CFD STUDY ON THE IMPINGING JET VENTILATION TOWARDS INDOOR AIR QUALITY

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DECLARATION

I declare that this project report entitled "CFD STUDY ON THE IMPINGING JET VENTILATION TOWARDS INDOOR AIR QUALITY" is the result of my own work except as cited in the references.

Signature : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : .....

Supervisor's Name : .....

Date : .....

ABSTRACT

The impinging jet ventilation system is a relative modern ventilation system which combine the positive effects from mixing and displacement ventilation. One of the demerits of this system is when for room cooling purpose, the cold supply air jet unable to distribute evenly in the room. The objective of this project is to develop a CFD model for impinging jet ventilation system and investigate the effects of position of exhaust and the shape of inlet toward the thermal condition and velocity field in a closed area. As the result, the position of exhaust brings a larger impact to the thermal condition in the test model while the shape of inlet shows a bigger influence in the velocity field in the test model when comparing to the position of exhaust. When placing the exhaust on the top of heat source, the heat generated can be remove more easily comparing to others location. Meanwhile by using a triangular inlet can lead to a higher inlet air velocity while maintaining a constant air flowrate. Finally, the recommendations for further research on the study of impinging jet ventilation system by using CFD are suggested such as run the simulation with ACT extension for thermal comfort so that the contour plots for mean age of air, PMV and PPD can be generate in the result tab.

ABSTRAK

Sistem pengudaraan jet pembantutan adalah sistem pengudaraan modern yang menggabungkan kesan positif daripada sistem pengudarran pencampuran dan anjakan. Salah satu demerit sistem ini ialah apabila guna dalam tujuan penyejukan bilik, jet udara bekalan sejuk tidak dapat mengedarkan jet udara ini secara sama rata di dalam bilik tersebut. Oleh itu tujuan projek ini adalah mengkaji beberapa aspek tentang sistem pengudaraan ini. Objektif projek tersebut adalah untuk membina model CFD untuk sistem pengudaraan tersebut dan menyiasat kesan-kesan tentang kedudukan ekzos dan bentuk salur masuk udara dengan keadaan terma dan medan halaju di dalam kawasan tertutup. Daripada hasil projek ini, didapati bahawa kedudukan ekzos membawa impak yang lebih besar kepada keadaan terma dalam model ujian manakala bentuk salur masuk menunjukkan pengaruh yang lebih besar dalam bidang medan halaju dalam model ujian. Apabila ekzos diletakkan di atas sumber haba, haba yang dihasilkan dapat dikeluarkan dengan lebih mudah berbanding dengan lokasi lain. Sementara itu dengan menggunakan bentuk salur masuk segi tiga dapat menjadikan halaju udara masuk tinggi manakala mengekalkan kadar aliran udara yang sama. Di dalam bahagian terakhir laporan ini, cadangan untuk penyelidikan lanjut mengenai kajian sistem pengudaraan tersebut dengan menggunakan CFD telah dicadangkan seperti menjalankan simulasi dengan sambungan ACT untuk keselesaan haba supaya plot kontur untuk umur min udara, PMV dan PPD boleh dijana dalam tab hasil.

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LIST OF ABBREVIATIONS

HVAC – Heating, Ventilating and Air-Conditioning

IJV – Impinging Jet Ventilation

IAQ – Indoor Air Quality

CFD – Computational Fluid Dynamic

SBS – Sick Building Syndrome

ICOP on IAQ 2010 - Industry Code Of Practice On Indoor Air Quality 2010

DV – Displacement Ventilation

MV – Mixing Ventilation

DR – Draught rate/ Draft

PD – Percentage Dissatisfied

PMV – Predict Mean Vote

CIJV – Corner Impinging Jet Ventilation

ACE – Air Change Efficiency

ADPI – Air Distribution Performance Index

LIST OF SYMBOLS

H/d – jet to plate distance

S/d – jet-to-jet spacing

d – diameter

L – length

η - energy efficiency index

ε - contaminant removal efficiency

CHAPTER 1

INTRODUCTION

1.1 Background

In order to provide a preferable indoor thermal condition and air quality various types of heating, ventilating and air-conditioning (HVAC) system have been created and provide to the market. While in terms of ventilating system there are various types of mechanical ventilation system present which are mixing ventilation, displacement ventilation, impinging jet ventilation and confluent jet ventilation.

The key concept for a mixing ventilation system is to mix the fresh air outdoor with indoor air to dilute the emissions such as heat from indoor source. Normally, mixing ventilation system is design by having an air jet supplied at the ceiling or upper part of wall with air velocity equal or higher than 2 m/s to provide air jets circulation around the room. While in order to prevent high pressure accumulated inside the room an outlet for air flow is set at high level. Although the design is simply and easy, this mixing ventilation system still has its disadvantages which includes the uniform air velocity is high in working space and lead to a higher turbulence in the specific room and making the people inside feels discomfort. Besides that, mixing ventilation system has a low efficiency of ventilation this will causes high pollutant concentrations remain in the air for long periods.

Meanwhile for displacement ventilation system is a ventilation strategy that emerged in the 1970's. The key concept of this ventilation system is based on the principle of displacing indoor air with fresh air supplied from outside. Not like the mixing

ventilation system, this system having a low inlet air velocity which is around 0.5m/s and is supplied near the floor level. While the outlet is set at high level. This design will create an upward air flow inside the room, as the air flow through the heat sources in the room the cold air will absorb heat from the heat sources and create thermal plumes at the high level in the room. This situation will form a vertical gradient of air temperature which fits the concept of buoyancy and have a positive effect for the air ventilation. While the disadvantage of this design is also critical which is displacement ventilation has a limited penetration depth into the room which make this system less efficient in a large room.

Due to the shortcoming in the mixing ventilation and displacement ventilation system, new ventilating system are introduced which are impinging jet ventilation system and confluent jet ventilation system. These two types of ventilating system not only combine the positive outcome of mixing ventilation system and displacement ventilation system also solve the problems face by these two systems. As for impinging jet ventilation system, this system used a duct to supply air jet toward the floor and spread over the floor. Due the characteristic of a medium momentum air supply, the supplied air will cover a larger surface area compare to the displacement ventilation system. While for confluent jet ventilation, the supply air is not supply to the room through directly hit on the floor but using a closely spaced slots or circular apertures with same flow directions to supply a jet of air at the floor level of the room. This creates a similar effect to impinging jet ventilation system.

1.2 Problem Statement

The impinging jet ventilation (IJV) system is a relatively modern ventilation method that proposed in the late 1990's. Although this system holds the strength of mixing ventilation and displacement ventilation, it still has its own weakness. One of the demerits of this system when for room cooling purpose, the cold supply air jet unable to distribute evenly in the room. This situation will make the crowd who staying inside the room experience different thermal condition. The person who near to the nozzle of IJV system in the room will feel colder compare to those who far from it. Hence this report will carry out a study to improve the performance of impinging jet ventilation system so that the impinging jet ventilation system can evenly supply the air to all the places in a closed area compare to an investigation done by previous researcher using computational fluid dynamic (CFD).

1.3 Objective

The objectives of this study are:

i. To develop CFD model of impinging jet ventilation in a closed area.

ii. To analyse the effect of impinging jet with various nozzle and position of exhaust towards indoor air quality of a closed area.

1.4 Scope of study

The study for this project will be fully done by using the CFD software. The study will cover the investigation of previous case which had use IJV system as the mechanical ventilation system. Next in this study, the geometry and condition of the previous case will be reform and then by using the previous case as reference and this project will modify the IJV system in the previous case by changing nozzle size or height condition in order to achieve a better performance compare to the previous case.

CHAPTER 2

LITERATURE REVIEW

2.1 Indoor Air Quality

Indoor Air Quality (IAQ) is pointed to the air quality inside a building or structure. US Environmental Protection Agency (EPA, 2016) defines Indoor Air Quality (IAQ) as a quantitative variable which refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants." But due to lack of consistent metrics and standards, the measurement of IAQ is always vary depending on the perspectives for the person who planning to do this measurement. In general, measurement of IAQ for a building usually point to determine the percentage of pollutants found in the indoor air which include chemical pollutants, concentration of carbon monoxide, formaldehyde levels and others particular substance that can be dissolve in air. Next, IAQ also evaluate does the air condition inside the building is comfort and human friendly such as the thermal condition and humidity of the air around the building. (Anne Steinemann, et al, 2016)

The indoor air quality article at the official website of Department Of Occupational Safety And Health, Ministry of Human Resource has stated that a poor IAQ inside a workplace will make the person inside the building feeling discomfort and may lead to sick building syndrome (SBS). This situation will directly affect the productivity of the worker. Meanwhile a good IAQ not only will protect the health of the people inside the building but will also provide a pleasant and comfort environment.

2.1.1 Sick Building Syndrome

Sick Building Syndrome also known as SBS is an amalgamation of symptoms that due to various exposure on specific building conditions (Lu, et al, 2017). The name of this Sick Building Syndrome is come from the World Health Organization (WHO) where it is a collection of some common symptoms including itchy eyes, running nose and throat irritation, mental fatigue, headaches, nausea, dizziness and skin irritations, which mostly have relationship with environment of the individu. (Ghaffarianhoseini, et al, 2018; WHO 1983). Not like others well-defined building-related illnesses that can easily diagnosed, sick building syndrome is point to the situation in which building occupants experience ill health that appear to be linked to combination of several element in a particular building, hence the identification of illness or cause become very troublesome (Carrie A Redlich, et al, 1997). The rise of this SBS is due to the energy crisis in 1970's which make the air ventilation inside the indoor office decrease significantly. This condition has affected the rate of air change indoor per hour drop from 2 to 0.2 or 0.3 which lead to the fresh supply air for the building occupants drop to $5ft^3$/person from original 20-30 ft^3/ person (Mohammad Javad Jafari, et al, 2015; Hess-Kosa K., 2010).

2.1.2 Industry Code Of Practice On Indoor Air Quality 2010

Industry Code of Practice on Indoor Air Quality 2010 (ICOP on IAQ 2010) is a standard code of practice for industry that publish by Department of Occupational Safety and Health (DOSH). On 30 August 2010, Minister had approved this ICOP and replace the Code of Practice on Indoor Air Quality launched by the him on July 2005. The main purpose of this ICOP is to provide guidance on achieving better IAQ and to set minimum standard for some selected parameters which can avoid discomfort and adverse health effect among the person who most of the time staying inside an enclosed area which is equip with mechanical ventilating and air conditioning (MVAC) system including air-cooled split unit.

This ICOP applies to all type of buildings which are equip with MVAC system in Malaysia, except:

1. domestic buildings;
2. any area or any part of the building which is constructed, used or intended to be used for domestic or industrial purposes;
3. any area or part of building where any chemicals hazardous to health are used for analytical, research or preservation purposes; or
4. removal and disposal of asbestos containing materials.

Table 2.1 shows the parameters which normally will include in testing the indoor air quality of a building and their acceptable range in this industry code.

Table 2.1: IAQ Test Parameters and Acceptable Range or Limits (Department of Occupational Safety and Health (DOSH), 2010)

No.	Test Parameter	Acceptable Range / Limit
Physical Parameter		
1.	Air Temperature	23 ° C - 26 ° C
2.	Relative Humidity	40 % - 70 %
3.	Air Movement	0.15 - 0.50 m/s
Chemical Contaminants		
4.	Carbon Monoxide (CO)	10 ppm
5.	Formaldehyde (CH_2O)	0.1 ppm
6.	Ozone (O_3)	0.05 ppm
7.	Respirable particulates (PM_{10})	0.150 mg/m^3
8.	Total volatile organic compounds ($TVOC_S$)	3.00 ppm
Biological Contaminants		
9.	Total Bacterial Counts	1000 cfu/m^3
10.	Total Fungal Counts	500 cfu/m^3
Ventilation Performance Indicator		
11.	Carbon Dioxide	Ceiling limit: 1000 ppm

Notes for Table 2.1:

a. For chemical contaminants, the limits are eight-hour time-weighted average airborne concentrations.

b. mg/m^3 is milligrams per cubic meter of air at 25° Celsius and one atmosphere pressure.

c. ppm is parts of vapour or gas per million parts of contaminated air by volume.

d. cfu/m^3 is colony forming units per cubic meter.

e. the ceiling limit shall not be exceeded at any time. Readings above 1000ppm are indication of inadequate ventilation.

f. excess of bacterial counts does not necessarily imply health risk but serve as an indicator for further investigation.

2.2 Impinging Jet

Impinging Jet is a strong technique to be used in various cooling situation such as maintaining working temperature for certain electronic components, reducing temperature for metal and glass tempering, cooling of gas turbine blades, paper drying, etc (G.J. Poitras, et al, 2017). Due to its high heat transfer coefficients properties, impinging jet cooling not only efficient in low heat load cooling but also a good cooling mechanism for high heat loads condition. (Julia Wienand, et al, 2016). The properties that make this impinging jet special from others jet is the flow field of impinging jet has several different flow properties. The flow field produced by impinging jet can be separate into three different region which are free-jet region, impingement region and wall-jet region (Figure 2.1). Where the d and h in the Figure 2.1 is the diameter of nozzle and the nozzle to plate distance. The free jet region can be further distinct into three zones depending on the distance between the nozzle and the plate perpendicular to the nozzle. These zones are the potential core zone, developing zone and fully developed zone (Figure 2.2).

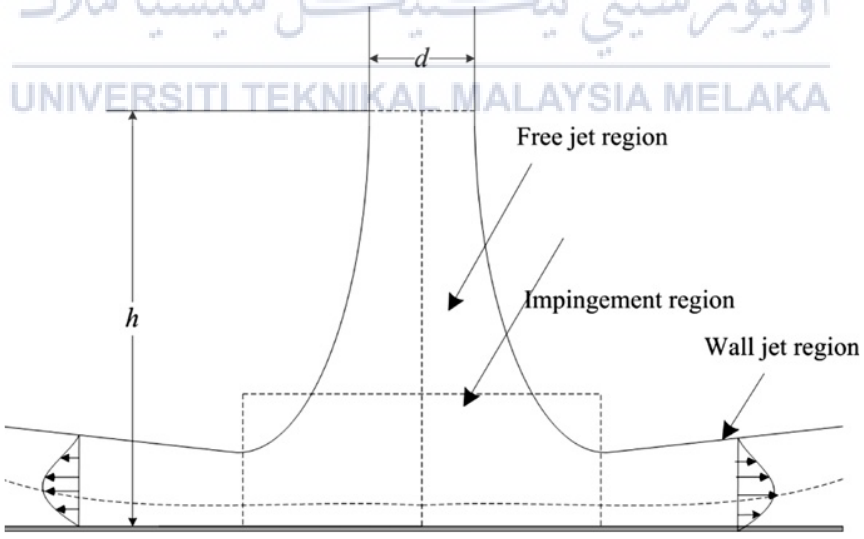

Figure 2.1: Flow regions of an impinging jet (Karimipanah, et al, 2002)

Initially the air jet pump out from the nozzle and the impulsive force on the air jet entrained the surrounding air to flow in the same direction with it thus reducing the