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A STUDY ON IMPROVING AIR CIRCULATION IN A CONFINED SPACE

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Department of Thermal-Fluids
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ABSTRACT

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(Keywords: Air Circulation, Double-Layer Wall, Natural Ventilation)

The effectiveness of the natural air ventilation in providing fresh air and cooler environment still need further investigation. This natural system has great potential to minimize the utilization of the air conditioning system and its negative effect to our environment. This study proposed a new method which is the usage of double-layer wall and a prism deflector to improve an air circulation in a confined space. Both experimental and simulation approaches were conducted in this study. In the experimental study, an air circulation apparatus was used to study the effectiveness of a double-layer wall and a prism deflector configuration in improving air circulation in a confined space. By fixing the wall distance with various holes angle of inner wall and the prism deflector ratio, data of air velocity, temperature and humidity obtained in this study were used as indication of air circulation improvement in a confined space. The experimental results show CASE 1 to 3 that used 0° hole angle configuration produced about five times higher air velocity than 45° hole angle configuration. However by considering all cases, CASE 6 with 45° hole angle and prism deflector ratio of 2.0 had the highest overall cooling rate. In the other hand, the simulation test modelled the experimental apparatus and the result obtained from the simulation was analyze by using ANSYS FLUENT 14.0. The parameters that were investigated are wall distance, hole angle and prism deflector ratio. The best parameter configuration obtained in this simulation was CASE 9 with 10 mm distance between walls, 45° hole angle and prism deflector ratio of 2.0. From this study, both experimental and simulation approach obtained a similar conclusion on the best configuration. Thus, it was found that the double-layer wall configuration can be used to promote and improve the air circulation in a confined space. However, there is no significant effect for the prism deflector.

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LIST OF ABBREVIATIONS

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers
BSRIA Building Research and Information Association
CFD Computational Fluid Dynamics
EIA U.S. Energy Information Administration
FKM Faculty of Mechanical Engineering
HVAC Heating, Ventilation and Air Conditioning
LES Large eddy simulation
NPL Neutral Pressure Level
PIV Particle Image Velocimetry
RECS Residential Energy Consumption Survey
RANS Reynolds averages Navier-Stokes equation
UTeM Universiti Teknikal Malaysia Melaka
2D Two Dimensional
**NOMENCLATURE**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_o$</td>
<td>Area of the smaller opening</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$A$</td>
<td>Angle of the opening holes at inner wall</td>
<td>$[^\circ]$</td>
</tr>
<tr>
<td>$A$</td>
<td>Equivalent opening area</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$A_N$</td>
<td>Opening cross-sectional area</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$A_1$</td>
<td>Inlet opening area</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$A_2$</td>
<td>Outlet opening area</td>
<td>$[m^2]$</td>
</tr>
<tr>
<td>$a$</td>
<td>Height of prism deflector</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$a/b$</td>
<td>Prism deflector ratio</td>
<td>[-]</td>
</tr>
<tr>
<td>$b$</td>
<td>Width of prism deflector</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$C_D$</td>
<td>Opening’s discharge coefficient</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{D,total}$</td>
<td>Total discharge coefficient</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{D1}$</td>
<td>Inlet discharge coefficient</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{D2}$</td>
<td>Outlet discharge coefficient</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{p,leeward}$</td>
<td>Pressure coefficient on leeward site</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{p,windward}$</td>
<td>Pressure coefficient on windward site</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{p,w}$</td>
<td>Pressure coefficient on windward site</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_{p,l}$</td>
<td>Pressure coefficient on leeward site</td>
<td>[-]</td>
</tr>
<tr>
<td>$C_2$</td>
<td>Unit conversion factor</td>
<td>[-]</td>
</tr>
<tr>
<td>$D_H$</td>
<td>Hydraulic ray</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$d_o$</td>
<td>Jet’s diameter on wall</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$g$</td>
<td>Gravity acceleration</td>
<td>$[ms^{-2}]$</td>
</tr>
<tr>
<td>$H$</td>
<td>Height at required location</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$H_c$</td>
<td>Height of confined space</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$H_{NPL}$</td>
<td>Height at neutral pressure</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$K$</td>
<td>Coefficient of effectiveness</td>
<td>[-]</td>
</tr>
<tr>
<td>$L$</td>
<td>Distance between walls</td>
<td>$[mm]$</td>
</tr>
<tr>
<td>$L_c$</td>
<td>Length of confined space</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$P_s$</td>
<td>Stack effect pressure different</td>
<td>$[m]$</td>
</tr>
<tr>
<td>$P_V$</td>
<td>Velocity pressure</td>
<td>$[kPa]$</td>
</tr>
</tbody>
</table>
\( Q \) Air volumetric flow rate, \([m^3/h]\)

\( \dot{Q} \) Mean air flow rate \([m^3/s]\)

\( Q_s \) Stack effect air flow rate \([m^3/s]\)

\( Q_w \) Mean volumetric air flow rate \([m^3/s]\)

\( R \) Prism deflector ratio [-]

\( R_{H_0} \) Relative humidity of air at the moment of spotlight turns on [-]

\( R_{H_e} \) Relative humidity of air [-]

\( T_c \) Confined space temperature \([^\circ C]\)

\( T_{c,1} \) Final confined space temperature \([^\circ C]\)

\( T_{c,0} \) Initial confined space temperature \([^\circ C]\)

\( T_i \) Average inside temperature \([^\circ C]\)

\( T_{in} \) Average indoor air temperature at height H \([^\circ C]\)

\( T_o \) Confined space temperature at the moment of spotlight turns on \([^\circ C]\)

\( T_o \) Average outside temperature \([^\circ C]\)

\( T_{out} \) Average outdoor air temperature \([^\circ C]\)

\( T_R \) Roof temperature \([^\circ C]\)

\( \Delta T_c \) Confined space temperature difference \([^\circ C]\)

\( \Delta T_{c,overall} \) Overall temperature difference \([^\circ C]\)

\( t \) Time in minute \([\text{min}]\)

\( \Delta t \) Time in 60 minute \([\text{min}]\)

\( U_H \) Maximum wind velocity \([\text{ms}^{-2}]\)

\( U_{ref} \) Reference wing velocity \([\text{ms}^{-2}]\)

\( V \) Speed of the outside air \([\text{m/h}]\)

\( V_c \) Confined space air velocity \([\text{ms}^{-1}]\)

\( V_{in} \) Inlet air velocity \([\text{ms}^{-1}]\)

\( V_{in,avg} \) Average inlet air velocity \([\text{ms}^{-1}]\)

\( W_c \) Width of confined space \([\text{m}]\)

\( x \) Cartesian coordinate \([\text{m}]\)

\( x \) Velocity core distance from wall \([\text{m}]\)

\( x_o \) Jet’s virtual origin distance \([\text{m}]\)
# GREEK LETTERS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Inclination angle</td>
<td>$[^\circ]$</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Air density</td>
<td>$[\text{kgm}^{-3}]$</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Inner wall hole angle</td>
<td>$[^\circ]$</td>
</tr>
<tr>
<td>$\theta_i$</td>
<td>Inner louver angle</td>
<td>$[^\circ]$</td>
</tr>
<tr>
<td>$\theta_o$</td>
<td>Outer louver angle</td>
<td>$[^\circ]$</td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

1.1 BACKGROUND

The manipulation of natural air ventilation in a house is important to reduce cooling load, reduce energy consumption and increase the human comfort of the inner house environment. To find out how effective this natural air ventilation system, an investigation on air circulation in a confined space is significant. By improving the air circulation, the system is able to reduce a cooling load and energy consumption in our daily life.

Nowadays, the concern on manipulating the natural air ventilation becomes more significant due to energy and environment factors. Thus, many researchers have done a lot of investigation on these matters. Initially, the understanding on how previous generation effectively used this system needs to be studied. Fordham, (2000), studied about how previous generation used the system by implementing specific building design and describe few factor that need to be considered for natural air ventilation system such as warm summer temperatures, provision of clean air, air movement, heat reclaim, and thermal capacity. Hirano et al., (2006), proposed a porous building method that used upto 50% void ratio of the building. The method achieves much more efficient natural ventilation because of the air flow rate inside the voids. Most of the researchers conducted a simulation to study the natural air ventilation system. Ayata et al., (2006) used computational fluid dynamic (CFD) method to investigate the potential use of natural ventilation in new building designs and found that the orientation of building and a proper indoor design can significantly increase the capability of air ventilation during hot days.

In Malaysia, the country environment is hot and humid. Most of the people prefer to use air conditioning system to increase their comfort. There are still lacks of awareness on the negative effect of the system to our people. One of the possible methods is by manipulation the natural air ventilation system. Our previous generation house design is
fully appreciate the utilization of the natural air ventilation system. It is significant if we can reuse again this concept to minimizing the utilization of air conditioning system.

Nowadays, air conditioning system is used intensively for ventilating and cooling buildings space. As energy demand is keeps on increasing significantly while oil price is surging high, a better solution on decreasing total energy usage is extremely needed. Thus, passive cooling strategy comes into play. Passive cooling strategy which can be easily adopted by harvesting natural surrounding air for ventilation purposes were extensively studied by researchers. These studies had proven that natural cooling can be an alternative way on cutting down energy consumption rate.

A building which is occupied by people tends to consume a lot of electricity. This is because human tends to spend most of his time for indoor activities. Scientific studies on energy used in service and residential buildings showed that 6.9% of total energy consumption for space cooling was contributed by Heating, Ventilation and Air Conditioning (HVAC) systems (Orme, 2001). Paper published by Orme (2001) only holds true in Europe and North America as the investigation was based on energy consumption of 13 countries from these two continents. On the other hand, total energy consumption for space cooling in countries with all year round hot climate was expected greater than countries which endure 4 seasons.

In the perspectives of environmental stand point, the utilization of natural cooling can protect the living environment of human being. This is because natural cooling strategy utilization in buildings able to counter the effect of global warming. Severe decrease of fossil fuel consumption will results in less release of Carbon content gases into the air atmosphere, which severely contributes to greenhouse effect.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamental 2001 reveals that ventilation in building is important. The level of ventilation in a given building space determines the level of sickness for that particular confined space. Thermal stress and air humidity build up in poor ventilated space will severely affects the air quality. Temperature and moisture hike in a confined space will results in deteriorative machineries performance and short machineries lifespan.

Although there are many kinds of passive technologies adopted into building design nowadays, there are still ample of improvement and research on natural cooling has
to be done. This is mainly due to many implemented natural ventilation strategies which used to enhance air circulation suffered from different short outcomes. However, focus on improving ventilation in confined space should remain firmed as findings from this specific field will able to provide a fuel saving solution, which will be beneficial to many parties.

There are two main types of building cooling strategy which are active cooling and passive cooling. Active cooling would be HVAC system and depends to electricity. Mechanical ventilation like fan and duct are under this category. On the other hand, passive cooling does not require any energy. There are many design of passive cooling such as wind tower, wind catcher or ventilation.

The purpose of ventilation is not just create the air flow in a building, it also remove heat generated from people and other equipment in the occupied space. Other than that, ventilation is needed to remove hazardous chemicals from the confined space. The most likely purpose of ventilation is for maintaining human comfort and health.

Natural ventilation uses the design of the wall openings to utilize air flow in the building. There are low pressure and high pressure openings. The difference between these openings will create air flow that flows from high pressure to low pressure. The air flow also helps to cools the interior building. The wall that has high pressure openings is called windward side while the wall of low pressure side is called leeward side. There are two major type of ventilation, which is wind induced ventilation and stack ventilation. Sometimes, it is normal to have the combination of both.

In this study we proposed new method which is the usage of double-layer wall and a prism deflector in order to improve air circulation in a confined space. Both experimental and simulation approach were conducted in this study to investigate how effective these methods in promoting the natural air circulation in a confined space.
1.2 PROBLEM STATEMENTS

A confined space which is ineffective in exchanging inside air with outside air will prone to dissipate heat less effectively. As the result, poor air ventilation will induce biological strain to occupant. In this case, energy consumption unit such as air-conditioning and fan is needed to cool down the temperature and circulates the air in confined space.

In this twenty first century, the global warming issue is becoming serious. The earth has its temperature increased. The effect of global warming is catastrophic. It makes the iceberg melts, ocean level rises and major weather changes. Crop start to reduce due to weather changes and human would end in starving if no action is being taken to prevail global warming. The cause of the global warming comes from greenhouse gases. Greenhouse gases consist of carbon dioxide, methane, nitrous oxide and refrigerant gases. Carbon dioxide has the highest global warming potential compare to others, referring from Figure 1-1. From the annual energy review 2010 as shown in Figure 1-2, carbon emission from electricity generation is the highest in present and also in predicted future. The electricity demand is increasing and so as the carbon dioxide emission.

![Figure 1-1](image)

*Figure 1-1 Emissions of greenhouse gases 1990-2009 (Annual Energy Review 2010)*
The major source of carbon dioxide production was from petroleum, coal and natural gas energy production as shown in Figure 1-3. Although the trend is start is to decrease slightly, more efforts need to be put on to prevent global warming like decreasing the demand of the electricity load. When population increases, the buildings are also increased to meet the demand. Buildings in present are often relied to HVAC system to cool or heat itself which consume a lot of energy.

Figure 1-2 U.S carbon dioxide emission by sector and fuel, 2005 and 2035 (million metric tons) (Annual Energy Review, 2010)

Figure 1-3 Carbon dioxide emissions from energy consumption (Annual Energy Review 2010)

The refrigerant gases are often leak from HVAC system in building cooling system. The refrigerant gases are often flow through a closed pipeline but a small amount
of leakage in unavoidable. As in the population of seven million in earth, more and more buildings are going to build and more HVAC system is installed. According to Residential Energy Consumption Survey (RECS, 2009) from Energy Information Administration (EIA), the survey was taken from 12,083 household from four different regions. From Figure 1-4, it was expected the air conditioning in residential to be increase. The data is reliable because it was compared with data from energy supplier.

![Figure 1-4](image)

Figure 1-4 Steady rise of air conditioned homes in all regions of the U.S. (RECS, 2009)

Carbon dioxide and refrigerant gases would become greater and global warming effect would be increase if no action has been taken. Out of many solutions, this study tackles building cooling strategy without depending to the HVAC system.

In this study, natural cooling using double layer wall is simulated. It does not require any extra energy to operate the cooling system. If this natural cooling system can be applied to all buildings, it can saves energy. When it saves energy, it also reduces carbon emission which reduces the global warming effect. As energy demand and green gas released are getting higher nowadays, implement of natural cooling strategy on confined space is necessary. The effectiveness of the double-layer wall system with prism deflector was investigated in this study. The investigation was based on both an actual model experimental apparatus and a simulation approach to assure that air circulation in confined space can be improved.
1.3 OBJECTIVES

1.3.1 To investigate the utilization of double-layer wall sand the prism deflector configuration in improving air circulation in a confined space by using an experimental apparatus.

1.3.2 To investigate the utilization of double layer walls and prism deflector with different configuration to enhance the air circulation in a confined space by using ANSYS FLUENT 14.0 simulation software.

1.4 SCOPES

1.4.1 Experimental Approach

a) To develop an experimental apparatus to investigate air circulation improvement in a confined space by using double-layer wall and prism deflector system.

b) To improve air circulation by using double-layer wall with certain hole angle ($\theta = 0^\circ$ and $45^\circ$) and prism deflector with certain ratio ($R = 0.5$, $1.0$ and $2.0$).

c) To measure air velocity, air temperature and air humidity continuously at the center of a confined space to show the air flow and air condition changes due to air circulation enhancement.

d) To analyze the result obtained to show the effectiveness of double-layer wall and prism deflector in promoting the air circulation.