SIMULATION OF NATURAL VENTILATION SYSTEM IN CHEMISTRY LABORATORY OF FACULTY CHEMICAL AND NATURAL RESOURCES ENGINEERING LAB BUILDING

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A thesis submitted in fulfillment of the requirements for the award of the Degree of Bachelor of Chemical Engineering (Gas Technology)

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BORANG PENGESAHAN STATUS TESIS♦

JUDUL : SIMULATION OF NATURAL VENTILATION SYSTEM IN CHEMISTRY LABORATORY OF FACULTY CHEMICAL AND NATURAL RESOURCES ENGINEERING LAB BUILDING

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To Allah
"Thank you for blessing me and strengthen me up"
To Abah, Ummi and Mak
"Thank you for trusting me and love you all forever"
To my sibling and friends
"Thanks for the supportive advise, appreciate it"

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ABSTRACT

The performance of natural ventilation in buildings is often being performed by using computational fluid dynamics (CFD) software, who's gaining its popularity recently. The main goal for this research is to improve the ventilation system by comparing the performance for the current ventilation system and the modified ventilation system. The air distribution is being focused more in order to predict the performance. Chemistry lab of faculty Chemical and natural resource engineering laboratory building is used as the model. Large Eddy Simulation (LES) is applied to estimate the air distribution of ventilation system in the cubic room of chemistry lab. The ambient temperature and pressure are used to be substitute into numerical model. The numerical result that obtained from the simulation is compared with the existing experimental data which the air change rate of laboratory must be at least 30% less than the standard which the standard value of ACH is in the range of 6 to 12 ACH. As the result, the modified ventilation system is showing the optimum of air change rate inside the chemistry lab. The air change rate for a person inside the laboratory is 9 ACH compared to current ventilation which that the value is over the standard value. As the conclusion, the modified ventilation system of the chemistry lab enhances the performance of the ventilation.

ABSTRAK

Prestasi pengudaraan semulajadi dalam bangunan kebiasaannya dipersembahkan dengan menggunakan perisian bendalir dinamik (CFD), yang mana tahap penggunaannya semakin meningkat dari hari ke hari. Penyelidikan ini bertujuan untuk memperbaiki sistem pengudaraan yang sedia ada dan system pengudaraan yang telah diubah suai. Makmal kimia di dalam bangunan makmal kejuruteraan kimia dan sumber asli dijadikan sebagai model. Large Eddy Simulation (LES) digunapakai untuk menjangka pembahagian udara daripada sistem pengudaraan dalam bilik segi empat padu makmal kimia. Suhu dan tekanan persekitaran digunakan untuk dimasukkan ke dalam model berangka. Keputusan yang diperolehi daripada simulasi dibandingkan dengan keputusan eksperimen yang sedia ada di mana kadar perubahan udara (ACH) di dalam makmal mestilah 30 % lebih rendah daripada spesifikasi yang telah ditetapkan yang mana lingkungannya mestilah berada dalam 6 hingga 12 ACH. Keputusannya menunjukkan sistem pengudaraan yang telah diubahsuai menepati syarat yang telah ditetapkan di mana ACH adalah 9 dan jika dibandingkan dengan system pengudaraan semulajadi yang sedia ada, menunjukkan ianya telah melebihi had spesifikasi yang telah ditetapkan. Kesimpulannya, pengubahsuaian sistem pengudaraan menunjukkan prestasi cemerlang untuk system pengudaraan di makmal kimia.

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LIST OF ABBREVIATION

ACH	Air change per hour
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CFD	Computational fluid dynamic
CFM	Cubic feet per minute
DC	Direct current
FKKSA	Faculty of Chemical Engineering and Natural Resources
HVAC	Heating, Ventilation, and Air conditioning
IAQ	Indoor air quality
LES	Large Eddy Simulation
P	Pressure
T	Time
VAV	variable air volume
WHO	World Health Organization
2D	2 Dimensional
3D	3 Dimensional

LIST OF SYMBOLS

Cfm	Cubic feet meter
C_7H_5OCl	Benzene Carbonyl Chloride
CO_2	Carbon Dioxide
Ft^2	Feet square
kW	Kilowatt
l	Liter
l/m	Liter per minutes
l/m^3	Liter per meter cubic
l/s	Liter per second
m	Meter
m/s	Meter per second
m^2	Meter square
m3	Meter cubic
m^3/h	Meter cubic per hour
m^3/s	Meter cubic per second
Qins, T	Ventilation rate
O_2	Oxygen
S	Second
s/h	Second per hour
^oC	Degree Celsius

ρ	Density
τ_{ij}	Subgrid scale Reynolds stresses
$\bar{\upsilon}$	Velocity vector
ν	Kinetic viscosity

CHAPTER 1

INTRODUCTION

1.1 Background of study

Ventilation system is a system that relies on the movement of air which it moves either from outside in or inside out and it should be continuously in order to enhance the quality of indoor air (Khan *et al.*, 2008).

The ventilation systems consist of natural ventilation and mechanical ventilation. The natural ventilation can be describe as a system that using a nature phenomena to drive in or out the air from the building. Moreover, mechanical ventilation is simply known as a system that is using a mechanical device such as fan to force the air from the inside to the outside of the building.

Nonetheless, the ventilation system is significant to ensure the integrity of human health (Hooff and Blocken, 2009). The failure of ventilation system will cause some problems that connected with humidity (Fanger, 1971; Wolkoff and Kjaergaard, 2007; Wyon *et al* .2002), overheating, and some sort of odours, smokes and pollutant.

Common effects that related with bad performance of ventilation are shortness in breath, unconscious, and headache. However, the most critical effect involving the failure of ventilation system is it also can cause chronic disease such as lung cancer and asthma.

As the early prevention care method, the ventilated air from a better ventilation system will indirectly decrease the worst effect on human health which by diluting odours and limiting the concentration of carbon dioxide that had been released by the human through respiration process.

1.2 Problem statement

FKKSA Lab is divided into five sub laboratory which are unit operation, chemical reaction, and separation laboratory, clean room, chemistry laboratory, pilot plant, and gas engineering laboratory. The laboratory is situated in a different area and it also equipped with different general ventilation system. The focusing laboratory is chemistry laboratory.

From the observation that had been made, chemistry lab is facing a problem regarding on the lower air distribution. The lower air distributions cause the room to become overheating and it will affect the comfortness of the consumer that using the lab to conduct their experiment. A study on the airflow inside the laboratory should be carry on in order to overcome the problem.

1.3 Objectives

The objective of this research is to overcome the ventilation system problem in chemistry lab of FKKSA Lab by study on the airflow of only considering the natural ventilation system. The chemistry lab model will be simulated by using computational fluid dynamic (CFD).

1.4 Significance of study

This research will improve the airflow for current natural ventilation system in the FKKSA Lab and in the future, the newcomer students and lecturers of the faculty will feel comfy while using the laboratory to run the experiment.

1.5 Research scope

The scope of this research will consist of:

a) Modification on current ventilation system in chemistry lab

b) Simulate the data by using computational fluid dynamic (CFD) software for current and modified ventilation system of chemistry lab.

c) Determination on the air distribution inside the chemistry lab of FKKSA's laboratory

d) Comparison data between the standard air distribution data in laboratory with the current and modified ventilation system in laboratory.

CHAPTER 2

LITERATURE REVIEW

2.1 Ventilation

Ventilation is one of the HVAC systems where all of it (heating, ventilating and air conditioning) relies on the movement of air. Basically, the movement air for ventilation either from outside in or inside out of an enclosed space in a building (Hall and Greeno, 2009; Khan *et al*, 2008).

There are several terms that need to be known related to ventilation in order to comply with human health (Hoof and Blocken, 2009). The movement of air will accommodate fresh air for respiration process where it must contained approximate 0.1 to 0.2 l/s per person and at the same time maintaining the percentage of oxygen (O_2) in the air that is theoretically approximate percentage of 21%. The maintaining of oxygen will control the amount of carbon dioxide (CO_2) which the concentration of CO_2 must less than 2% and if the concentration is too high, it will poison the human health and as the effect, it may cause fatal damage.

Furthermore, the movement of air will limit moisture of the enclosed space where the relative humidity is acceptable around 30% to 70%. Discharge heat from mechanical equipment, human, and lighting, remove odours, smokes, dust and other contaminants, comfort stagnation and at the same time provide a sense of freshness (Etheridge and Sandberg, 1996; Spencer, 1998; Awbi, 2003).

Hence, adequate ventilation system will provide enough air to be distributed inside the building and at the same time, some problems which involving excessive humidity, condensation, overheating, odour, smokes and pollutant can be avoided (Khan *et al*, 2008). It should be continuously from time to time in order to enhance the quality of indoor air (Etheridge and Sandberg, 1996; Oakley, 2002; Awbi, 2003; Khan *et al*, 2008; Hall and Greeno, 2009).

2.1.1 Type of ventilation

There are two types of ventilation system that had been used in the building (Jong and Sang, 2007). The types for the ventilation system consist of;

a) Natural ventilation

Natural ventilation can be describe as a system that using a nature phenomena to drive in or out the air from the building by the opening part such as windows or doors or stack without any mechanical fan. This kind of ventilation system is commonly used because it is an energy consumption saver method (Busch, 1992; Zhao and Xia, 1998) and it also easier to be installed. The natural ventilation system basically depending on wind effects, thermal buoyancy and the combination of wind and thermal buoyancy. Two major types of natural ventilation are;

i. Cross ventilation

It is oftenly used in the tropic climate countries and for certain cases, this system are circumventing from being utilized. The closest example of circumvent of cross ventilation is thick building (Munir and Wonorahardjo, 2004). Hence, in this situation, single sided ventilation is much more suitable to be practiced.

ii. Single sided ventilation

Single sided natural ventilation system is attained by exchanging the air between indoors and outdoors through the same openings on the same side of a space at the equivalent height. In other words, it also can be define by the flowing of air into a space through one or more inlet of the openings and flowing out from different exit openings which when the inlet and outlet openings are at a different levels.

b) Mechanical ventilation

Mechanical ventilation is a ventilation system using a mechanical device such as fan to force the air inside to outside of the building. The fans of the mechanical ventilation system can be built in the opening part of the building such as windows or walls or in the air duct. The figure 2.1 below shows the example of mechanical ventilation, a prototype turbine ventilator incorporating a PV-fan system.

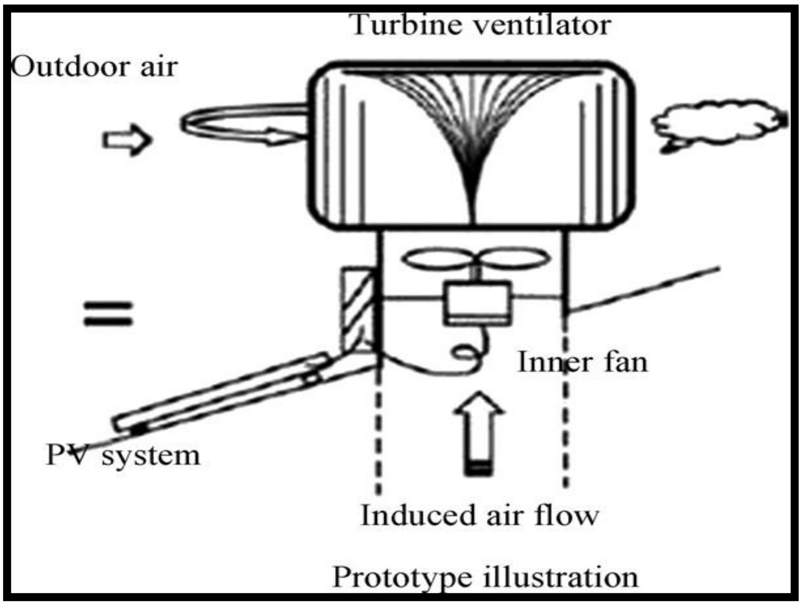

Figure 1: Prototype turbine ventilator incorporating a PV-fan system

Source: Khan, Su and Riffat (2008)

Figure 1 shows the example of mechanical ventilation system which using a small direct current (DC) fan powered by the PV cell. This prototype turbine ventilator can manage to increase the operation and energy efficiency compare with the standard commercial existing ventilator.

Nonetheless, the surrounding condition helps mechanical ventilation system to operate well for example in warm and humid condition. In this kind of situation, infiltration is needed to obviate condensation where the warm moist air from inside the building accessed the wall, roof, or floor and meets cold surface from happening. As the result, the positive pressure of mechanical ventilation system is frequently applied. Positive pressure of the mechanical ventilation system means the room air is escaped out through openings of the building either leakage envelope or windows (WHO Publication Guideline).

However, if it is in cold climate, exfiltration need to be prevented in order to reduce condensation from happening. The negative pressure of mechanical ventilation system applied in cold surrounding. Negative pressure means the room air is actually neutralized by sucking air from the outside (WHO Publication Guideline).

2.2 Laboratory ventilation

2.2.1 Outdoor air requirement in laboratory

There are differences between ventilation system in laboratory and ventilation system in other building because laboratory needs more fresh air in order to neutralize the surrounding.

Table 1: Minimum ventilation rates in breathing zone

Occupancy category	Occupant density	Outdoor air requirement				
		$\frac{cfm}{person}$	$\frac{l}{s\,.person}$	$\frac{Cfm}{ft2}$	$\frac{L}{s.m2}$	Air class
Education						
classroom	65	7.5	3.8	0.06	0.3	1
laboratories	25	5	5.0	0.18	0.9	2
Multi use assembly	100	7.5	3.8	0.06	0.3	1

Source: ASHRAE Standards 62.1-2007, Ventilation for Acceptable Indoor Air Quality

General notes for table 1;

[1] Related requirement: the rates in this table are based on all other applicable requirement of this standard being met.

[2] Smoking: These tables apply for no smoking areas. Rates for smoking permitted spaces must be determined using other methods.

Table 1 shows that the outdoor requirement for laboratory and other places for educational purposes. The occupant density for laboratory is lower than the other because lower occupant density will provide a huge space. Normally, huge space can decrease the possibility of shortness of breath in a confined place compared to a place that surrounds by many people for example classroom (ASHRAE 62.1-2007).

The difference outdoor air requirement between laboratory and other places determine by the function of the place itself. Laboratory is used by the occupant to run some experiment and in the experiment; they are dealing with hazardous chemical. Hazardous chemical is dangerous to all human being and other living life because of its property for example Benzene Carbonyl Chloride (C_7H_5OCl). Benzene carbonyl chloride is a corrosive chemical which high concentration exposure will cause severe irritation and burns and for long term effect, it will cause lung cancer (Guidelines, 1997).

2.2.2 Requirement for laboratory ventilation

The requirement of the design for the new ventilation system depends on the specific needs of the laboratory. Furthermore, the requirement of laboratory ventilation will be as the additional guide in spite of referring to the requirement stated in code and standard

(Laboratory ventilation, 2009). Basic requirement of ventilation system in the laboratory is as follow:

a) General laboratory ventilation

In general, mechanical ventilation should be used in the laboratory. The laboratory ventilation stated that the mechanical ventilation will help to exhaust the fume inside the laboratory to the outside faster than using natural ventilation. In order to provide adequate air for fume hoods, exhaust or stack, and bio safety cabinet, the design of air change rate for each laboratory room is needed and it should be documented. Combination of general and fume hood exhaust will be the preferred ventilation system which the design is only required few cost and little energy consumption. More than that, the design should also be excess in capacity for equipment aging and future expansion (Laboratory ventilation, 2009)

b) Fume hood exhaust system

Fume hood design must be cooperated with user needs, room configuration and general ventilation. The fume hoods functioning as the fume remover by circulate the fume from the fume hoods through stack finally to the outside. It must be situated near the door for at least 6 feet length. Alarm should be provided in case any emergency can be alert such as explosion or fire (Laboratory ventilation, 2009). There are two types of hood that used by the consumer in order to exhaust the fume of the chemical exposure to the outside surrounding.

i) Types of laboratory fume hood

Conventional and bypass is the type of laboratory hood. The differences between those two types of hood are depending on the operational airflow (Labconco, 2003).

Conventional hood had been used for ages. Nowadays, most of the conventional hood had been replaced by the bypass hood which by pass hood can be classified as a superior type performance of hood. The bypass hood can be vary in term of its high performance, auxiliary air and reduced air volume.

I. By pass fume hood

Basically, the constant air volume for by pass hood is constant. It had been design to be sash closed. The condition cause the air to be redistributed, hence minimizing the high velocity of air streams.

In figure 2, the bypass opening located above the sash and below the air foil. Actually, the bypass can reduce fluctuations in face velocity as the sash is being fully or halfly open (Labconco, 2003). However, it cannot achieve the level that required when it relates to face velocity.

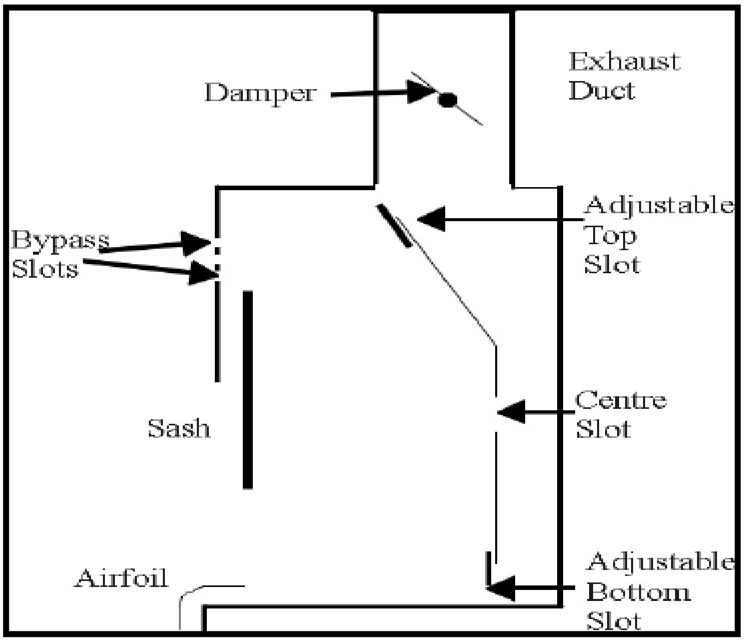

Figure 2: Example of bypass hood

Source: www.safetyoffice.uwaterloo.ca

II. Conventional fume hood

The conventional hood is generally not containing air foil eventhough that the sash is movable (labconco,2003). Moreover, the conventional hood is just a basic enclosure with the interior baffle.

The conventional hood is operating at constant of exhaust volume which is it remains opened to let all of the exhaust air to enter the hood. If the sash of hood is in close condition, the air speed will be higher. This condition will make the important apparatus situated inside the hood being damage. It also will disturb the instrumentation, slowing the distillation rates, cool hot plates and disperse valuable sample.

ii) Fume hood selection requirement

In order to select a suitable hood, the face velocity and contaiment issues need to be focussed more (labconco, 2003). The issues will give an impact on concentration for contaminants where the concentration of contaminants is significant to be kept as low as possible in order to maintain the ventilation performance for the laboratory.

However, several researcher thought that containment issue is more crucial compared to face velocity issue. Its happen because the higher value of face velocity will cause the movement of fluid become turbulence within the hood where it also prevent the hood to contain containment (Diberndinish, 1999). Hence, the higher value of face velocity is not necessarily good.

2.3 Laboratory ventilation standard

The laboratory ventilation standard is being used to establish the requirement and procedures for the ventilation system which to avoid over exposure of chemical that generated while conducting experiments (ANSI Z9.5). Each of the laboratories is required to follow the standard of ANSI Z9.5 where the laboratory needs to have a 'Ventilation Management Programme'. This kind of programme can emphasize the importance of management ventilation system in term of selection, design and operation of laboratory's ventilation system. A coordinator will be the responsible person to manage the programme in order to make it efficient as it plans. Nonetheless, a test of ventilation system is needed to effectively stress out the purpose of the programme.

2.3.1 Test of ventilation system

The periodic test on ventilation system is significant to be done to improve the performance of the ventilation system even though that the face velocity of the hood was optimum. The testing will be done as stated in ASHRAE 110-1995.

The testing of performance for ventilation system according to ASHRAE 110-1995 is done by doing three part of test. Part one; the test should be tested in term of its face velocity profile. The optimum face velocity will be in range of 60-100 fpm. Part two; the test should undergo smoke generation of titanium tetrachloride and part three, the test should undergo tracer gas containment by using sulfur hexafluoride which the sulfur hexafluoride needs to be released for 4 liters per minute (*l*/m).

2.3.2 Variable air volume systems

Variable air volume (VAV) system is one of the required matters in evaluating the performance of the ventilation system. The air volume is measured by the sash opening multiply by average velocity desired (Labconco). The satisfied of variable air volumes is 10 percent (10%) per foot of hood for cubic feet per minute (CFM) that is fully open.

2.3.3 Exhaust stack discharge

The exhaust stack discharge of hood needs to be in vertical direction with a minimum of 10 feet, above the contiguous of the roofline (Newman). The purpose of the height is to avoid the students or workers from looking directly to the discharge of fluid through the stack. Other than that, the discharge stack also needs to be situated with respect to the air inhalation to prevent reentry of fluid. The flowing of fluid needs to be from lower to higher hazard in order for controlling the exposure. Hence, the discharge velocity is expected to be at least of 300 fpm.

Moreover, the relative volumes of air supply and exhaust through any opening include door must be minimum of 50 fpm and a velocity of 100 fpm for desired direction.

2.3.4 Ventilation flow rate

Mainly, the natural ventilation rate may refer to the change of air in a room. The changes transpire when the quantity of air is comparable to the volume of the room. It can be calculated by following equation for openings such as window and door;

$$Ventilation\,rate\ (l/s) = 0.65 \times windspeed\ (m/s) \times smallest\ opening\ area\ (m^2) \times 1000\, l/m^3$$

2.3.5 Air distribution in laboratory

Classification of a place will determine the rate change per hour of the distribution air. Mainly, the higher the value, the higher changes air needed. Table 2 shows the air changes per hour of the building.

An air rate change in laboratory is compulsory to maintain the quality of indoor air where the quality of indoor air will ensure the entire occupant working healthily. Healthy occupants will conduct their works actively compared to those who are in the opposite condition.

Table 2: Table of air change per hour at various areas

Room/building/accommodation	Air changes per hour
Assembly/entrance halls	3 – 6
Boiler plant rooms	10 – 30[a]
Classrooms	3 - 4
Factories/garages/industrial units	6 - 10
Factories-fabric processing	10 – 20
Factories (open plan/spacious)	1 – 4
Factories with unhealthy fumes	20 - 30
Laboratories	6 - 12
Lobbies/corridors	3 - 4
offices	2 - 6
warehousing	1 - 2

Source: Hall and Greeno (2009)

Notes:

[a] 18 air changes per hour is generally acceptable, plus an allowance of 0.5 l/s (1.8 m3/h) per kW boiler rating for combustion air. Double the combustion allowance for gas boilers with a diverter flue

See also: BS 5925: code of practice for ventilation principles and designing for natural ventilation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this research, computational fluid dynamic (CFD) will be used as the method to indicate the performance of the ventilation system. CFD will afford information of the air flow variables in the calculation domain, under welled control conditions and without similarity constraints (Hooff and Blocken, 2009). Moreover, CFD is the most accurate method for fluid dynamic. Unfortunately, it is the most difficult software compared to others (Qingyan et. al., 2009).

3.1.1 Studied configuration

The simulation case will be based on the FKKSA's of University Malaysia Pahang chemistry laboratory model.

a) Chemistry laboratory of FKKSA laboratory

Chemistry laboratory is a room with an area that is approximately in width of 9 meter (m), length of 16 m and height of 4 m. It is situated at the back of the single storey FKKSA's laboratory building and near to the exit 5. Basically, the laboratory is used by the student to carry out the experiment that related to chemical either in liquid or gas phase. Figure below shows the current arrangement of the chemistry laboratory.

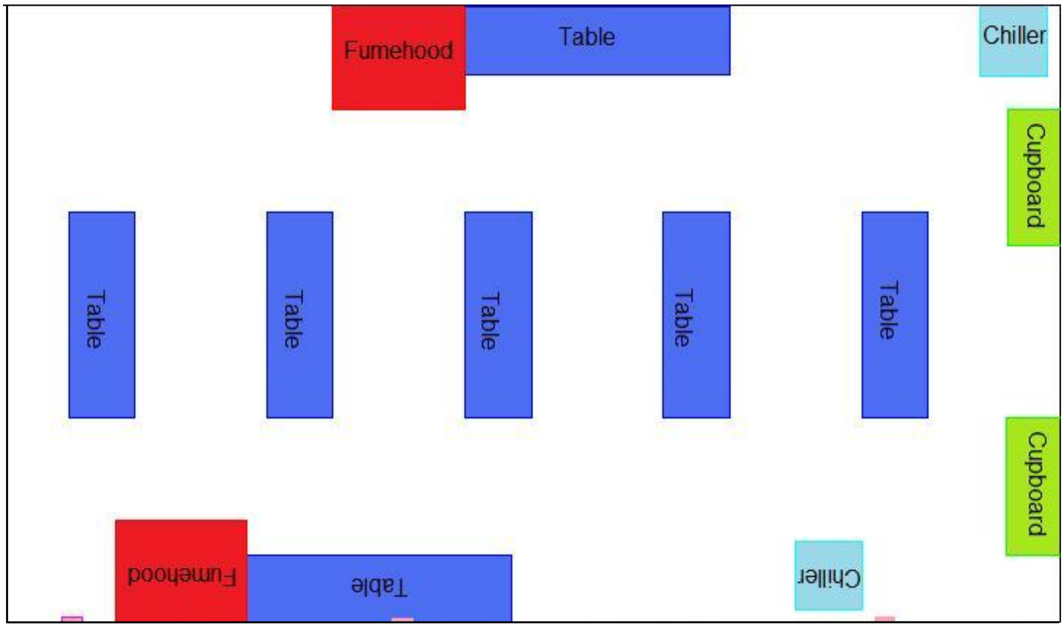

Figure 3: The current arrangement in chemistry lab by using AutoCAD 2009 software in 2D (top view only)

Source: FKKSA laboratory

The figure 3 shows the current arrangement of chemistry lab by using AutoCAD 2009 software for top view only. Moreover, the drawing had been labeled by specific color that represents specific furniture or equipment. The tables in the chemistry lab had been represented by the blue object; fume hood is red in color, cupboard is green in colour, chiller is cyan in colour and ventilator represent by magenta colour. Hence, there are 7 tables, two fume hoods, 2 cupboards, 2 chillers and 3 ventilators in the chemistry lab.

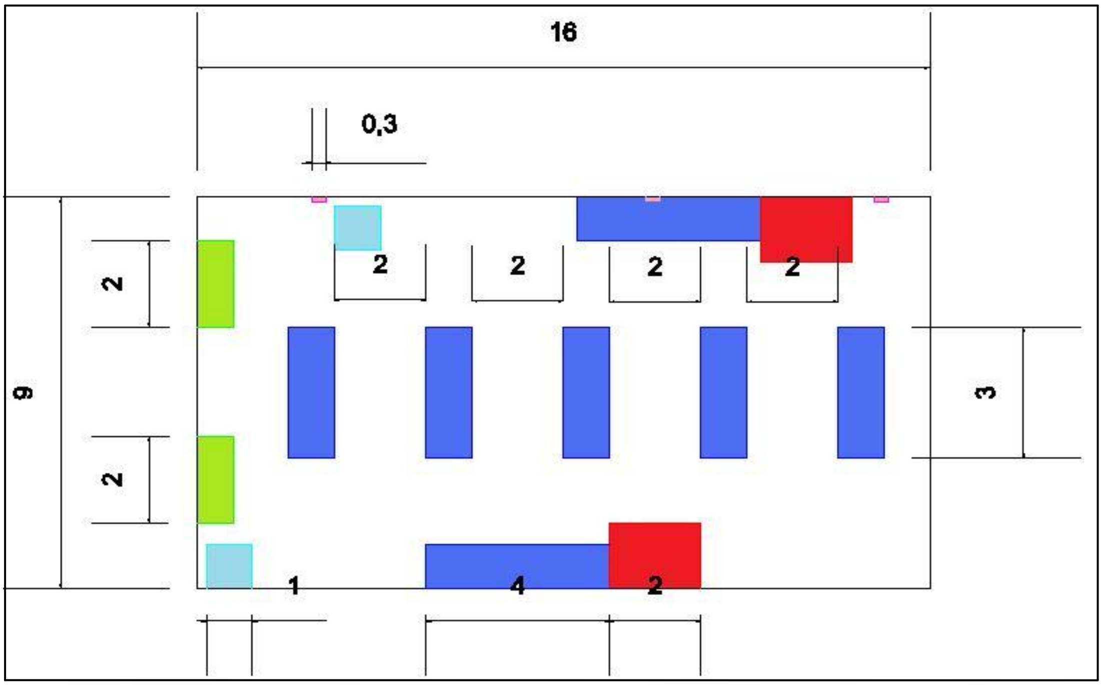

Figure 4: Dimension of the furniture and equipment inside chemistry lab.

The table, hood, table near the hood, cupboard, chiller and ventilator dimensions that given as shown in the figure 3.2 is 3x1 m, 1.5x2 m, 4x1 m, 2x0.8 m, 1x1 m and 0.3x0.1 m, respectively. The dimension that provided in the figure of 3.2 will be used to create the 3 dimensional (3D) drawing of chemistry lab in CFD.

Some assumptions had being made to simplify the drawing of chemistry lab in the 3D drawing where the chairs had been assumed to be placed under the table and the fume hood stack ventilation also being assumed as negligible and the energy settings also being set off. Furthermore, the air flow in the room is assumed to be 25°C. The dimension for doors of the chemistry lab is 1.5 m in width and 2 m in length.

3.2 Simulation tool

As being mention above in the introduction of the methodology chapter, the computational fluid dynamic (CFD) will be used as the simulation tool for this research.

CFD can be describe as the science in predicting fluid flow, heat transfer, chemical reactions, and some other phenomena by sorting out the mathematical equations represent physical laws, using the numerical process (introductory fluent notes, 2002)

The result that obtained from CFD analysis can be categorized as a relevant engineering data where it contributes to;

- the conceptual studies of the new design,
- detailed product development
- troubleshooting
- redesign

Furthermore, CFD helps user by saving their time from consuming comparing by using experimental method in solving such problem that can be solved by using CFD.

3.2.1 Preprocessing

In preprocessing part, the problem needs to be identified in order to model the building. In this research, the chemistry lab room will be the model. The chemistry lab room is modeled by referring to the chemistry lab configuration that had been mention earlier. The model needs to be inserting together with the furniture that is available. By using some assumptions to simplify the model, hence, the first stage is done.

3.2.2 Solver

The next stage of the simulation is solver. The numerical model which is Large Eddy Simulation (LES) equation is being set up by substituting the data that needed in order to obtain the result. The result that obtain is correlating to the air distribution inside the chemistry lab.

3.2.3 Post processing

The last stage of the simulation tool is the post processing. At this stage, the post processing will compute the result after evaluating it in the solver. Furthermore, the result will be examined by observing the node that available on the surface of the model. The node is represented by the colour such as red, blue and etc.

3.2.4 Procedure of CFD

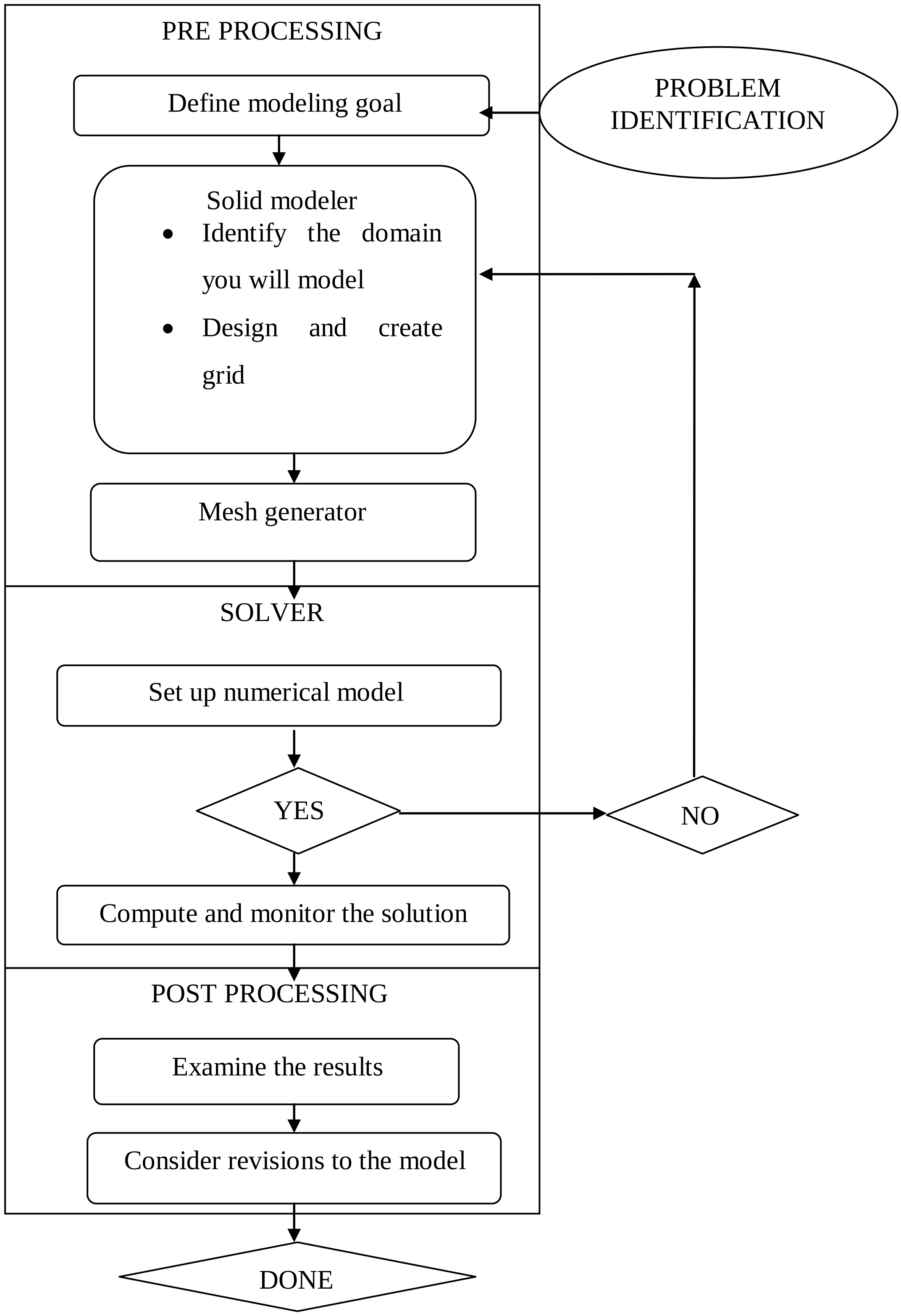

Figure 5: Procedure for CFD

CHAPTER 4

RESULT AND DISCUSSION

4.1 Outdoor and indoor air flows

An excellent design of a ventilated building is an adventurous job, due to the complexity of the phenomena that involved which specifically in physical phenomena. Setting up a correct boundary condition before starting using the simulation tool is a key in generated an excellent result of the simulation for the airflow.

However, the inadequacy for movement of air in the laboratory has become a fastidious problem for this research. From the result that attain, the movement can be considered as uniform.

Undoubtedly, the nature of movement can be determine either physically or theoretically. Theoretically, the movement of fluid is determined by using Reynolds number. Reynolds number is the significant dimensionless number in fluid mechanics where it is represented by;

$$Re = \frac{\rho UL}{\mu}$$

Which U is a characteristic velocity scale, L is a characteristic length scale, ρ is the density of the fluid and μ is the dynamic viscosity. The 'characteristic' velocity and length scales are different for different problems. The complex problem will ramification the characteristic scales to be more difficult.

The Reynolds number is actually represents the ratio of the importance of inertial effects in the flow. Inertia in physics definition is categorized as the property of an object to remain at a constant velocity unless an outside force acts on it. The large inertia will contradict strongly to a change in velocity. The velocity is basically difficult to be start and stop in this condition. Oppositely, small inertia will almost instantaneously start or stop when an external or internal act had been generated. Indisputably, inertia of fluid flows is caused by non linear interactions within the flow field. The non linearity dispenses the instabilities in flow and therefore, the flow is classified as turbulent, that is, for large Reynolds number which is above 2000. For a small Reynolds number, the flow will be laminar which is below 2000.

Mathematically, fluid flow is rehearsed by the Navier Stokes equation which describe by the evolution of the velocity vector field.

$$\frac{\delta \bar{u}}{\partial t} + (\bar{u} \cdot \nabla)\bar{u} = -\frac{1}{\rho}\nabla p + \frac{\mu}{\rho}\nabla^2 \bar{u}$$

In this equation, ū is the velocity vector and p is the pressure. On the left hand side, the first term is the unsteady (time dependent) inertial component. The second term is the non linear inertial term. For the right hand side, the first term is the driving pressure gradient, and the final term represents viscous dissipation.

The simulation solver of the research is innovated from the Reynolds number and Navier Stokes equations. The equation of the solver is called as the Large Eddies Simulation (LES). By filtering the Navier Stokes and continuity equations, the governing equations for the Large-Eddy motions as

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + v\frac{\partial^2 \bar{u}_i}{\partial x_j \partial x_j} - \frac{\partial \tau_{ij}}{\delta x_j}$$

Where

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0$$

U_i and U_j are the components of the velocity vector in the x_i and x_j direction, respectively. The variables ρ, p τ_{ij} and v represent air density, air pressure, sub-grid scale Reynolds stresses and kinetic viscosity, respectively. The bar represents grid filtering. For example, a one dimensional filtered velocity is obtained from;

$$\bar{u}_i = \int G\,(x, x')u_i\,(x)dx'$$

Where $G(x, x')$, the filter kernel, is a localized function. $G(x, x')$ is large only when (x, x') less than length is scale or filter width. The length scale is a length over which averaging is performed. Flow eddies larger than the length scale are ‘large eddies” and smaller than length scale are “small eddies”.

However, the better way in predicting the flow either turbulence or laminar is by illustrating the velocity physically. The flow of the Reynolds number is illustrated by the figure containing velocity flowing through object that had been tested. Hence, for the model of chemistry lab, the Reynolds number is determined theoretically to be above than 2000 which is approximately 5000. The 5000 is predicted to be turbulence. The turbulence flow can be seen through the figure 6 below.

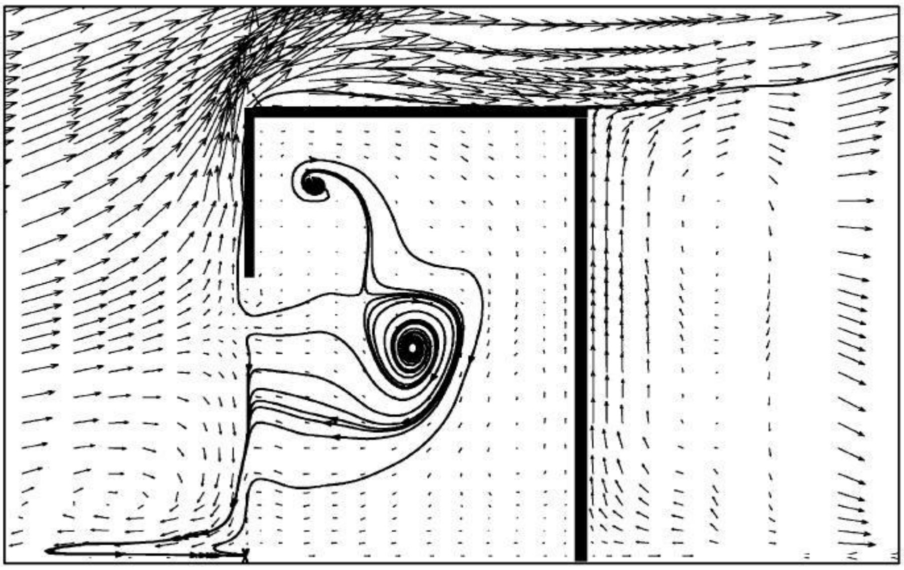

Figure 6: Velocity of the air in the middle of the modified natural ventilation system in chemistry lab room

The turbulence flow is occurred at the outside of the chemistry room. The turbulence flow is caused by the wind that flowing with a velocity of 5.5 m/s (minimum) and 11.11 m/s (maximum). Otherwise, the velocity of air can be seen enlighten in the middle of the chemistry lab. The circulation spot that placed in the middle of the chemistry lab room revealed that the air cannot penetrate the room thoroughly. It is unlike the velocity for the current model. The velocity is illustrated as in the figure 7 below:

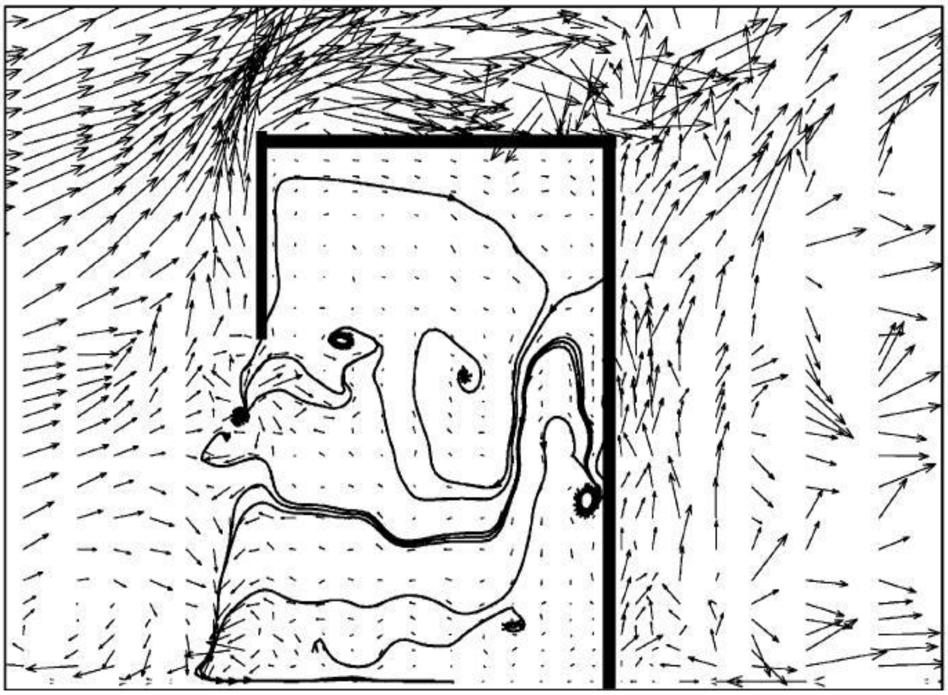

Figure 7: The velocity of the air in the middle of the current model of natural ventilation in chemistry lab room

The figure 7 shows that the air can certainly attain the opposite wall to the opening. The difference can be distinguished between the velocities by referring through the figure of 6 and 7.

Generally, this situation occurs because of the effect by the turbulence flow around the room. It had been proved in the previous study that flowing of wind around buildings is complex (Aynsley *et al.*, 1977; Liu, 1991). Otherwise, laminar flow can be seen moving inside the room Walls of the room also play a big role in term of giving effect on the flow movement. Wherefore, the differences in pressure measurement is actually causing the air to move from in and out of the building (Jiang and Chen, 2001).

4.2 Ventilation rate

After obtaining the pattern for the movement of air, the ventilation rate of the chemistry lab room is calculated for both current and modified ventilation system. The ventilation rate of modified chemistry lab is shown as below;

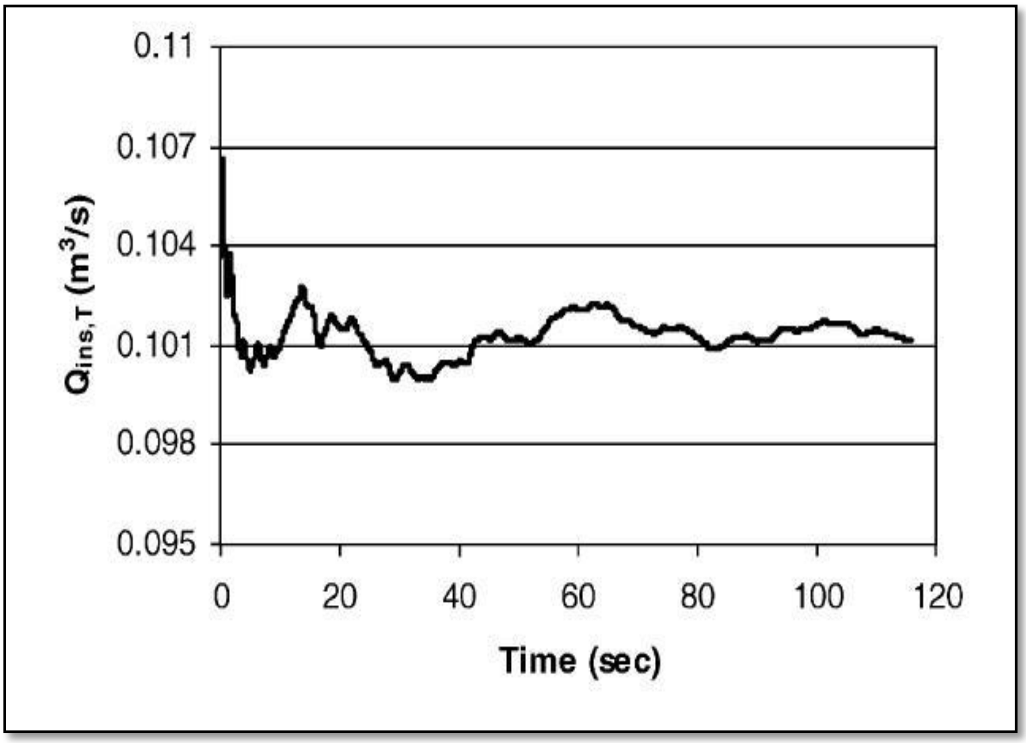

Figure 8: The ventilation rate of the modified natural ventilation system, $Q_{ins,\,T}$ (m^3/s) over time (T)

Figure 8 shows the ventilation rate for current natural ventilation where the ventilation rate is wide for small values of T and narrower as T inclined. When the T increased to 120 s, the ventilation rate is 0.101 m^3/s, which is among the acceptable accuracy for the ventilation rate.

The result of the ventilation rate for the current ventilation of the chemistry lab is shown as below;

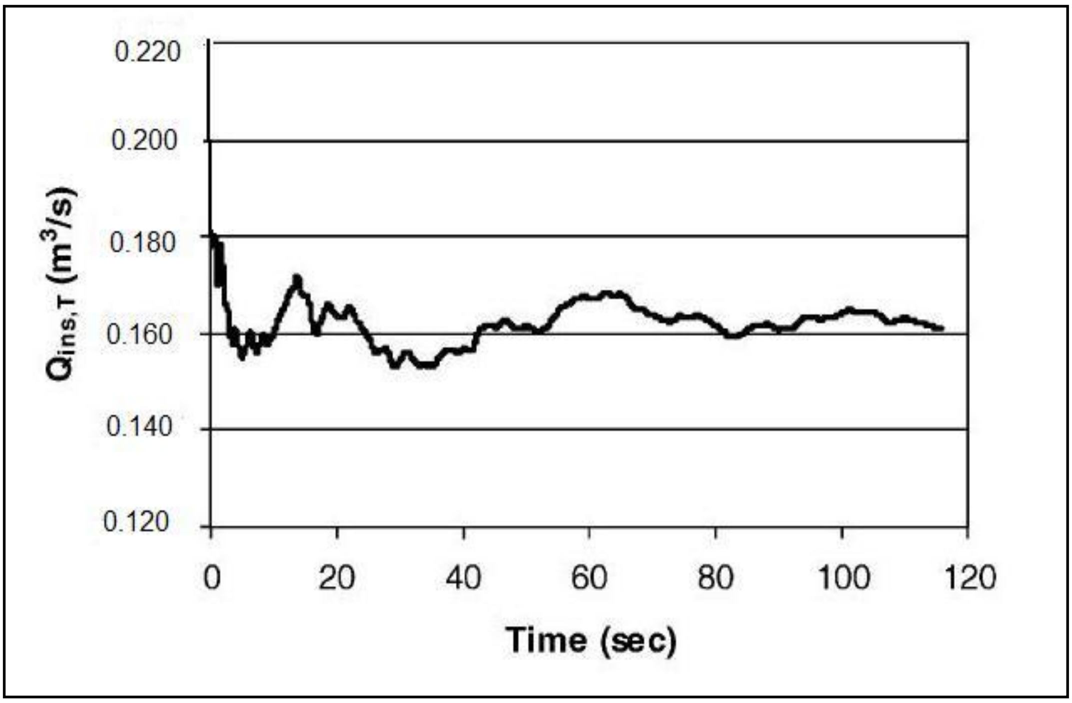

Figure 9: The ventilation rate for current ventilation chemistry lab

The figure 9 above showing that the ventilation rate for current ventilation of chemistry lab. The current ventilation had been set as the reference to be compared with the modified ventilation value. Hence, as the simplification, the value of the modified is acceptable because of the difference is not too large where the ventilation rate of current at T equal 120 is arround 0.16 m^3/s.

4.3 Air change rate

Natural ventilation is one of the effective ways in discovering the performance of the building. In this research, the natural ventilation unveils the effectiveness of the performance for the chemistry laboratory. Basically, the air change effectiveness exhibit the adroitness of the natural ventilation system which related to deliver the fresh air from outside to the inside or vice versa into the building (ASHRAE fundamental handbook, 1997).

Ordinarily, the change is actually transpired when the quantity of air is comparable to the volume of the room. It can be calculated by following equation for openings such as window and door;

$$ACH = \frac{0.65 \times Wind\ speed\ (m/s) \times smallestopening\ area(m^2) \times 3600\,s/h}{room\ volume(m^3)}$$

Where the wind speed that had been used is around 5.5 m/s with the smallest opening area of door only for the current natural ventilation system of chemistry lab and windows and door opening for the modified natural ventilation system. Table 4.1 shows the value of the ACH for the modified and current ventilation.

Table 3: Comparison of the ACH value for current and modified ventilation system of the chemistry lab

	Standard	Modified model (Qins, 120s)	Current model (Qins,120s)
ACH	6 -12	9	12.5

From the table 3 above, it can be simplified that the ACH value of the current ventilation is over the limitation that had been standardize in order to predict the performance of ventilation system. Normally, the air change rate must be at least 30% less than the standard ACH to analyze whether the performance is better or not. Hence, only the modified ventilation is matched with the standard value condition.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Comparison between the current natural ventilation with the modified ventilation system shows that appropriate design, installation, maintenance and adequate operation ventilation system can maintain a better indoor air quality (IAQ), especially utilization for breathing. The comparison between the modified and the current ventilation with the available standard had shown that the modified ventilation for the chemistry lab had a better performance compared to the current ventilation.

The performance of the ventilation between the modified and current ventilation is measured by the value of ACH where the modified ventilation had accurately fulfill the minimum requirement of the acceptable ACH in a laboratory. Hence, in order to increase the performance of the ventilation system for the chemistry lab, several changes is needed to be done. Finally, it is more comfortable for the future and current students and staff with the changes that will be made someday.

5.2 Recommendation

a) In order to enhance the quality of the performance for the ventilation, it is expected that a further research of measured the ACH value by experimental to justify the value of the ACH that had theoretically calculated.

b) All of the data used to be substitute into the simulation tool must be more precise in order to generate a better result.

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APPENDIX

APPENDIX A

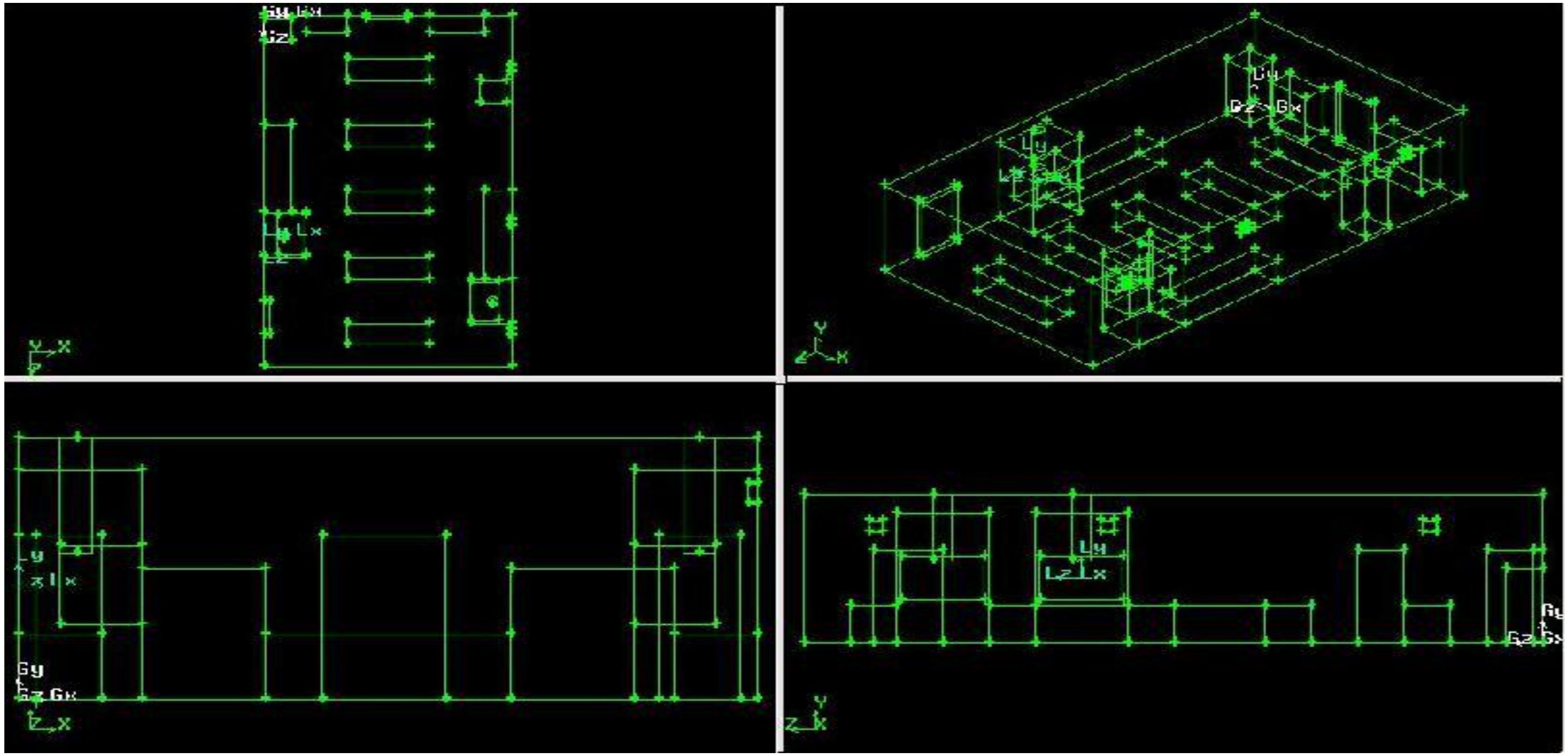

Figure 10: Model for chemistry laboratory by using GAMBIT