REDUCING INDOOR AIR CONTAMINANTS INSIDE A CAMPUS BUS PASSENGER COMPARTMENT

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This is dedicated to my beloved husband (Dr. Iqbal Bin Mokhtar) and parents (Ahmad Shafie Bin Ariffin, Noor Lida Binti Raffie, Mokhtar Bin Ahmad & Sabariah Binti Md. Kassim).

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ABSTRACT

Good ventilation system is important to provide fresh air and comfortable environment for passengers. Lack of fresh air inside a bus compartment may cause various illnesses such as headache, asthma, cardiovascular and lung cancer. Two factors influence the ventilation system effectiveness namely the arrangement of air supply diffusers and the air return grilles. This thesis presents a study on air contaminants inside a university's bus passenger compartment. The goal is to find a suitable ventilation arrangement that can reduce the concentration of the air contaminants. First a field measurement was carried out on a selected bus to measure the air contaminants at the front section, middle section and rear section. The contaminants include carbon monoxide, carbon dioxide, formaldehyde and particulate matter. Then computational fluid dynamics flow analyses were carried out on simplified model of the bus compartment employing renormalization group k-ε model for air flow, species transport for gases and discrete phase for particles. Five cases of ventilation arrangements were considered namely displacement ventilation with two air return grilles, underfloor air distribution with two air return grilles, mixing ventilation with four air return grilles, displacement ventilation with four air return grilles and underfloor air distribution with four air return grilles. It was found from the field measurements that the concentration of carbon monoxide, carbon dioxide, formaldehyde, particulate matter 1, particulate matter 2.5 and particulate matter 10 were 7 ppm, 1102 ppm, 0.18 ppm, 52 $\mu g/m^3$, 52 $\mu g/m^3$ and 51 $\mu g/m^3$, respectively. Results of flow simulations show that the underfloor air distribution with four air return grilles is able to reduce the contaminants concentration inside the passenger compartment. On average, the concentrations of carbon monoxide, carbon dioxide, formaldehyde, particulate matter 1, particulate matter 2.5 and particulate matter 10 were reduced by about 40%, 10%, 38%, 37%, 33% and 30%, respectively.

ABSTRAK

Sistem pengudaraan yang baik adalah penting untuk memberikan udara segar dan persekitaran yang selesa kepada penumpang. Kekurangan udara di dalam ruangan bas akan menyebabkan pelbagai penyakit seperti sakit kepala, asma, sakit jantung dan kanser paru-paru. Dua faktor mempengaruhi keberkesanan sistem pengudaraan iaitu susun atur sistem bekalan udara peresap dan jeriji udara pulangan. Tesis ini membentangkan kajian terhadap bahan cemar udara di dalam ruangan penumpang bas universiti. Matlamat kajian ini adalah untuk mencari susun atur sistem pengudaraan yang sesuai bagi mengurangkan kepekatan bahan cemar udara. Pertama pengukuran lapangan telah dijalankan pada bas yang telah dipilih untuk mengukur bahan cemar pada bahagian depan, bahagian tengah dan bahagian belakang. Bahan cemar ini terdiri daripada karbon monoksida, karbon dioksida, formaldehid dan zarah. Kemudian analisis aliran pengkomputeraan dinamik bendalir telah dijalankan pada model ruangan bas dengan menggunakan model *renormalization group* k-ε untuk aliran udara, *species transport* untuk gas dan *discrete phase* untuk zarah. Lima kes susun atur pengudaraan iaitu pengudaraan anjakan dengan dua jeriji udara pulangan, pengudaraan udara bawah lantai dengan dua jeriji udara pulangan, pengudaraan percampuran dengan empat jeriji udara pulangan, pengudaraan anjakan dengan empat jeriji udara pulangan dan pengudaraan udara bawah lantai dengan empat jeriji udara pulangan telah dikaji. Didapati daripada data pengukuran dimana tahap kepekatan karbon monoksida, karbon dioksida, formaldehid, zarah 1, zarah 2.5 dan zarah 10 adalah 7 ppm, 1102 ppm, 0.18 ppm, 52 $\mu g/m^3$, 52 $\mu g/m^3$ dan 51 $\mu g/m^3$, masing-masing. Keputusan simulasi aliran menunjukkan pengudaraan udara bawah lantai dengan empat jeriji udara pulangan mampu mengurangkan tahap kepekatan bahan cemar di dalam ruangan penumpang. Secara purata, tahap kepekatan karbon monoksida, karbon dioksida, formaldehid, zarah 1, zarah 2.5 dan zarah 10 telah berkurang sebanyak 40%, 10%, 38%, 37%, 33% dan 30%, masing-masing.

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LIST OF ABBREVIATIONS

ACH	-	Air exchange rate
ASHRAE	-	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BC	-	Baseline case
BTEX	-	Benzene, toluene, ethyl-benzene and xylenes
CFD	-	Computational fluid dynamics
C1	-	Case 1
C2	-	Case 2
C3	-	Case 3
C4	-	Case 4
C5	-	Case 5
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
CH_2O	-	Formaldehyde
DPM	-	Discrete phase model
DV	-	Displacement ventilation
EPA	-	Environment Protection Agency
GCI	-	Grid convergence index
HPC	-	Handheld particle counter
H1N1	-	Avian influenza and swine influenza
IAQ	-	Indoor air quality
IAC	-	Indoor air contaminant
IEQ	-	Indoor environmental quality
$MAHC_S$	-	Monoaromatic hydrocarbons
MV	-	Mixing ventilation

NIOSH	-	National Institute for Occupational Safety and Health
NO_2	-	Nitrogen dioxide
OSHA	-	Occupational Safety and Health Administration
O_2	-	Oxygen
PPM	-	Part per million
PMs	-	Particulate matters
PM1	-	Particulate matter 1
PM2.5	-	Particulate matter 2.5
PM10	-	Particulate matter 10
RANS	-	Reynolds-averaged Navier-Stokes
RG	-	Return grille
RNG	-	Renormalization-group
SARS	-	Severe acute respiratory syndrome
SD	-	Standard deviation
SIMPLE	-	Semi-implicit method for pressure linked equations
SO_2	-	Sulphur dioxide
SF_6	-	Sulphur hexafluoride
TLVs	-	Threshold limit values
UTM	-	Universiti Teknologi Malaysia
UFP_S	-	Ultrafine particles
UFAD	-	Underfloor air distribution
WHO	-	World Health Organization

LIST OF SYMBOLS

A	-	Cross sectional area
C	-	Contaminant
Cm	-	Maximum measured
Cp	-	Maximum predicted
D	-	Diameter
D_H	-	Hydraulic diameter
g	-	Gravity
hr	-	Hour
L	-	Length
m	-	Meter
m^3	-	Cubic meter
$\dot{m}_p$	-	Mass flowrate of particle
P	-	Wetted perimeter
Re	-	Reynold number
S_T	-	Rate of thermal energy production
T	-	Diffusion coefficient
u_f	-	Friction velocity
v, u, w	-	Velocity
y	-	Distance to the wall
y^+	-	Non-dimensional number
ρ	-	Density
υ	-	Kinematic viscosity
μg	-	Microgram

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Indoor air quality is one of the major environmental concerns since people spend about 90% of their time indoors and about 7% of their daily time commuting, mostly between their workplace and their residence [1]. At present, many people use public transport buses for workplace, shopping, recreation and others [2]. Apart from public transport buses, university shuttle buses have attracted extensive attention since many students use this transportation in a university campus to travel to class, extracurricular activities and others [3].

Indoor air contaminants are typically found inside the bus passenger compartment namely gases (CO, CO_2, and CH_2O) and particles (PM1, PM2.5 and PM10) [4]. The air contaminants such as CO, CO_2, CH_2O, PM1, PM2.5 and PM10 originate from mobile sources (exhaust gas) [5]. Based on the previous studies, the concentration levels of CO, CO_2, CH_2O, PM1, PM2.5 and PM10 were exceeded the threshold limit values by the World Health Organization guideline [2]. Peak hours, passenger's board and unboard, weather condition, ventilation setting, ventilation system, bus engine and bus age are the factors that influences the air contaminants concentration level inside the bus passenger compartment [6]. The exposure of CO, CO_2, CH_2O, PM1, PM2.5 and PM10 concentrations could threaten the passenger's health in both the short and long term. Air contaminants concentration is responsible for a wide range of health consequences such as headache, eye irritation, lung cancer, cardiovascular, tuberculosis, asthma and airborne transmission (Severe Acute Respiratory Syndrome and Avian Influenza and Swine Influenza) [7]. The particulate matters such as PM1, PM2.5 and PM10 can penetrate into the thoracic part of the airway and accumulate in the respiratory system [8]. Particles less than 10 μm in diameter can be inhaled and 80% of them will be deposited in the human respiratory system, possibly leading to fatal outcomes [9].

In bus passenger compartments require good ventilation system to provide fresh air and comfortable environment for passenger. In engineering approach, the efficiency of ventilation system is evaluated by the indoor air quality. Indoor Air Quality (IAQ) refers to the effect, good or bad of the contents of the air inside an enclosed environment [10]. Good IAQ is the quality of air which has no unwanted contaminants. Poor IAQ occurs when contaminants are present in excessive concentrations. Knowledge concerning the air contaminants concentration level is very important to prevent the inhalation of harmful air contaminants by passengers when commuting in a bus. The ventilation systems of buses must be improved as bus travel is used for business, shopping, campus, school, recreation or others activities. Several factors affect the performance of the ventilation system such as air supply velocity, air supply temperature, layout of the air supply diffusers and layout of the air return grilles [11].

Three types of ventilation system have been widely used in an enclosed environment such as mixing ventilation, displacement ventilation and underfloor air distribution [12]. Within the last few years, the mixing ventilation system has become a popular design and has been used in bus transportation. A common example of the mixing ventilation system is one equipped with ceiling-based air supply diffusers and air return grilles [12]. In bus transportation, the air is supplied via air supply diffusers (placed on the ceiling mounted ducting above passenger seats) and released through the air return grilles (placed on the roof). Based on the previous studies, this system is not capable of removing the indoor air contaminants when the door is opened for boarding and unboarding passengers [2]. This is because much of the supply air leaves the compartment without mixing with compartment air due to improper layout of air supply diffusers and air return grilles. When this situation occurs, the air contaminants will accumulate at the tight space of the compartment such as on the floor and passenger seats [13]. Therefore, as an alternative, modification of the present ventilation system is needed to reduce the air contaminants concentration inside the bus passenger compartment.

The bus ventilation system is very important in order to reduce the air contaminants concentration level. At present, research works on reducing indoor air contaminants inside the bus passenger compartment is limited especially using computational fluid dynamics (CFD) software [14]. CFD software offers an alternative platform which is more convenient than experimental practice to predict the indoor air contaminant in various applications [15]. Hence, an investigation of indoor air contaminants using CFD method is necessity to find a suitable ventilation system design that would lower the level of air contaminants inside the bus passenger compartment.

1.2 Problem Statement

The present ventilation system in bus is not capable of reducing the air contaminants. This is due to improper arrangements of the ventilation system such as the air supply diffusers and the air return grilles. In bus compartment the concentration level of air contaminants such as gases and particles exceeded the threshold limit set by the World Health Organization guideline due to improper arrangements of the ventilation system. The excessive concentration of gas and particle contaminants could affect passenger's health when commuting in a bus. Therefore, the bus ventilation systems need to redesign to reduce the level of air contaminants. Two methods were identified namely a field measurement and CFD simulation. The field measurement was carried out to quantify the concentrations of CO, CO_2, CH_2O, PM1, PM2.5 and PM10 inside the bus. The CFD simulation model is to predict the air contaminants concentration level inside the bus. Five types of ventilation system design were considered namely a displacement ventilation with two air return grilles, underfloor air distribution with two air return grilles, mixing ventilation with four air return grilles, displacement ventilation with four air return grilles and underfloor air distribution with four air return grilles.

1.3 Objectives of the Research

Three objectives were developed to achieve the aim of this research. The following objectives are as follows:

1. To quantify the indoor air contaminants concentration level inside a campus bus passenger compartment.
2. To examine the effects of present ventilation system design (baseline case) on contaminants concentration level through the use of CFD method.
3. To establish suitable ventilation system design for reducing the indoor air contaminants concentration level inside the campus bus passenger compartment.

1.4 Scopes of the Research

The scope of this research is divided in two parts, i.e. field measurement and CFD simulation. The field measurements were carried out in a university shuttle bus passenger compartment. The distance of bus travelled within a university campus is 48 km. The measurements were conducted during the peak hour period to examine the gas (CO, CO_2 and CH_2O) and particle (PM1, PM2.5 and PM10) concentration. In this study, the door is opened during quantification of the air contaminants concentration inside the bus passenger compartment. The weather condition was clear and no rain fell while the field measurements were conducted.

Ansys CFD Fluent software (R-14) was used to develop a simplified three-dimensional model of the bus passenger compartment. The CFD model was meshed using the tetrahedron elements. In this study, the boundary condition of the air contaminants was prescribed at the door only due to outside air contaminants entering the bus. The passenger compartment is assumed clean and without air contaminants. Three types of air flow analysis namely RNG k-ε turbulent model, species transport model and discrete phase model were used to predict the distribution of air flow and air contaminants. Five types of ventilation system design were considered namely a displacement ventilation with two air return grilles, underfloor air distribution with two air return grilles, mixing ventilation with four air return grilles, displacement ventilation with four air return grilles and underfloor air distribution with four air return grilles. The comparison between the field data and CFD simulation on various ventilation system designs were discussed.

1.5 Important of the Research

Understanding the link between ventilation system design and air contaminants concentration can help to reduce the level of air contaminants concentration inside a bus passenger compartment. The reducing of air contaminants concentration enhances the air quality inside the bus compartment and to prevent the indoor air diseases to passengers.

1.6 Thesis Outline

Chapter 1 presents an introduction, problem statement, objectives and scopes of this research.

In Chapter 2, a review on field measurement and CFD simulation on air contaminants concentration in an enclosed environment are presented. Different types of air contaminants namely gases and particles are investigated. The effects of air contaminants on passenger health are also presented in this chapter. The methodology on a field measurement and CFD analysis on air contaminants concentration in an enclosed environment has been reviewed. In addition, different types of ventilation systems such as mixing ventilation, displacement ventilation and underfloor air distribution in an enclosed environment are presented.

Chapter 3 presents the methodology of this study. The methodology is divided into two parts, i.e. field measurement and CFD simulation analysis. The field measurements are conducted to quantify the air contaminants concentration level inside the bus passenger compartment. The measured data is used for boundary condition in the CFD model and validation. A three-dimensional CFD model has been developed in order to simulate and predict the air contaminants concentration inside the bus environment. Five cases of parametric analysis are presented in this chapter.

In Chapter 4, the results of field measurements and CFD simulation on air contaminants concentration are presented. The levels of air contaminants concentration are discussed at the front section, middle section and rear section of the passenger compartment. The CFD simulations results are discussed based on the whole bus compartment, passenger seats and breathing level to examine the air contaminants concentration level. A parametric analysis on the various cases of ventilation system design is presented in this chapter. A new ventilation system design that was obtained from the parametric analysis was discussed based on the air flow and air contaminants.

Chapter 5 presents a conclusion on air contaminant concentration levels inside the bus passenger compartment. The levels of air contaminants concentration levels and the effects of present ventilation system are concluded in this chapter. As well, the best ventilation system designs that reduce the indoor air contaminants inside the passenger compartment are presented. Several recommendations for future work have been proposed in this chapter.

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