing was carried out for 7-seaters car which is Honda Freed. Additionally, a separate test has been conducted while the car is idling for at least 5-minute intervals. At the end of the session, the collected data were downloaded into the instrument software (Detection Management Software) and then into excel where they were matched with the activity log. See **Figure 3.6** for instrument connection to the software.

Figure 3. 6: Working method of EVM and Detection Management Software

3.5.1 Sampling Procedures

1. The equipment were stationed accordingly and was setup inside the car at 2 places to see different concentration of the result.

2. The car and Air Conditioning has been started while the IAQ reading has been initiated 5-minutes after.

3. The EVMs has been started and the researcher recorded the activity (time, passenger count, vehicle operation, location and traffic).

4. Step 2 and 3 have been repeated for the every trip being made for both cars.

5. The reading session for the day has been concluded and data were downloaded from the equipment and extracted into the software and Microsoft Excel.

6. For session involving different passenger capacity, step 2 – 4 were repeated while completing a session with high-capacity passenger.

7. Another session has been repeated with low-capacity passengers, and the data were downloaded and extracted .

3.5.2 Car activity monitoring

2 car activities were monitored. This study focuses on only two factors influencing the concentration of CO2 and PM10. These are the number of passengers and vehicle-operation (idling or driving). Refer **Figure 3.7** for Adjusting impactor for Particulate Matter, PM10.

i. Vehicle operation

The vehicle-operation factor is split into two which are defined as; (non-operation) for when the car is idling and (operation) for when the car is moving. The idling data has been obtained through separate test conducted for at least 10 minutes, measuring the parameter (CO_2 and PM_{10}) after the completion of both trips.

ii. Number of passenger

Number of passenger is defined as; high-capacity for > 2 passengers on board, and low-capacity for 2 passengers on board. The data reading session switched from low-capacity to high-capacity after the completion of the first trip where the EVMs were stopped before reaching 30-minutes. By then, the reading session for high-capacity is switched to low-capacity testing and repeat the steps. This was decided based on the practice done by (Kim, H., Yang, X., Ryu, S., & Yu, 2018).

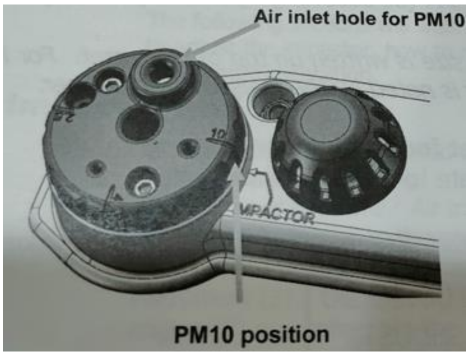


Figure 3. 7: PM10 Adjusting Impactor

3.6 Data Quality

In order to maintain data quality, the 3M Environmental Monitors were calibrated before the start of IAQ reading, refer **Figure 3.8**. A zero calibration is recommended the first time measure particulates in the run mode. For particulate calibration, place a zero filter (also called a HEPA filter) with attached coupler into the vent of the turret. The impactor setting must be set at PM in order to conduct a zero cal. Additionally, the two units has been running a comparative reading to detect any off-reading prior to testing. Other measures of maintaining the data quality includes:

a) The data collecting session for the day is terminated if one of the equipment were to shut off or stop taking reading.
b) Data collecting session for the day is terminated if the vehicle no longer follow the designated route.
c) Data collecting session must be repeated if the constant variables were not kept constant during both trips.

Figure 3. 8: Calibration of EVM using Zero/HEPA filter

3.7 Data Analysis

The nature of this study requires extensive data handling in order to produce the results needed for both objectives. All data were download into the Detection Management Software (DMS) equipment software. For the first objective, which is the IAQ analysis, the raw data were calculated for average of temperature, CO2 and PM10 by the DMS. Then by using Microsoft Excel, the vehicle activities were paired with the parameter concentration line graft produced by the DMS and tabulated.

3.7.1 Analysis of temperature, concentration of CO2 and PM10

Research Objective I (To access and analyze the cabin indoor air quality (CO_2 and PM_{10}) of car with compares to the IAQ Standard by DOSH and USEPA for minimum and maximum passengers capacity.

For the IAQ analysis, the raw data of the physical parameters (temperature) and the concentration of air pollutants (CO_2, PM_{10}) data collecting session were organized.

a. From the testing, the data taken from the low-capacity sessions were used as the default data set to find the car average temperature, CO_2 and PM10.
b. Microsoft Excel was used to tabulate the data and paired with their respective activity logs.
c. The results were obtained and graphs were constructed to map the influxes occurred during the trip. It is then used for analyse the changes of IAQ throughout the driving period and discuss the contributing factors based on previous research articles.
d. The effects of number of passengers onto the concentration of the CO_2 and PM10 was analyze thru graph comparison.

The minimum and maximum recorded value for CO_2 and PM10 were also calculated. Finally, the calculated parameters' value were compared to standard by DOSH and USEPA.

Research Objective 2 (To analyze the difference between driving and idling of vehicle operation). To achieve this objective, idling condition was tested for both types of car specific in evening time. This time selection is made based on the time frequently involved in traffic. The same parameter was also done which different number of passengers.

3.8 Expected outcomes

The mean CO_2 concentration for the car may exceeds the DOSH recommended 1000ppm during operation and under high-capacity. Meanwhile, the mean concentration for PM10 remains below the USEPA $\mu g/m^3$ (24-hour mean) as long as the cabin remains sealed.

Based on the past studies, carbon dioxide experienced high concentration when the number of passenger is high due to respiration process. Meanwhile, the concentration is at low when the number of passenger decreased, or when the cabin takes in outside air (via outside air-mode, opening door or window).

The PM concentration level will experience high concentration when the vehicle is either idling or stopping for traffic, and influenced by the ambient concentration. For this study's setting, the high concentration is expected during the evening session due to the increase in traffic. However the concentration will subside after the vehicle is moving.

RESULT AND DISCUSSION

4.1 Introduction

The assessment was conducted on a 5-seater car (Perodua Myvi) and 7-seater car (Honda Freed) where the cabin air quality was monitored using two EVM taking reading simultaneously throughout a testing session. The car travelled the route, from FTK campus to UTeM main campus and back, referred to as a “trip”. During the test, windows were kept closed and the actuator was on recycling mode. Similarly, the air-conditioner blower speed and temperature dials were also kept constant throughout each testing.

For the first objective, the testing session was to conduct an IAQ analysis for the cabin by monitoring the parameters (CO_2, and PM_{10}), including the car activities during trip. Specifically regarding the location, traffic condition, and car operation. The results were then produced for each session using Microsoft Excel and Detection Management Software (DMS) and a graph was then produced for discussion regarding DOSH and USEPA acceptable standard. Low and High passenger capacity condition are conducted to include the difference in number of passengers in the car.

The second objective, data was analyze to make a comparison between driving and idling of vehicle operation. Data collection shows the increasing of Particulate Matter, PM_{10} due to traffic emission. In addition to this factor, factors such as human emissions, textile fibre and skin flakes also contribute to the increase in particulate matter.

4.2 Vehicle IAQ overview

The IAQ test managed to be conducted were on 27th August for evening session of both cars with high and low capacity passenger. For morning session, data taken on 28th August for both cars with high and low capacity passengers. In each trip, the duration to reach the main campus main gate from FTK took between 8 – 9 minutes and completing a single trip was between 15 – 18 minutes. Since time varied during testing due to traffic and driving speed while conducting the test, approximation time is used to divide the data for uniformity. As for the overall summary on the experiment result, refer below **Table 4.1** for each Figures related. The graph in **Figure 4.1 till Figure 4.8** reveals average values of Particulate Matter (PM_{10}) and Carbon Dioxide (CO_2) of the experiments for 2 and 5 number of passengers in both car.

Table 4. 1: Summary of Experiment Result per session (Driving)

Figure No.	**Figure Name**	**Vehicle Type**	**No. of passenger**	**Session**
Figure 4.1	Particulate Matter and CO_2 concentration of Myvi during Morning (2 passengers)	Perodua Myvi	2	Morning
Figure 4.2	Particulate Matter and CO_2 concentration of Myvi during Morning (5 passengers)	Perodua Myvi	5	Morning
Figure 4.3	Particulate Matter and CO_2 concentration of Freed during Morning (2 passengers)	Honda Freed	2	Morning
Figure 4.4	Particulate Matter and CO_2 concentration of Freed during Morning (5 passengers)	Honda Freed	5	Morning
Figure 4.5	Particulate Matter and CO_2 concentration of Myvi during Evening (2 passengers)	Perodua Myvi	2	Evening

Figure 4.6	Particulate Matter and CO_2 concentration of Myvi during Evening (5 passengers)	Perodua Myvi	5	Evening
Figure 4.7	Particulate Matter and CO_2 concentration of Freed during Evening (2 passengers)	Honda Freed	2	Evening
Figure 4.8	Particulate Matter and CO_2 concentration of Freed during Evening (5 passengers)	Honda Freed	5	Evening

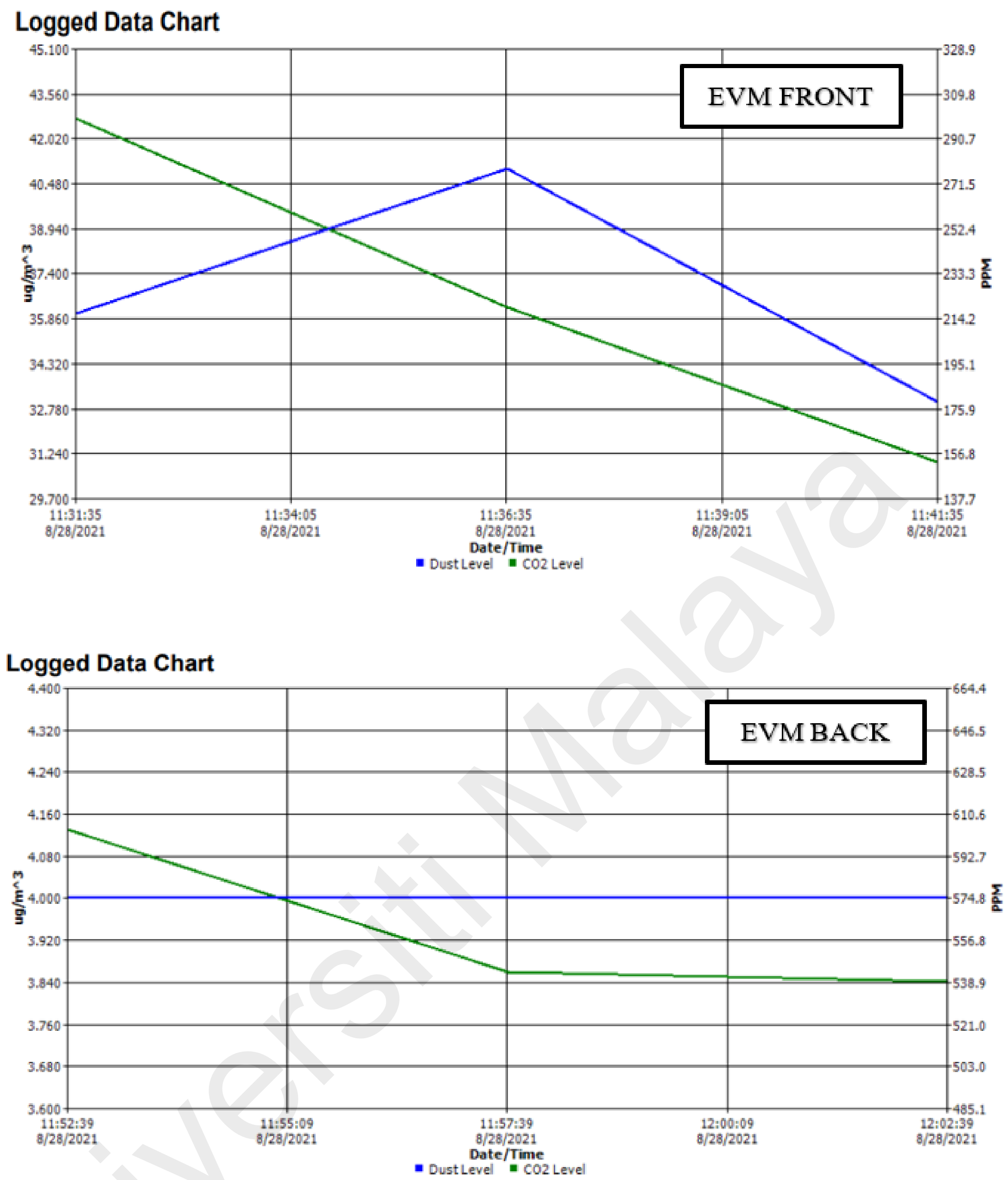
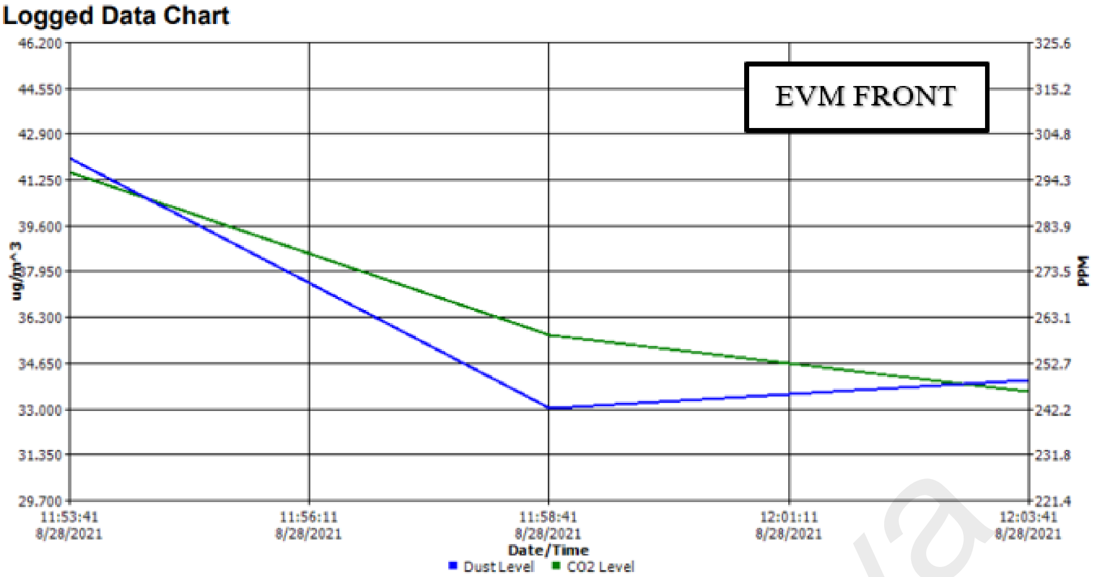


Figure 4. 1: Particulate Matter and CO_2 concentration of Myvi during morning (2 passengers)

For front of EVM, result of Particulate Matter is gradually increase and start to reduce after 5 minutes travel. The Carbon Dioxide decreased from the start of the trip to the end. While for back location of EVM, the concentration of Particulate Matter are constantly remain the same with 4.00 $\mu g/m^3$ till the end of the trip. The number of CO_2 level gradually reduce and approximately maintain after 5 minutes of travel.



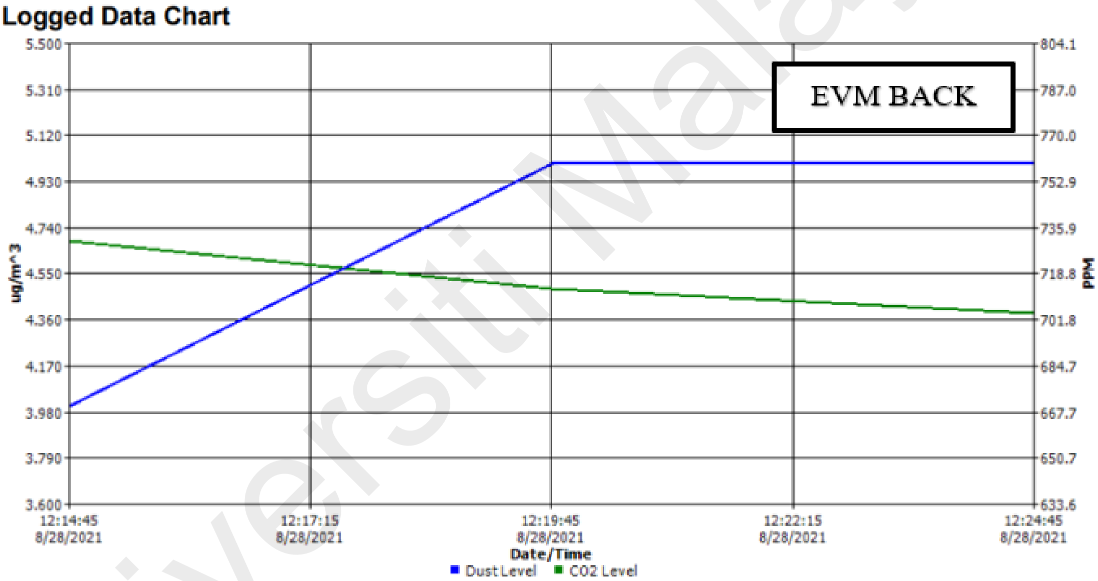


Figure 4. 2: Particulate Matter and CO_2 concentration of Myvi during morning (5 passengers)

For front of EVM, result of CO_2 is gradually reduce in the first 5 minutes and slowly reduce to 247ppm at the end of travel, up 37.2% compared to 2 passengers graph. While particulate matter is decreased rapidly from 42μg/m^3 to 33μg/m^3 and slowly increase back to 34μg/m$^{3.}$ For back EVM, graph are showing a drastic increase in Particulate Matter for the first 5 minutes of travel and the value is maintain till the end. The Carbon Dioxide maintain in slowly decreased from early and end with value of 701ppm.

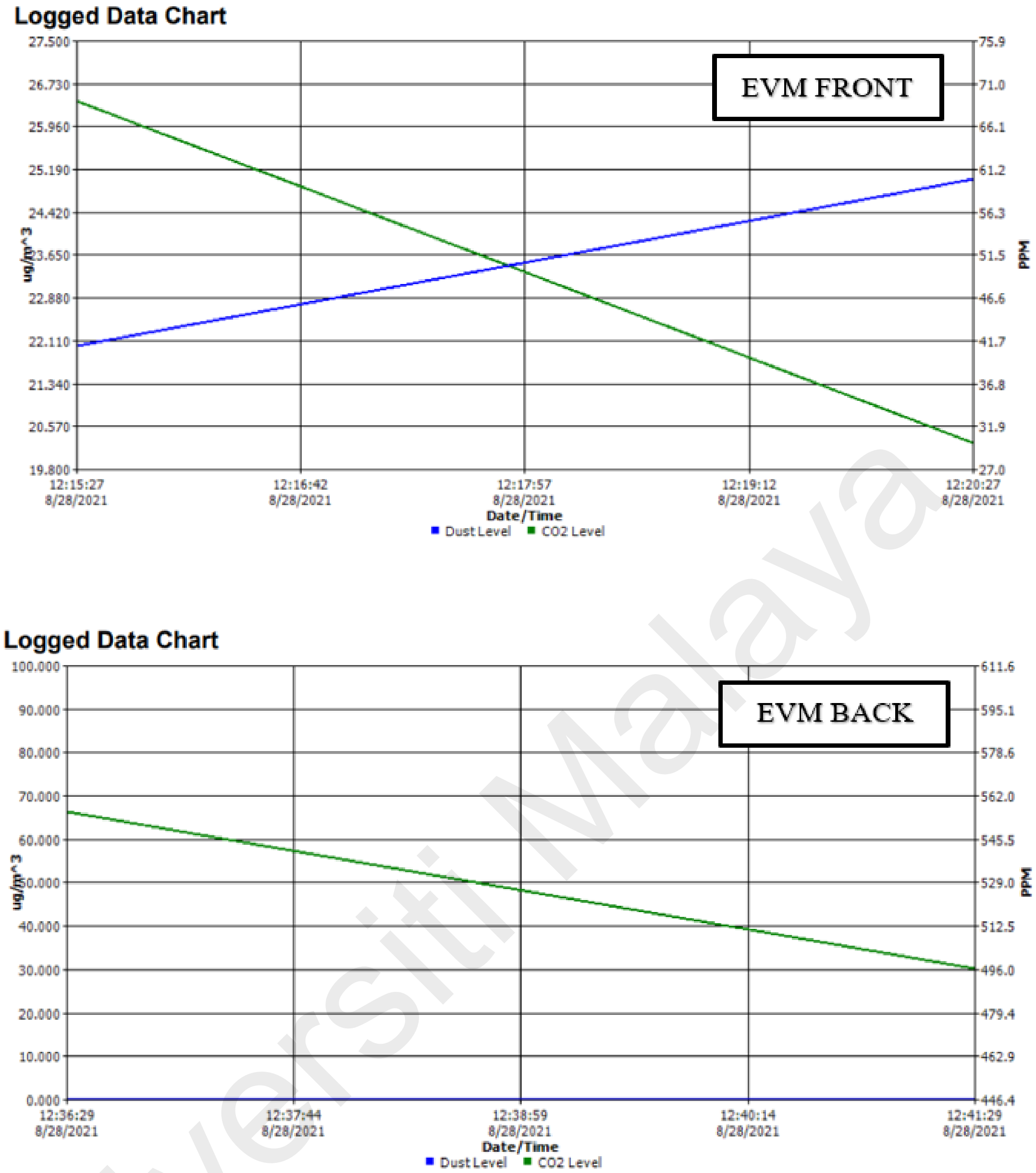
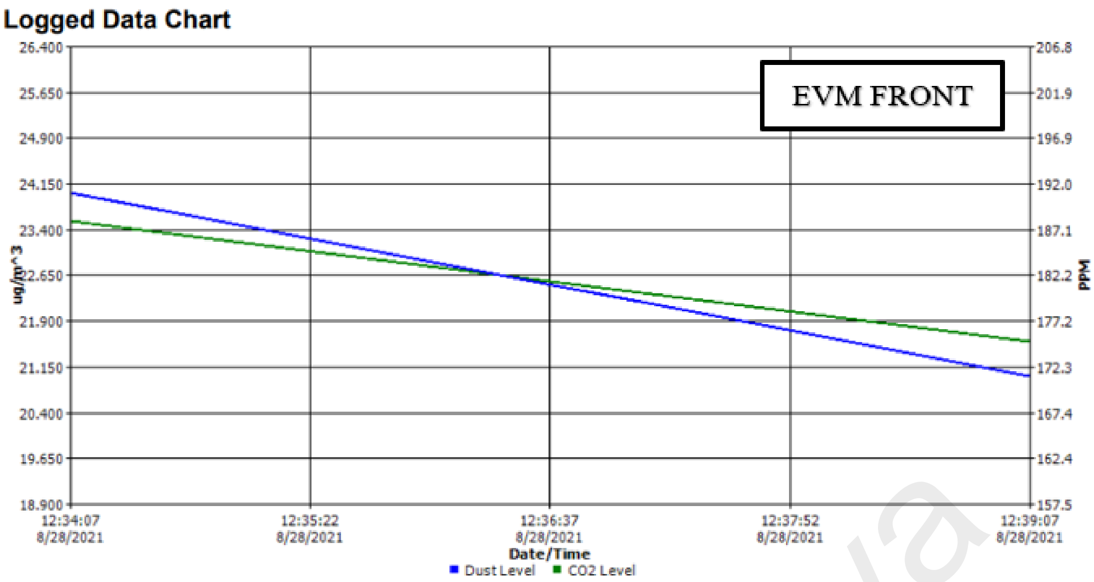


Figure 4. 3: Particulate Matter and CO_2 concentration of Freed during morning (2 passengers)

Above figure shows data collected for Honda Freed during morning for 2 passengers. Front EVM shows that the Carbon Dioxide was gradually decrease from 70ppm to 30ppm, while for Particulate Matter was gradually increase from 22.1µg/m^3 to 25µg/m^3. It is also noted that the test conducted by (Geiss et al., 2010) shows an increase in PM_{10} level during driving. The huge different of the CO_2 result for EVM back is shows above. The CO_2 concentration is starting with 553ppm and reduce to 496ppm at the end. While the particulate matter remain zero till the end.



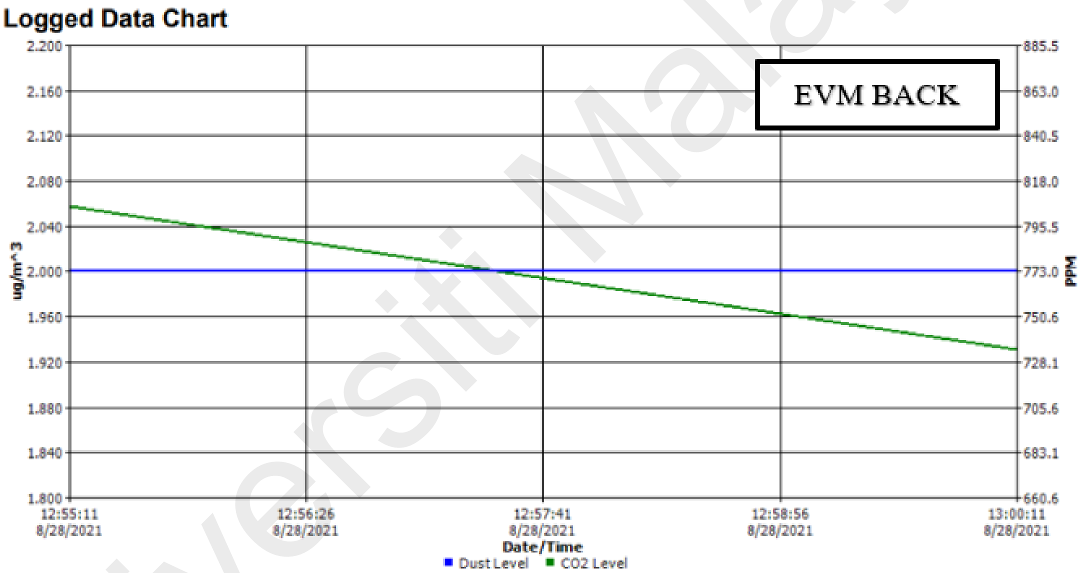
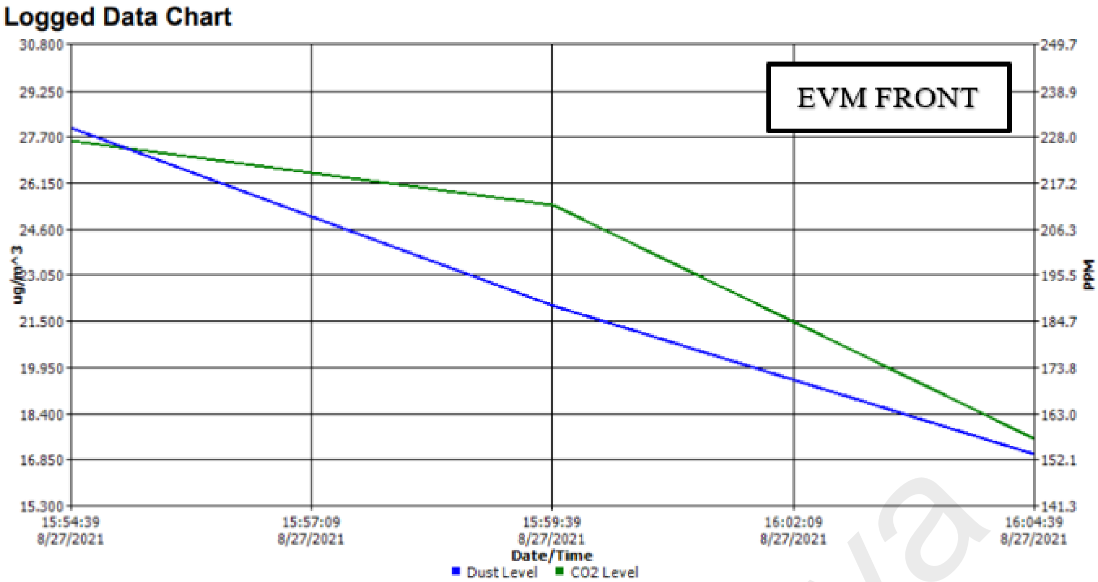


Figure 4. 4: Particulate Matter and CO_2 concentration of Freed during morning (5 passengers)

During morning time, Freed result shows the concentration of CO_2 and is slowly reduce but 64.9% up compared with 2 passengers result. Same behavior with Particulate Matter, the data shows reducing from 24µg/m^3 to 21µg/m^3 but at the end, it is lower than 2 passengers data which shows reducing of 66.6%. For EVM which is behind in turn shows a moderate decline against Carbon Dioxide level while the Particulate Matter remains the same with 2.00µg/m^3 value till the end.

Figure 4. 5: Particulate Matter and CO_2 concentration of Myvi during evening (2 passengers)

During evening time, Myvi result shows the reducing of both parameter for the first 5 minutes and moreless the same till the end. While for back EVM show the drastic increment of particulate matter and drastic reduce from 1.98μg/m^3 to the lowest as 0μg/m^3 at the end of travel. Carbon dioxide level increase slowly from time to time with less than 12ppm of increment.



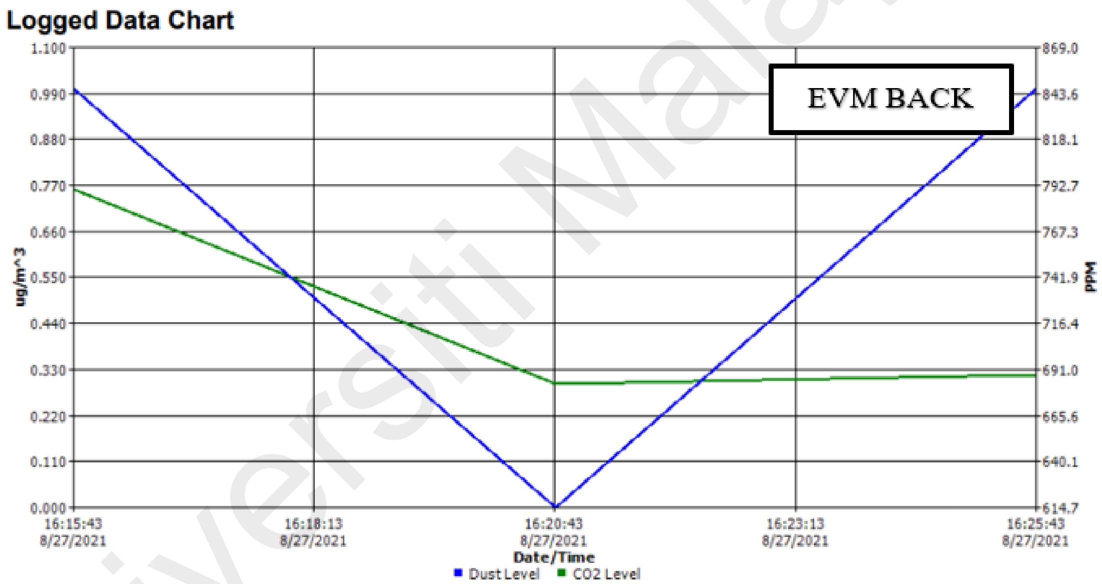
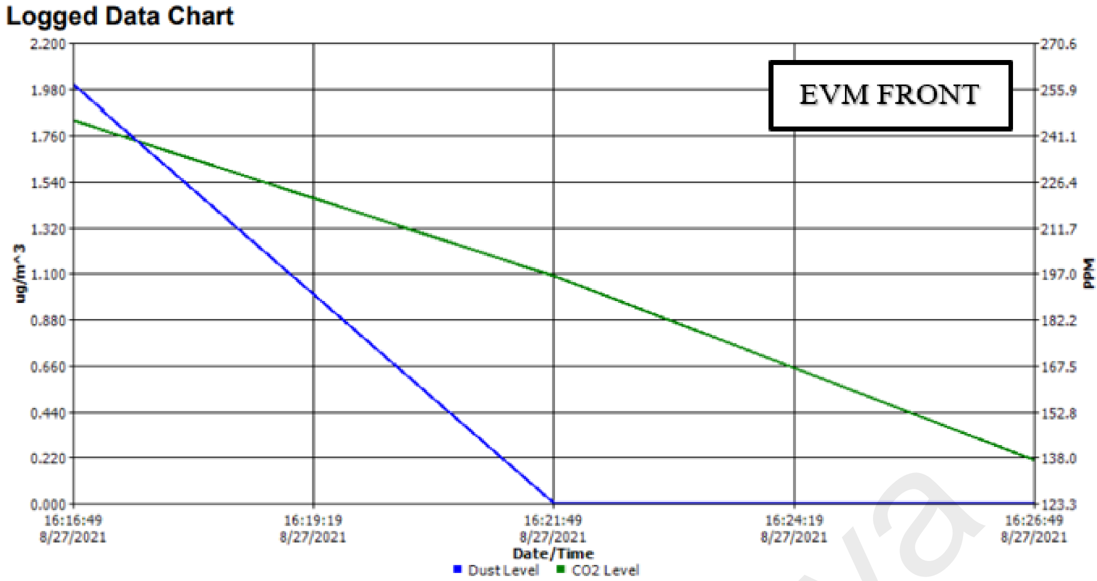


Figure 4. 6: Particulate Matter and CO_2 concentration of Myvi during evening (5 passengers)

Figure 4.6 shows the result during evening. For front EVM, particulate matter is sharply reduce and slightly reduce for Carbon Dioxide. While for back of EVM, the data of particulate matter reduce to 0µg/m^3 and increase back to 0.99µg/m^3 at the end of trip. While carbon dioxide, CO_2 level reduce from 792ppm to 691ppm. Reducing of CO_2 for 5 passenger is round 101ppm while 12ppm reducing of 2 passengers.



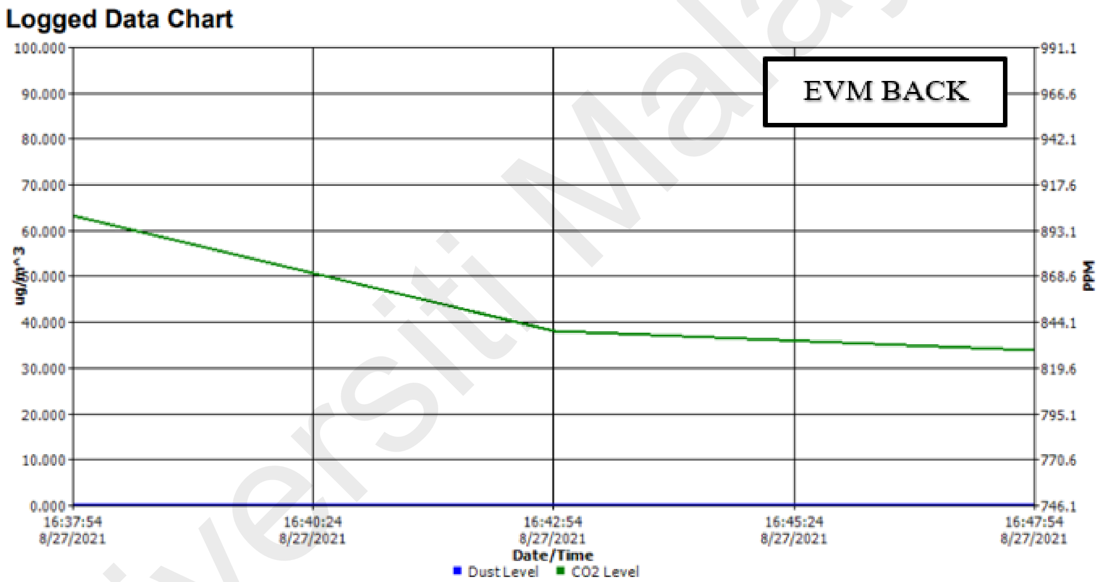
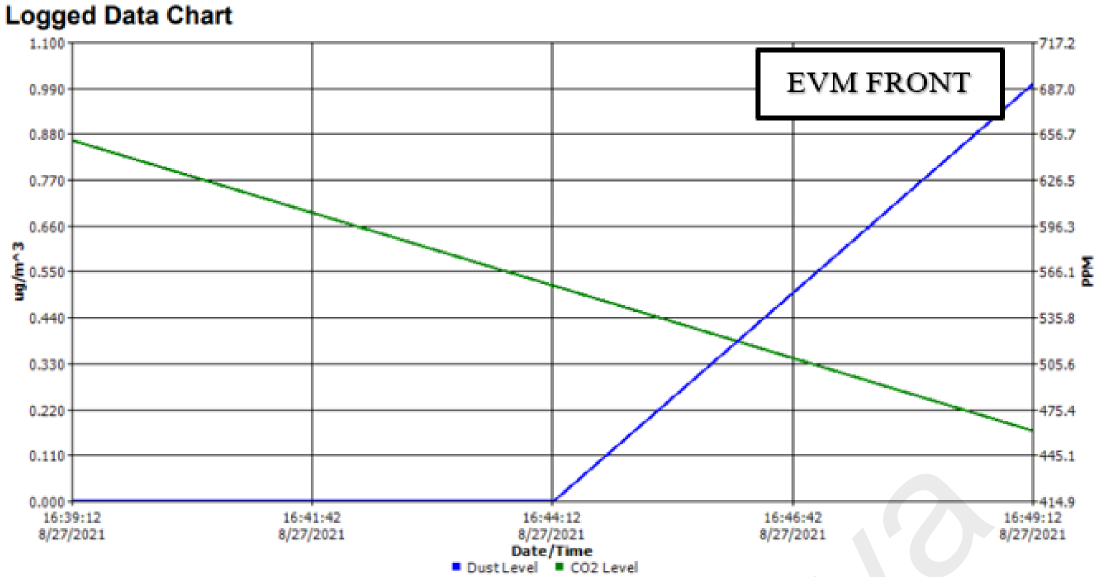


Figure 4. 7: Particulate Matter and CO_2 concentration of Freed during evening (2 passengers)

Figure 4.7 shows the result during evening time for Honda Freed. For 2 passengers, the particulate matter was slightly reduce to 0μg/m^3 at the first 5 minutes travel and remain the same till the end. But for back EVM, the value is 0 till the end. For CO_2 level, the trend shows slowly reduce and slightly reduce of Carbon Dioxide and if compare the trend to Figure 4.3, during morning the particulate matter was increase but will reduce while evening time.



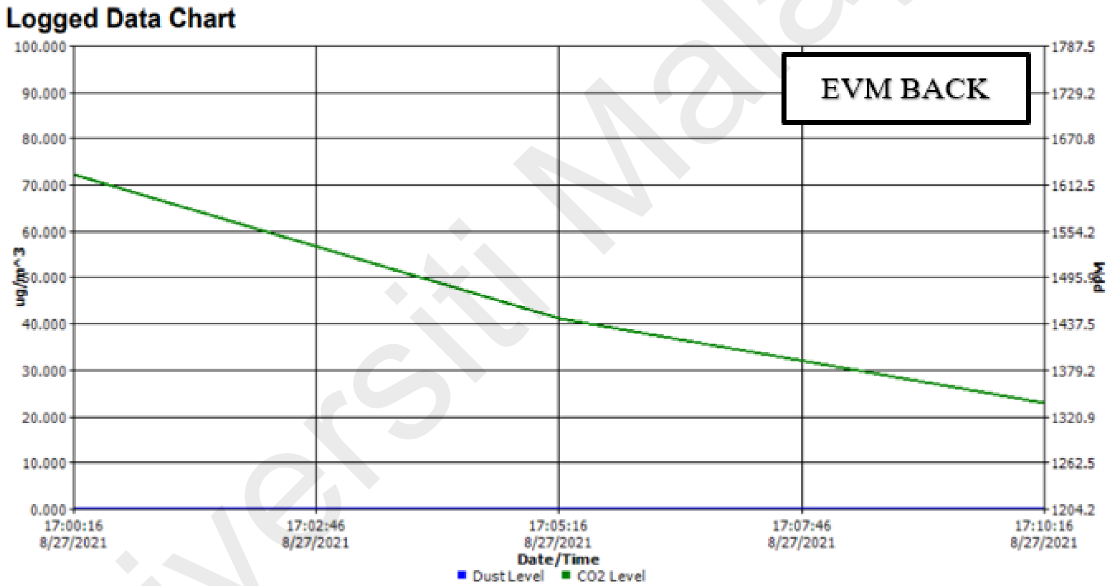


Figure 4. 8: Particulate Matter and CO_2 concentration of Freed during evening (5 passengers)

During evening time, Freed result of 5 passengers shows the concentration of CO_2 is slowly reduce for both EVM. But for particulate matter it start with 0μg/m^3 till the end and slightly increase to 1.0μg/m^3 after 5 minutes operation of front EVM.

4.2.1 IAQ analysis of the route between FTK and UTeM main campus

In a single trip, the car started the journey in front of the FTK gate and through Lebuh SPA and later Jalan UTeM. Once it has reached the main campus front entrance, the car made a U-turns and headed back to FTK by using the same route.

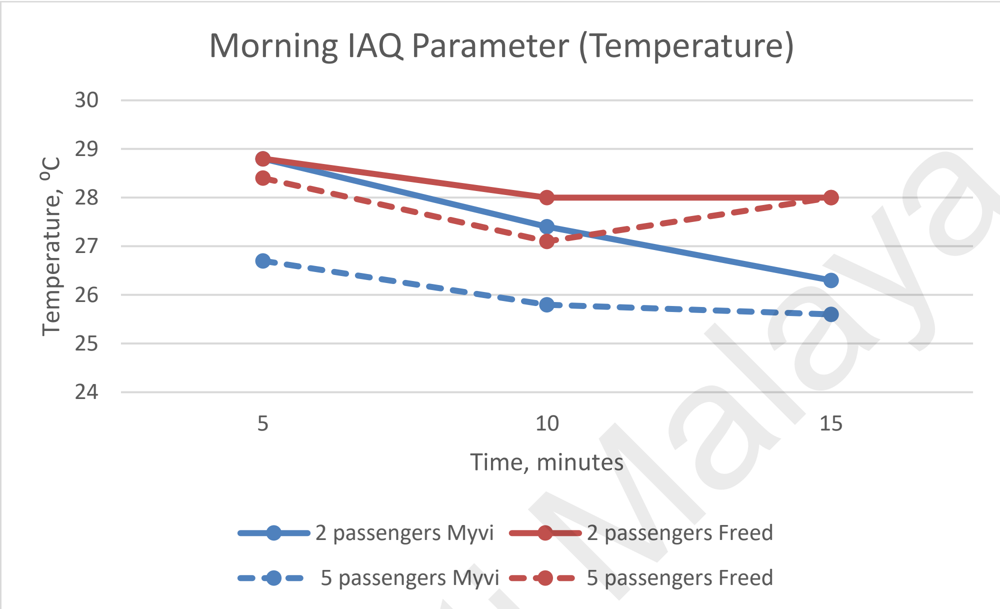


Figure 4. 9: Morning IAQ parameter (Temperature)

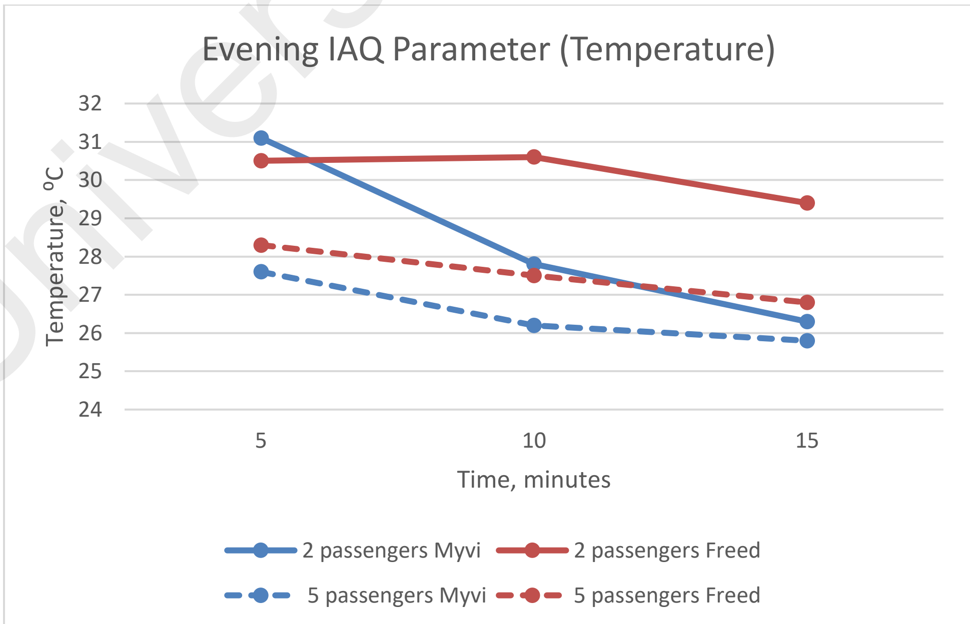


Figure 4. 10: Evening IAQ parameter (Temperature)

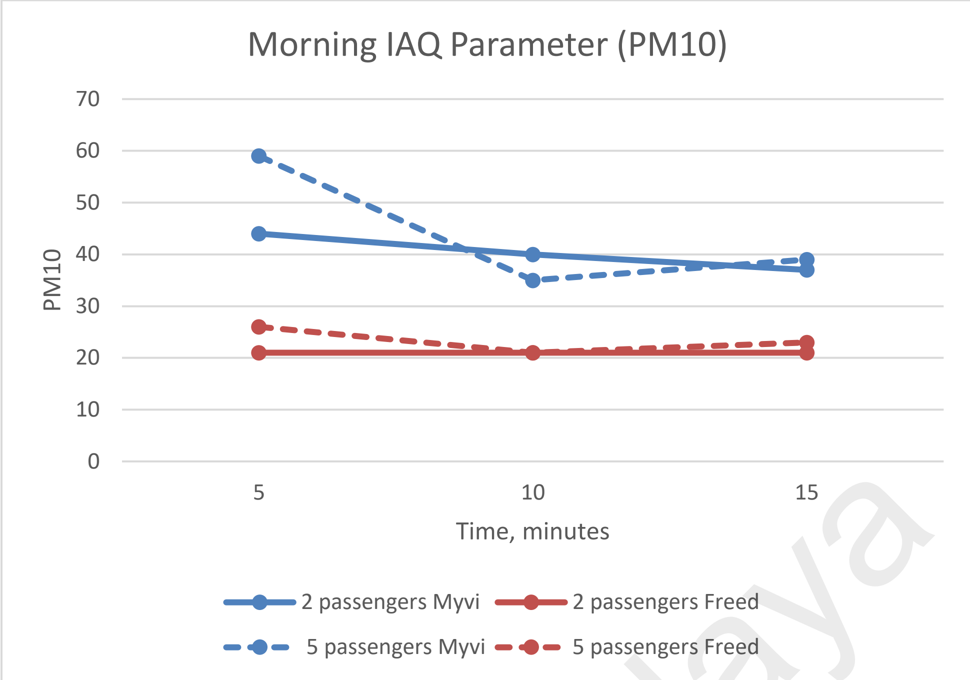


Figure 4. 11: Morning IAQ parameter (PM10)

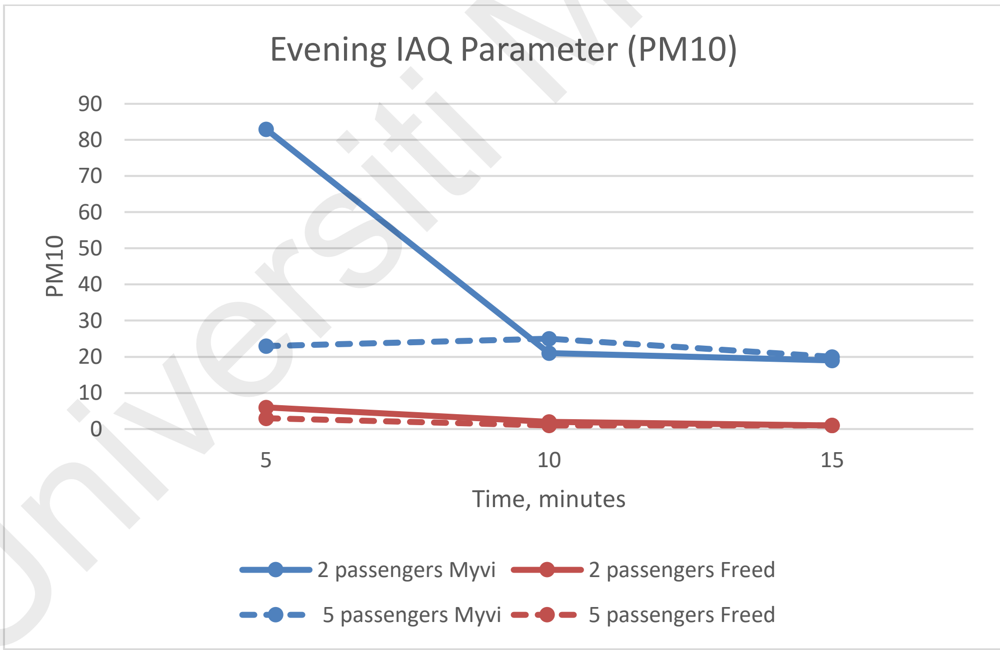


Figure 4. 12: Morning IAQ parameter (PM10)

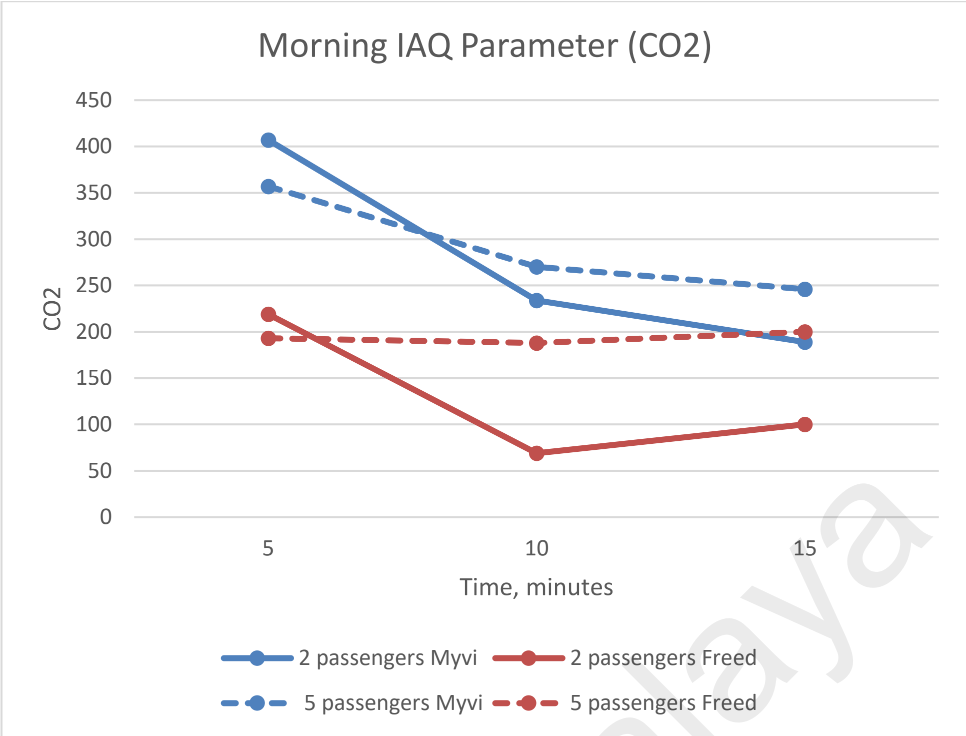


Figure 4. 13: Morning IAQ parameter (CO_2)

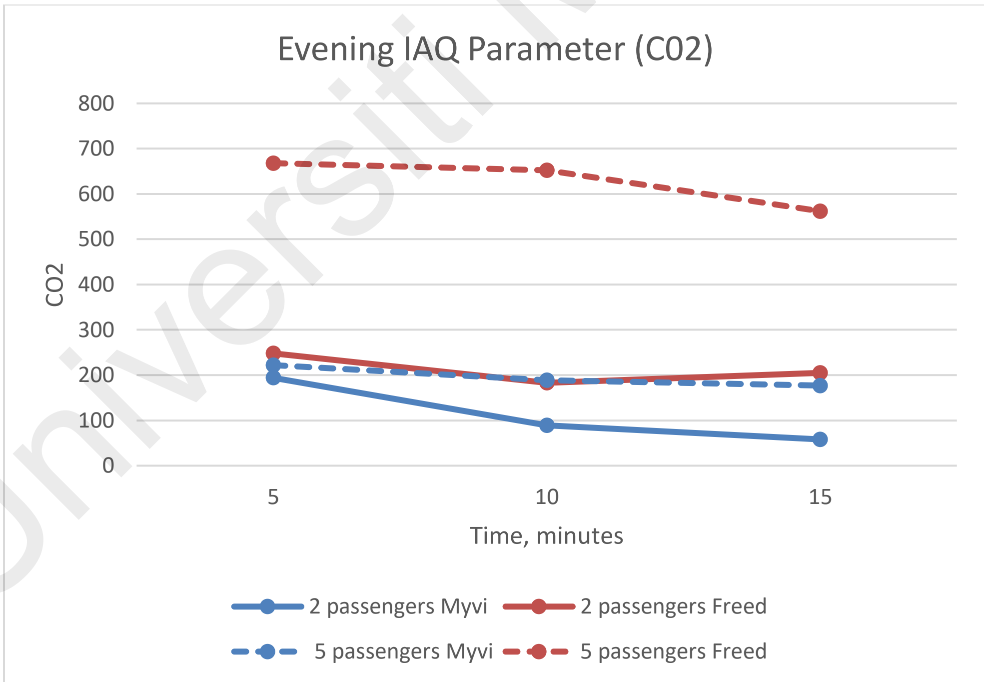


Figure 4. 14: Evening IAQ parameter (CO_2)

2 passengers

Parameter	MYVI		FREED	
	Morning	Evening	Morning	Evening
Temperature (°C)	27.5	28.4	28.2	30.2
Particulate Matter 10 ($\mu g/m^3$)	40	41	21	3
Carbon Dioxide (ppm)	276	114	129	212

Figure 4. 15: Average Data of 2 Passengers

5 passengers

Parameter	MYVI		FREED	
	Morning	Evening	Morning	Evening
Temperature (°C)	26	26.5	27.8	27.5
Particulate Matter 10 ($\mu g/m^3$)	44.3	23	97.6	1.67
Carbon Dioxide (ppm)	291	196	194	627

Figure 4. 16: Average Data of 5 Passengers

The figure depicts the average calculated from the 3interval time during the making of trip between FTK and Main Campus. The mean temperature for the morning trip was 26.9°C, while 27.0°C for evening which staying within the DOSH acceptable temperature range, 26-27°C. This indicates that the cabin is properly cooled during the trip. Furthermore, the highest temperature reached was for Honda Freed during evening is 30.9 °C during the initial run of the test. That is for front location of EVM. It is speculated that the car had not properly cooled by the A/C during that time. Meanwhile the minimum temperature of 25.3°C was reached for front EVM. There were distinguishable difference from the change in temperature as the different car volume is applied. However, the trend shows a gradual decrease.

The overall mean of CO_2 concentration for Perodua Myvi during morning time for 2 passengers and 5 passengers trip was 276 and 291 respectively. While during evening, the value was 114 and 196 respectively. The result for Honda Freed during morning time was 129 dan 194 while during evening was 212, and gradual increase to 627 for 5 passengers. The cabin CO_2 level not exceeded DOSH recommended safe limit of 1000ppm. From this result we can conclude that as the number of passengers increase, the concentration of Carbon Dioxide (CO_2) will gradually increase. But for long distance travel, the number will accumulate as the CO_2 concentration will increase more. The comparison of 2 types of vehicles used for this experiment shows that the number of concentrations for Perodua Myvi was higher than Honda Freed during morning time. However, the situation was different when the evening comes. Honda Freed will outperform Perodua Myvi. This situation is the same between 2 and 5 passengers. High level of CO_2 can have several health effects on the passengers such as sleepiness, feeling tired, dizziness, headache and drowsiness. The highest CO_2 concentration is 668, while the lowest is 9 ppm, much lower than (Zakaria et al., 2019) in their testing which was 3553 ppm for the highest value of CO2 concentration while the lowest value was 2056 ppm. This is because the total time for their travel is 2 hours. The increasing trend shows the longest the time while driving the highest the carbon dioxide concentration can be accumulated. The drivers could experience acute symptoms effect from the increasing trend of carbon dioxide concentration inside the car such as sleepiness, feeling tired, dizziness, headache and drowsiness. This serious condition inside the car may leads to danger accident due to acute effect that could lower concentration of driver on the road. According to the (O & Juliana, 2014) had done a research onto effect of concentration of carbon dioxide to health of human or driver inside the car for short and long term effect which are known as acute and chronic effect. Comparison table of minimum and maximum Carbon Dioxide concentration for 2 mode of time (morning and evening) for 2 types of car and 2 numbers of passenger as **Table 4.2** below.

Table 4. 2: Min and Max data of CO2 concentration

	2 passengers				**5 passengers**			
	Morning		Evening		Morning		Evening	
	Min (ppm)	Max (ppm)	Min (ppm)	Max (ppm)	Min (ppm)	Max (ppm)	Min (ppm)	Max (ppm)
Myvi	138	509	34	314	196	476	51	277
Freed	9	219	212	329	17	258	216	668

The result of Particulate Matter, PM_{10}, (USEPA) set the level concentration for particulate matter, PM_{10} to be on the level of 150 μg/m$^{3.}$ All data taken during morning and evening for both car types is within allowable range, refer **Table 4.3** below. Based on data collection, the amount of Particulate Matter for Perodua Myvi is higher than Honda Freed. This is because this situation occurs because Myvi is more stuck when in traffic light which causes an increase in Particulate Matter.

Table 4. 3: Min and Max data of Particulate Matter, PM_{10}

	2 passengers				**5 passengers**			
	Morning		Evening		Morning		Evening	
	Min (μg/m^3)	Max (μg/m^3)	Min (μg/m^3)	Max (μg/m^3)	Min (μg/m^3)	Max (μg/m^3)	Min (μg/m^3)	Max (μg/m^3)
Myvi	31	62	14	270	28	172	22	47
Freed	13	30	0	13	15	41	0	12

Exposure to PM10 affects the lungs and heart, leading to health complication such as nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms (Unites States Environmental Potection Agency, 2020). The source for PM10 on road typically made up exhaust or non-exhaust source.

The chart trend remained oscillated for most of session and did not give any indication to the source for the influxes possibly due to the sealed cabin which filters out most of the ambient PM_{10} concentration (Geiss et al., 2010).

However it can be assumed that the contributor to the car PM_{10} exposure is the surrounding's ambient air as (Rivas et al., 2017) mentions the ambient concentration is considered as a predictor variables for PM_{10} concentrations for above-ground vehicles. It is also noted that the test conducted by (Geiss et al., 2010) shows an increase in PM_{10} level during driving.

To achieve the second objective of this project, the analysis of vehicle operation between driving and idling was made. Idling condition was done just after the route of travelling for morning and evening had finished. Passengers will stay in car for 10 minutes and all the parameter setting such air conditioning temperature, blower speed, re-circulation air mode are remain the same.

4.3 Factors influencing Indoor Air Quality

In order to assess the effect of number of passenger, additional testing was conducted alongside with the primary assessment. This experiment also measured a concentration of CO_2 and PM_{10} during idle condition. Concurrently for the vehicle operation, the car was left to idle for a minimum of 10 minutes to assess its effect on the cabin air quality through data.

4.3.1 Number of passenger

The high-capacity data consist of 5 passengers inside the cabin (including the driver), while the low-capacity data consist of only a driver and 1 passenger.

4.3.2 Vehicle operation

For vehicle operation, the data collected for idling was taken 10 minutes just after the route has finished. The car cabin was occupied by a 2 passengers and 5 passengers under similar cabin setting from previous session. For idling condition of both car, result graph may be refer to **Figure 4.17** till **Figure 4.20.** The testing was done for evening time only as consider the frequent time to face traffic conditions.

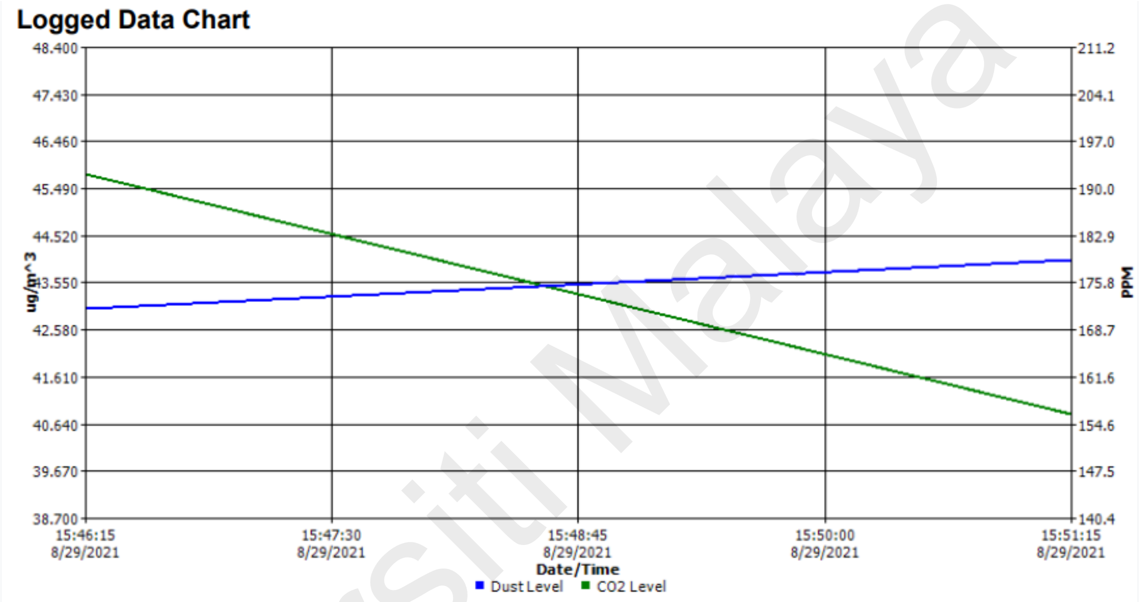


Figure 4. 17: Myvi 2 passengers (Idling)

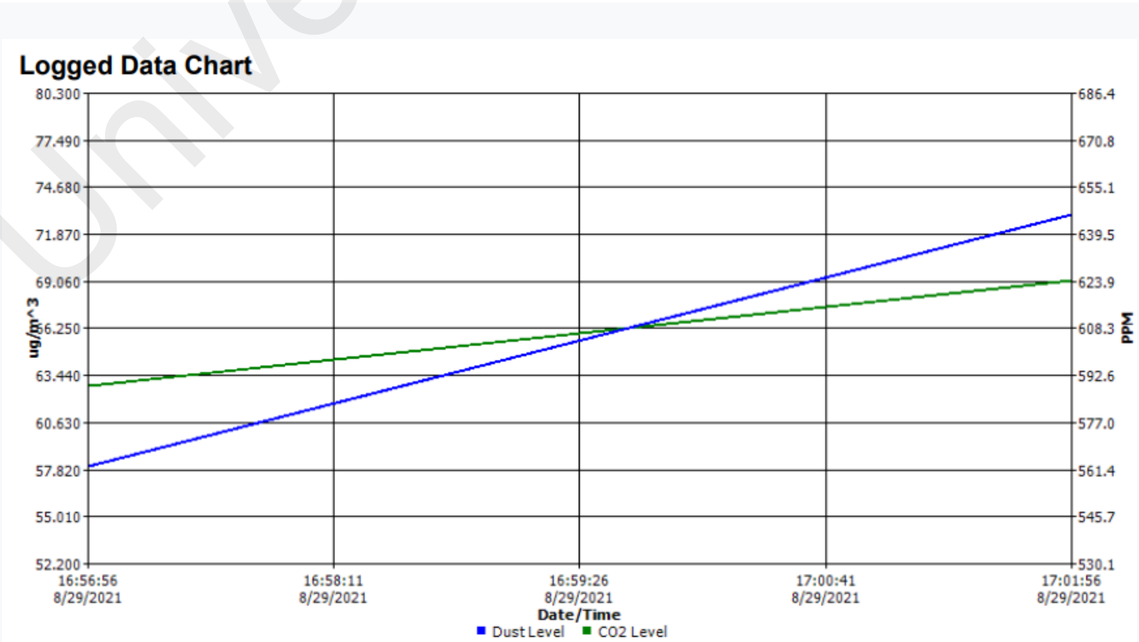


Figure 4. 18: Myvi 5 passengers (Idling)

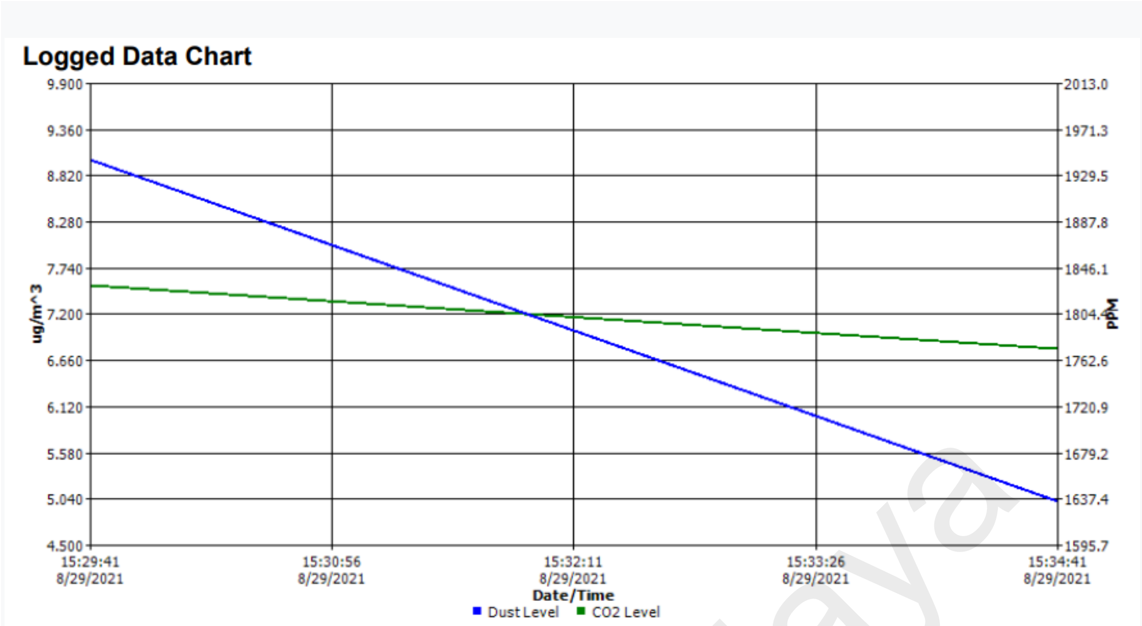


Figure 4. 19: Freed 2 passengers (Idling)

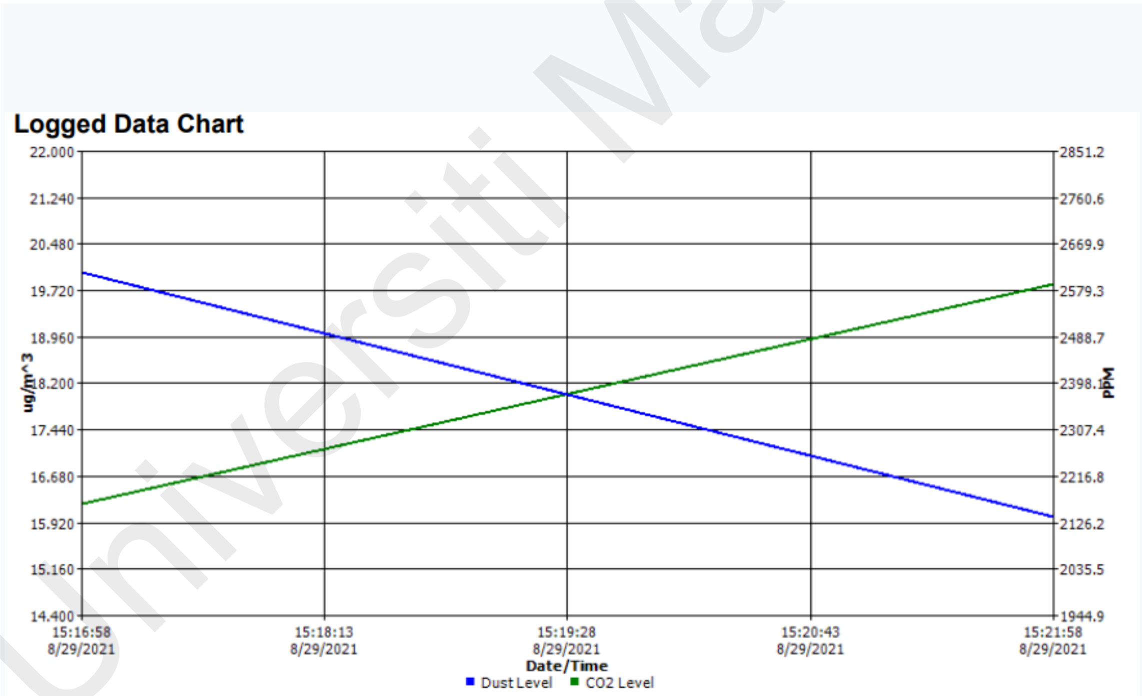


Figure 4. 20: Freed 5 passengers (Idling)

Table 4.4: Comparison Data during Driving and Idling (Evening)

IDLING		CO_2 (ppm)			PM_{10} (μg/m³)		
No of occupants	Car type	Min	Max	Ave	Min	Max	Ave
2	Myvi	147	449	196	37	51	43
2	Freed	1757	2393	1836	4	28	10
5	Myvi	549	732	615	49	136	69
5	Freed	1419	2619	2164	8	40	14
DRIVING		CO_2 (ppm)			PM_{10} (μg/m³)		
No of occupants	Car type	Min	Max	Ave	Min	Max	Ave
2	Myvi	34	314	109	14	270	39
2	Freed	96	329	193	0	13	2
5	Myvi	51	277	191	14	47	22
5	Freed	216	668	510	0	12	1

This comparison result is represented in a graph below.

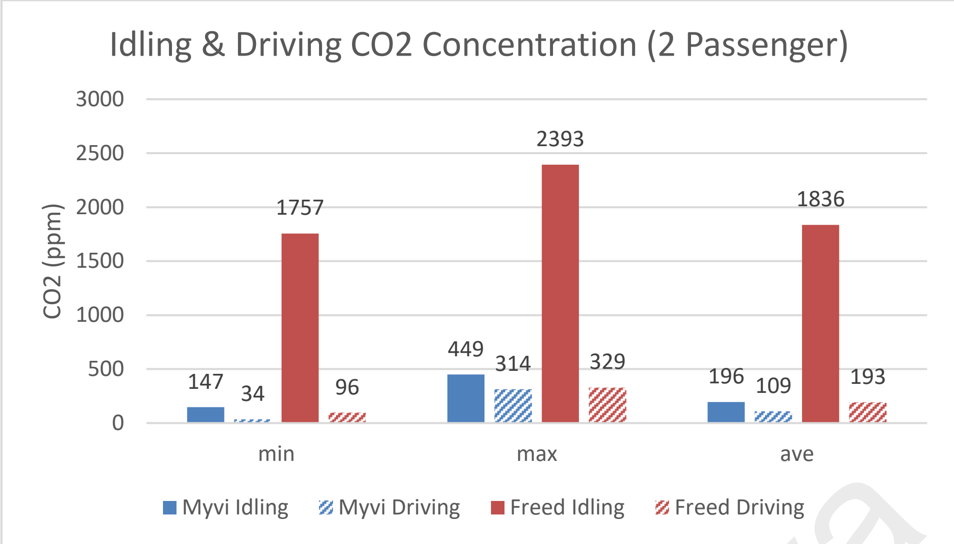


Figure 4. 21: CO_2 concentration (Vehicle Operation) 2 passengers

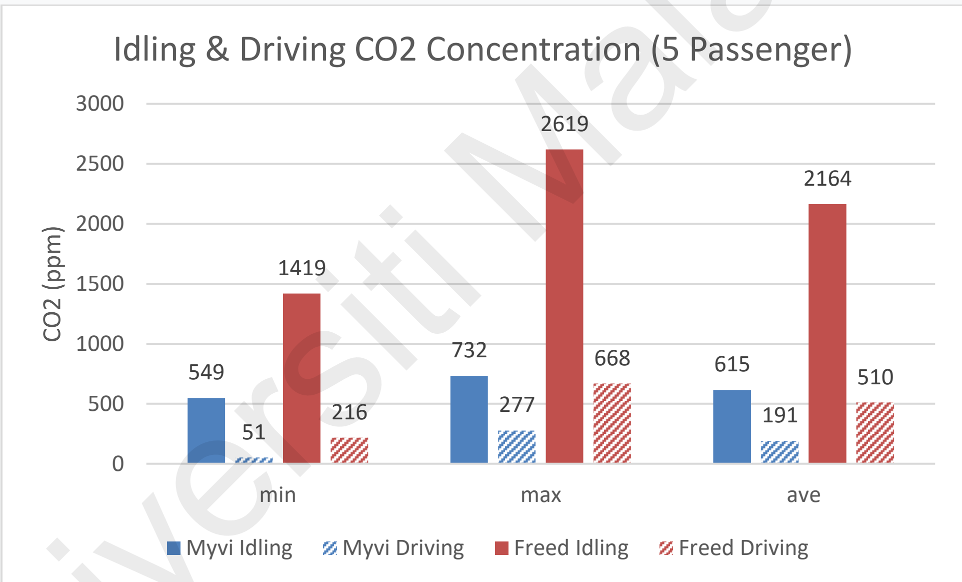


Figure 4. 22: CO_2 concentration (Vehicle Operation) 5 passengers

From figure 4.21 is shown the maximum CO_2 concentration for Perodua Myvi in idling and driving for 2 passengers are 449 and 314 respectively with a 30.0 % difference. While 732 and 277ppm for 5 passengers with 62.2% difference as Figure 4.22. For Honda Freed, idling and driving for 2 passengers are 2393 and 329 respectively with a 86.3% difference. While 2619 and 668 ppm for 5 passengers with 74.5% difference. These is showing that the during idling vehicle operation, the result are more higher than the driving condition in term of change in concentration for CO_2.

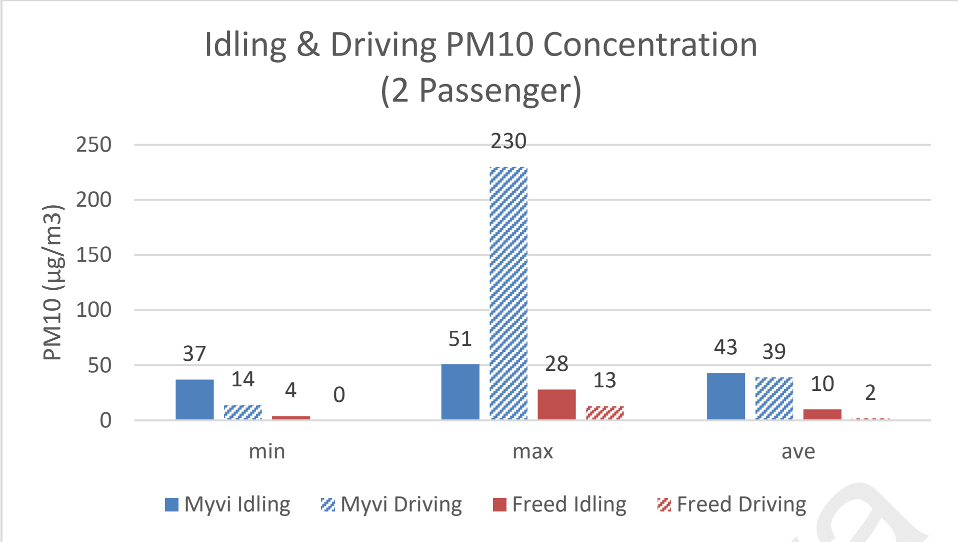


Figure 4. 23: PM_{10} (Vehicle Operation) 2 passengers

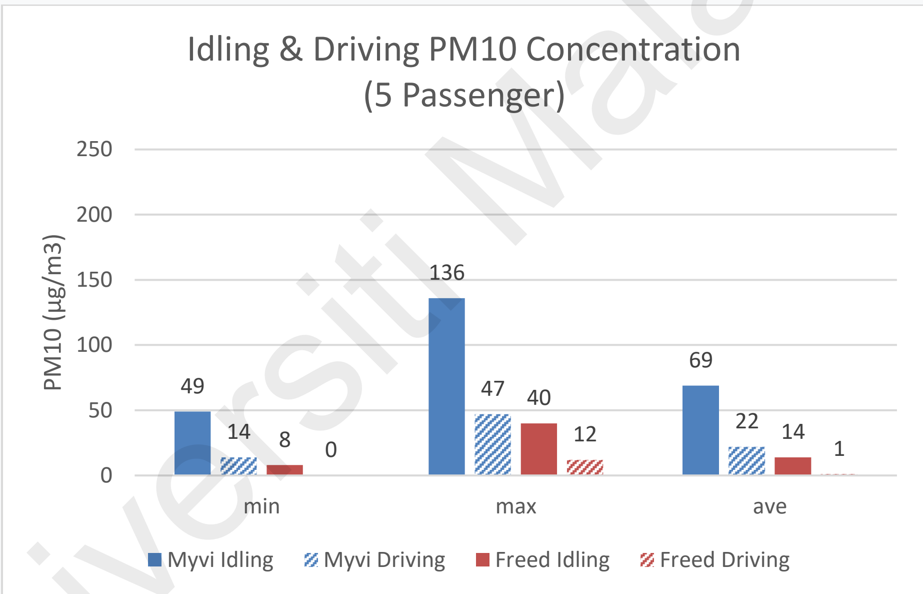


Figure 4. 24: PM_{10} (Vehicle Operation) 5 passengers

From Figure 4.23 is shown the maximum PM_{10} Perodua Myvi in idling and driving for 2 passengers are 51 and 230 respectively with increasing 93.5 % difference. While 136 and 47ppm for 5 passengers with reducing 65.4% difference as Figure 4.24. For Honda Freed, idling and driving for 2 passengers are 28 and 13 respectively with a reducing 53.6% difference. While 40 and 12 ppm for 5 passengers with reducing 70.0% difference. These is showing that the idling vehicle operation of change in PM_{10} is decreasing from idling to driving.

As a result, the purposes and objectives of this study has been successfully accomplished by determining and investigating the carbon dioxide concentration and Particulate Matter inside the car with 2 different time and 2 different cars. Moreover, the average value of carbon dioxide concentration inside the car increase gradually after add more passengers for both types of cars but still below the allowable carbon dioxide concentration stated by Department of Safety and Health , DOSH. For Particulate Matter 10, the number is gradually increase but still below allowable Particulate Matter stated by USEPA.

4.4 Conclusion

In conclusion, the IAQ level of travelling between FTK and UTeM main campus are within the acceptable level set up by DOSH and USEPA. However, further study is needed to be conduct first, with more repeatable test and build bigger data set to accurately obtain the results.

Furthermore, the road analysis reveals that location and area does not play a significant role while travelling between FTK and UTeM main campus. Instead, the prominent factor influencing the IAQ level was the duration of travel and speed of vehicle, specifically regarding the air exchange rate inside the cabin. The car's IAQ is relatively better when in the highway (Lebuh SPA and Jalan UTeM) when the car was moving. The carbon dioxide shows build-up and increase in area with traffic, such as T-junction to Jalan UTeM. To overcome the problem, it is recommended for driver and passenger to set Outside Air (OA) mode after 2 hours of travelling. They can also open the window for a sometime to get the fresh air intake come in to the car cabin. The Carbon Dioxide level can be minimize during travelling. Instead of action from driver or passengers itself, car manufacturer also can come out with the idea on the sensor automatic setting of Outside Air mode. This is to prevent the CO_2 will build up more because driver and passenger may forget to do the setting. The idea to car manufacturer is they can install an automatic sensor in the car cabin to trace the concentration of Carbon Dioxide. When the car cabin condition of CO_2 level exceed the safe condition, the sensor will detect the value and automatically required Outside Air mode in operating.

4.5 Recommendation for future study

During the testing phase of the study, several reading sessions have been attempted in order to obtain accurate readings. This is especially true for the recording of car activity report. To overcome this, the testing should be record the trip using video camera. Moreover, the testing session were with limitation which difficulty to do for 7 passengers due to restrictions caused by the Covid-19 pandemic. In order to get a more accurate data for the parameters, larger data set is needed for the assessment in order to get a more accurate data and the air cabin filter need to use the new one, instead of old.

For future research, there are several parameters that can be included for vehicle IAQ study:

1) IAQ analysis of for carbon monoxide (CO) and PM2.5
2) To study the effect of travelling for long distance (Ayer Keroh to UTHM, Pagoh)
3) Study the effect of air exchange rate to CO2 concentration
4) The effect of actuator mode on the IAQ level of car
5) Study the effect of PM2.5 on car cabin while idling and moving
6) Changing of Air Filter of vehicle before done experiment
7) Study regarding the health issues of students relating to IAQ

REFERENCES

Abdullah, S. (2018). *(Iaq) At Refinery Industry*. *9*(9), 925–932.

Akinwale, O. M., Oluwunmi, A. O., Utom, J., & Fadahunsi, J. (2019). A Review of the Effects of Sick Building Syndrome on Property and the Occupants. *Covenant Journal of Research in the Built Environment (CJRBE)*, *7*(1), 18–28. https://doi.org/10.20370/c03x-9q36

Al-Hemoud, A. (2018). *Building and Environment. Streamlining IAQ guidelines and investigating the effect of door opening/closing on concentrations of VOCs, formaldehyde, and NO2 in office buildings*. 127–137.

Autralian Government Department of Agriculture, W. and E. (2019). *National Pollutant Inventory*. http://www.npi.gov.au/resource/particulate-matter-pm10-and-pm25

Axelrad, R. (2009). Indoor Air Quality. *Safe and Healthy School Environments*, 1–6. https://doi.org/10.1093/acprof:oso/9780195179477.003.0010

Barbu, B.-A., Niculescu, Z., & Moise, L.-G. (2019). Sick building syndrome, a crossroad in modern occupational medicine assessment. *Romanian Journal of Occupational Medicine*, *69*(1), 12–17. https://doi.org/10.2478/rjom-2018-0002

Barnes, N. M., Ng, T., Ma, K. K., & Lai, K. M. (2018). In-cabin air quality during driving and engine idling in air-conditioned private vehicles in Hong Kong. *International Journal of Environmental Research and Public Health*, *15*(4). https://doi.org/10.3390/ijerph15040611

Cha, Y. (2019). *In-cabin Carbon Dioxide and Health Effects Yingying Cha Specifications , dimensions and drawings may be subject to change without notice*. *October*.

https://doi.org/10.13140/RG.2.2.22676.86405

Chiu, C. F., Chen, M. H., & Chang, F. H. (2015). Carbon dioxide concentrations and temperatures within tour buses under real-time traffic conditions. *PLoS ONE*, *10*(4), 1–12. https://doi.org/10.1371/journal.pone.0125117

Cincinelli, A., & Martellini, T. (2017). Indoor air quality and health. *International Journal of Environmental Research and Public Health*, *14*(11). https://doi.org/10.3390/ijerph14111286

Ding, H., Zhang, Y., Sun, H., & Feng, L. (2016). Analysis of PM2.5 distribution and transfer characteristics in a car cabin. *Energy and Buildings*, *127*, 252–258. https://doi.org/10.1016/j.enbuild.2016.06.004

DOSH. (2010). *Industry Code of Practice On Indoor Air Quality*. http://www.dosh.gov.my/index.php?option=com_docman&task=doc_download&gid=594&Itemid=183

DOSH. (2020). *Chemical Management/ IAQ*. https://www.dosh.gov.my

Environmental Protection Agency, U. S., & Environments Division, I. (1991). Indoor Air Facts No. 4 Sick Building Syndrome. *EPA - Air & Radiation (6609J), Research and Development (MD-56)*, 1–4. https://www.epa.gov/sites/production/files/2014-08/documents/sick_building_factsheet.pdf

Faber, J., & Brodzik, K. (2017). Air quality inside passenger cars. *AIMS Environmental Science*, *4*(1), 112–133. https://doi.org/10.3934/environsci.2017.1.112

Gajewski, A. (2013). Indoor air quality in a bus. *WIT Transactions on the Built Environment*, *134*(September 2013), 749–757.

https://doi.org/10.2495/SAFE130671

Geiss, O., Barrero-Moreno, J., Tirendi, S., & Kotzias, D. (2010). Exposure to particulate matter in vehicle cabins of private cars. *Aerosol and Air Quality Research*, *10*(6), 581–588. https://doi.org/10.4209/aaqr.2010.07.0054

Ham, W., Vijayan, A., Schulte, N., & Herner, J. D. (2017). Commuter exposure to PM2.5, BC, and UFP in six common transport microenvironments in Sacramento, California. *Atmospheric Environment*, *167*, 335–345. https://doi.org/10.1016/j.atmosenv.2017.08.024

Jang, Y. (2018). *Determination of factors associated with in-bus exposure to fine particulate matter (PM 2 . 5)*.

Kim, H., Yang, X., Ryu, S., & Yu, Y. (2018). *29. Carbon dioxide (CO_sub_2__sub_) concentrations and activated carbon fiber filters in passenger vehicles in urban areas of Jeonju, Korea.pdf*. *76*, 74–80.

Kokon, E. O., Yli-Tuomi, T., Turunen, A. W., Taimisto, P., Pennanen, A., Vouitsis, I., . . . Lanki. (2017). *Particulates and Noise Exposure During Bicycle, Bus and Car Commuting: A Study in Three European Cities*.

Mandin, C., Trantallidi, M., Cattaneo, A., Canha, N., Mihucz, V. G., Szigeti, T., Mabilia, R., Perreca, E., Spinazzè, A., Fossati, S., De Kluizenaar, Y., Cornelissen, E., Sakellaris, I., Saraga, D., Hänninen, O., De Oliveira Fernandes, E., Ventura, G., Wolkoff, P., Carrer, P., & Bartzis, J. (2017). Assessment of indoor air quality in office buildings across Europe – The OFFICAIR study. *Science of the Total Environment*, *579*, 169–178. https://doi.org/10.1016/j.scitotenv.2016.10.238

Masyita, M., Nornadiah, R., & Section, E. H. (2017). In Train Air Quality Analysis Of

The Public Railway Transit. *Journal of Fundamental and Applied Sciences*.

Moreno, T., Reche, C., Rivas, I., Cruz Minguillón, M., Martins, V., Vargas, C., Buonanno, G., Parga, J., Pandolfi, M., Brines, M., Ealo, M., Sofia Fonseca, A., Amato, F., Sosa, G., Capdevila, M., de Miguel, E., Querol, X., & Gibbons, W. (2015). Urban air quality comparison for bus, tram, subway and pedestrian commutes in Barcelona. *Environmental Research*, *142*, 495–510. https://doi.org/10.1016/j.envres.2015.07.022

O, M. F., & Juliana, J. (2014). Exposure to Indoor Air Pollutants (PM 10 , CO 2 And CO) and Respiratory Health Effects among Long Distance Express Bus Drivers. *Health and the Environment Journal*, *5*(3), 66–85.

Passarelli, G. R. (2009). Sick building syndrome: An overview to raise awareness. *Journal of Building Appraisal*, *5*(1), 55–66. https://doi.org/10.1057/jba.2009.20

Pham, L., Molden, N., Boyle, S., Johnson, K., & Jung, H. (2019). Development of a Standard Testing Method for Vehicle Cabin Air Quality Index. *SAE International Journal of Commercial Vehicles*, *12*(2). https://doi.org/10.4271/02-12-02-0012

Ramos, C. A., Reis, J. F., Almeida, T., Alves, F., Wolterbeek, H. T., & Almeida, S. M. (2015). Estimating the inhaled dose of pollutants during indoor physical activity. *Science of the Total Environment*, *527–528*, 111–118. https://doi.org/10.1016/j.scitotenv.2015.04.120

Rivas, I., Kumar, P., Hagen-Zanker, A., Andrade, M. de F., Slovic, A. D., Pritchard, J. P., & Geurs, K. T. (2017). Determinants of black carbon, particle mass and number concentrations in London transport microenvironments. *Atmospheric Environment*, *161*, 247–262. https://doi.org/10.1016/j.atmosenv.2017.05.004

Sun, Y., Hou, J., Cheng, R., Sheng, Y., Zhang, X., & Sundell, J. (2019). Indoor air quality, ventilation and their associations with sick building syndrome in Chinese homes. *Energy and Buildings*, *197*, 112–119.

Underwriters Laboratories UL LLC. (2015). *Vehicle Interior Air Quality: Addressing chemical exposure in automobiles*. 8.

Unites States Environmental Potection Agency. (2020). *Indoor Air Quality*. https://www.epa.gov

World Health Organisation. (2013). *Health effects of Particulate Matter*.

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

Zakaria, H., Sies, M. F., & Yew, W. K. (2019). *Carbon Dioxide Concentration inside Vehicle with Ventilation Setting*. *1*(2), 1–8.

Zulauf, N., Dröge, J., Klingelhöfer, D., Braun, M., Oremek, G. M., & Groneberg, D. A. (2019). Indoor air pollution in cars: An update on novel insights. *International Journal of Environmental Research and Public Health*, *16*(13). https://doi.org/10.3390/ijerph16132441