FEASIBILITY STUDY OF AIR CATCHER FOR NATURAL VENTILATION APPLICATION

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A thesis submitted in fulfillment of the requirements for the award of the degree of

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Faculty of Mechanical and Manufacturing Engineering

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ABSTRACT

Ventilation is the process of supplying fresh air and removing stale air. Natural ventilation is an effective method to save energy required to condition building and to improve indoor air quality. It is widely recognized as contributing in low energy building design. In present work, five types of low Reynolds number airfoils were used to design air catchers with three angles of attack and four different diameters. SolidWorks was used to build the geometries and Computational Fluid Dynamics (CFD) was used to simulate the buoyancy driven natural ventilation. Mesh dependency test has been done for three sizes of mesh and result was validated by comparing the numerical result with experimental result for NACA2415 airfoil. Sixty cases were studied by considering five types of airfoils air catchers, three angles of attack (0°, 10° and 20°) with four diameters (0.75C_{ax}, 1C_{ax}, 2.5C_{ax} and 3C_{ax}) for each type by using CFX ANSYS with k-ε turbulence model. All the configurations show improvement on the effective mass flow rate. Nominal and effective mass flow rates and improvement factor were calculated for each case. It is observed that the improving factor increased with angle of attack and decreased with diameter. The results showed that the best improvement factor was found at S1223 air catcher with 112.5 mm diameter and 20° angle of attack. Therefore, the air catcher is feasible for the natural ventilation application.
ABSTRAK

mesh telah dijalankan bagi aerofoil NACA2415 dan keputusan ujian berangka tersebut dibuktikan dengan membuat perbandingan bersama keputusan eksperimen. Enam puluh jenis konfigurasi yang terdiri daripada lima jenis aerofoil, tiga perbezaan sudut kecondongan; 0°, 10°, 20° dan empat jenis diameter; 0.75C_{ax}, 1.0C_{ax}, 2.5C_{ax}, 3C_{ax} telah diuji menggunakan ANSYS CFX dengan mengaplikasikan model turbulen k-ε. Nominal, kadar aliran jisim dan faktor peningkatan telah dikira bagi setiap konfigurasi. Semua jenis konfigurasi menunjukkan peningkatan bagi setiap kadar aliran jisim. Faktor peningkatan menunjukkan penambahbaikan apabila sudut kecendorongan meningkat manakala faktor peningkatan menurun apabila diameter meningkat. Keputusan menunjukkan bahawa perangkap angin S1223 dengan diameter 112.5mm dan sudut kecendorongan 20° mempunyai faktor peningkatan terbaik. Oleh itu, ciri-ciri tersebut sesuai untuk diaplikasikan dalam perangkap angin sebagai pengudaraan semula jadi. Pengalihan udara atau pengudaraan adalah satu proses membekalkan udara yang tidak tercemar dan segar bagi menggantikan udara yang tidak segar. Pengudaraan semula jadi merupakan satu proses yang menjimatkan tenaga di samping dapat membaik pulih kualiti udara di dalam bangunan. Selain itu, pengudaraan semula jadi hanya sesuai diaplikasikan pada bangunan yang menghasilkan tenaga yang rendah. Dalam kajian ini, lima jenis aerofoil daripada nombor Reynolds yang rendah telah digunakan bagi membentuk perangkap angin. Perbezaan beberapa pemboleh ubah seperti diameter dan sudut kecondongan aerofoil juga telah ditetapkan. SolidWorks telah digunakan bagi mencipta perangkap angin manakala Computational Fluid Dynamics digunakan untuk mengendalikan simulasi pengudaraan. Sebelum simulasi diteruskan, ujian pergantungan
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF SYMBOLS AND ABBREVIATION</td>
<td>xv</td>
</tr>
</tbody>
</table>

## CHAPTER 1  INTRODUCTION 1

1.1 Background 1

1.2 Problem Statement 2

1.3 Significant of Study 2

1.4 Objectives of Study 3

1.5 Scope of Study 4

## CHAPTER 2  LITERATURE REVIEW 6

2.1 Introduction 6
2.2 Indoor Air Quality 7

2.3 Indoor Thermal Environment 7

2.3.1 Air Temperature 9

2.3.2 Relative Humidity 9

2.3.3 Air Speed 9

2.3.4 Mean Radiant Temperature 9

2.3.5 The Operative Temperature 10

2.3.6 Metabolic Rate 11

2.3.7 Clothing Insulation 12

2.4 Fresh Air Requirement 12

2.5 Natural Ventilation 14

2.5.1 Wind Driven Natural Ventilation 14

2.5.2 Buoyancy Driven Natural Ventilation 17

2.5.2.1 Calculation of Buoyancy Driven Natural Ventilation 19

2.5.3 Combination of Buoyancy and Wind 20

2.5.4 Examples of Naturally Ventilated Buildings 21

2.6 Wind Lens 22

2.6.1 Air Catcher 23

2.6.2 Airfoil 25

2.7 Related Studies 26

2.7.1 Related Studies about Buoyancy Driven Natural Ventilation 27
2.7.2 Related Studies about Airfoils 30

CHAPTER 3 RESEARCH METHODOLOGY 32

3.1 Introduction 32
3.2 SolidWorks 33
3.3 Computational Fluid Dynamics 33
3.4 CFD Modeling Process 34
3.5 Physical Model 36
3.6 Computational Domain 38
3.7 Flow Chart 43

CHAPTER 4 RESULTS AND DISCUSSION 45

4.1 Introduction 45
4.2 Mesh Dependency Test and Result Validation 46
4.3 Airfoil Baselines 47
4.4 Results and Discussion 50

4.4.1 Effect of Angle of Attack 50

4.4.1.1 Effect of Angle of Attack on Velocity 50
4.4.1.2 Effect of Angle of Attack on Pressure 51
4.4.1.3 Effect of Angle of Attack on Improvement Factor 52

4.4.2 Effect of Diameter 54

4.4.2.1 Effect of Diameter on Velocity 54
4.4.2.2 Effect of Diameter on Pressure 55
### 4.4.2.3 Effect of Diameter on Improvement Factor

55

### 4.4.3 Comparison of Air Catchers

59

## CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

63

### 5.1 Conclusion

63

### 5.2 Recommendations

64

### REFERENCES

65

### APPENDICES

69

### APPENDIX A Figures

70

### APPENDIX B Tables

78
## LIST OF FIGURES

1.1 Five airfoils at angle of attack $\alpha=0^\circ$  
1.2 Examples of the airfoil at different angles of attack  
2.1 Negative and positive pressure due to wind  
2.2 Pressure differences created by wind on the building  
2.3 Single – sided ventilation  
2.4 Cross ventilation  
2.5 Buoyancy (stack) ventilation  
2.6 Wind catchers in Yazd City  
2.7 BRE Office Building Facades with Stacks  
2.8 Building interior  
2.9 The wind lens concept  
2.10 Wind lens turbines  
2.11 Air catcher  
2.12 Bernoulli effect  
2.13 Typical airfoil  
2.14 Pressure distributions over an airfoil  
2.15 Typical airfoil geometry  
3.1 Air catcher inlet
3.2 Diameter of the air catcher

3.3 Cross section of the air catcher

3.4 Computational domain for NACA2415 airfoil

3.5 Inlet and outlet of NACA2415

3.6 Zoomed mesh

3.7 Geometry of NACA2415 air catcher at α= 0°, D= 0.75 C_{ax}

3.8 Medium size mesh of the air catcher

3.9 Inlet and outlet for air catcher

3.10 Velocity contour for NACA2415 air catcher at α=0°, D=0.75 C_{ax}

3.11 Pressure contour for NACA2415 air catcher at α=0°, D=0.75 C_{ax}

3.12 Flow Chart

4.1 Mesh dependency test

4.2 C_p distribution along chord length

4.3 A comparison of C_p at the upper surfaces

4.4 A comparison of C_p at the lower surfaces

4.5 Effect of angle of attack on velocity for NACA2415 at D=0.75 C_{ax}

4.6 Effect of angle of attack on pressure for NACA2415 at D=0.75 C_{ax}

4.7 Effect of angle of attack on improvement factor

4.8 Effect of diameter on velocity for NACA2415 at α= 0°

4.9 Effect of diameter on pressure for NACA2415 at α = 0°

4.10 Effect of diameter on improvement factor for NACA2415 at α = 0°
4.11 Effect of angle of attack and diameter on velocity for NACA2415 case 57
4.12 Effect of angle of attack and diameter on pressure for NACA2415 cases 58
4.13 Velocity comparison for all air catchers at D=0.75 cax and α = 20° 60
4.14 Pressure comparison for all air catchers at D=0.75cax and α= 0° 60
4.15 A comparison of improvement factors for all air catchers 61
4.16 A comparison of velocity for all air catchers at D=0.75 cax 62

A.1 Pressure contour of Bergey BW3 air catcher 70
A.2 Velocity contour of Bergey BW3 air catcher 71
A.3 Pressure contour of MA409 air catcher 72
A.4 Velocity contour of MA409 air catcher 73
A.5 Pressure contour for S1223 air catcher 74
A.6 Velocity contour for S1223 air catcher 75
A.7 Pressure contour for S7055 air catcher 76
A.8 Velocity contour for S1223 air catcher 77
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Metabolic Rates according to ISO 7730</td>
<td>11</td>
</tr>
<tr>
<td>2.2</td>
<td>Fresh air ventilation requirement</td>
<td>13</td>
</tr>
<tr>
<td>2.3</td>
<td>Guideline on Minimum Ventilation Rates</td>
<td>13</td>
</tr>
<tr>
<td>4.1</td>
<td>Effect of angle of attack and diameter for NACA2415 cases</td>
<td>59</td>
</tr>
<tr>
<td>B.1</td>
<td>Mass flow rate and improvement factor of Bergey BW3 air catcher</td>
<td>78</td>
</tr>
<tr>
<td>B.2</td>
<td>Mass flow rate and improvement factor of MA409 air catcher</td>
<td>79</td>
</tr>
<tr>
<td>B.3</td>
<td>Mass flow rate and improvement factor of S1223 air catcher</td>
<td>80</td>
</tr>
<tr>
<td>B.4</td>
<td>Mass flow rate and improvement factor of S7055 air catcher</td>
<td>81</td>
</tr>
</tbody>
</table>
# LIST OF SYMBOLS AND ABBREVIATION

<table>
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<tr>
<th>Symbol</th>
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<tr>
<td>A</td>
<td>Area</td>
</tr>
<tr>
<td>$C_{ax}$</td>
<td>Chord Axial Length</td>
</tr>
<tr>
<td>$C_D$</td>
<td>Discharge Coefficient</td>
</tr>
<tr>
<td>Clo</td>
<td>Clothing Insulation</td>
</tr>
<tr>
<td>$C_p$</td>
<td>Pressure Coefficient</td>
</tr>
<tr>
<td>D</td>
<td>Diameter</td>
</tr>
<tr>
<td>$g$</td>
<td>Gravitational Acceleration</td>
</tr>
<tr>
<td>Gr</td>
<td>Grashof Number</td>
</tr>
<tr>
<td>H</td>
<td>Height</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilation and Air Conditioning</td>
</tr>
<tr>
<td>L</td>
<td>Litter</td>
</tr>
<tr>
<td>MRT</td>
<td>Mean Radiant Temperature</td>
</tr>
<tr>
<td>$m'_{eff}$</td>
<td>Effective Mass Flow Rate</td>
</tr>
<tr>
<td>$m'_{nom}$</td>
<td>Nominal Mass Flow Rate</td>
</tr>
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<td>Nu</td>
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</tr>
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<td>Description</td>
</tr>
<tr>
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<td>-------------------------</td>
</tr>
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<td>Reynolds Number</td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
</tr>
<tr>
<td>Top</td>
<td>Operative Temperature</td>
</tr>
<tr>
<td>U</td>
<td>Wind Speed</td>
</tr>
<tr>
<td>V</td>
<td>Air Velocity</td>
</tr>
</tbody>
</table>

**Greek Symbols**

<table>
<thead>
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<th>Symbol</th>
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</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>Angle of Attack</td>
</tr>
<tr>
<td>( \rho )</td>
<td>Air Density</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Dynamic Viscosity</td>
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</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background

Ventilation is the process by which clean air (normally outdoor air) is intentionally provided to a space and a stale air is removed. Fresh air is necessary in buildings to provide oxygen for respiration, to alleviate odors, and to increase thermal comfort. There are two categories of ventilation; mechanical ventilation and natural ventilation. Typical examples of mechanical ventilation are fans and HVAC units. In a well insulated building, such systems can provide full control of heating, cooling and humidity. This method can be both energy – intensive and have high maintenance costs, as well as yielding poor air quality for occupants in poorly designed and/or maintained systems. On the other hand, examples of natural ventilation involved building openings like windows and doors.
According to the World Business Council for Sustainable Development (WBCSD), buildings account for up to 40% of the world’s energy use [1]. Breaking down the energy consumption of buildings reveals that Heating, Ventilation and Air Conditioning (HVAC) systems account for up to 60% of domestic buildings energy consumption [2]. This represents a significant opportunity for reducing the buildings energy consumption and carbon footprint.

Natural ventilation application may play a key role in buildings energy associated with achieving good indoor air quality (IAQ) to the interior spaces. In addition, naturally ventilated buildings also have lower capital and lower operational costs. In general, there are two types of natural ventilation; wind driven and buoyancy driven natural ventilation.

1.2 Problem Statement

In urban area where most of the occupied building are surrounded by dense buildings or in the climate where no wind blowing, there will be a poor airflow for wind driven natural ventilation. In this case, buoyancy driven ventilation is preferred. However, buoyancy driven natural ventilation is not effective because it relies on buoyancy forces which are naturally weak, what will result a poor air circulation so focus should be paid to enhance the performance of buoyancy driven natural ventilation. The present study focuses on the feasibility study of a novel design known as air catcher with the aim to enhance the flow driven by buoyancy in natural ventilation.
1.3 Significant of Study

About 40% of the total energy consumption is used for air conditioning and mechanical ventilation of buildings. Natural ventilation plays an important role in reducing the operational and maintenance costs of buildings because it does not require any amount of energy. The importance of this study comes from studying the feasibility of air catcher in enhancing the air circulation and to propose the optimum geometry helping in improving the buoyancy driven natural ventilation in case of poor outdoor wind blowing.

1.4 Objectives of Study

The present study will be aligned based on several objectives as:

(a) To study the flow phenomenon through different airfoil shapes at low Reynolds number;
(b) To determine the effect of air catcher geometrical parameters on the flow phenomena; and
(c) To propose optimum geometrical parameters set of the air catcher for natural ventilation application.
1.5 Scope of Study

(a) The study will make use of the commercial Computational Fluid Dynamics software, ANSYS CFX to provide information on feasibility of the air catcher;
(b) Five different low Reynolds number airfoil shapes will be considered; and
(c) Four different values of the diameter $D$ ($0.75C_{ax}, 1 C_{ax}, 2.5C_{ax}$ and $3C_{ax}$) and three angles of attack $\alpha$ ($0^\circ, 10^\circ, 20^\circ$) will be considered for each airfoil.

Figure 1.1: Five airfoils at angle of attack $\alpha=0^\circ$. 
Figure 1.2: Examples of the airfoil at different angles of attack.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, important parameters in ventilation system will be explained. Initially, discussion on the indoor air quality will be made, followed by details on natural ventilation; types of natural ventilation, the mechanism and driving forces of each type. In addition, details about the air catcher and airfoils will be discussed and related to studies of natural ventilation and airfoils.
2.2 Indoor Air Quality

American Society of Heating, Refrigeration and Air Conditioning Engineers in ASHRAE Standard 62 – 1999 Ventilation for Acceptable Indoor Air Quality, has defined the acceptable indoor air quality (IAQ) as “air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.” [3].

The overall quality of indoor air is influenced by thermal acceptability and air contaminants. The factors affecting thermal acceptability include temperature, relative humidity and air movement as these physical parameters could affect people’s perception of the IAQ. Air contaminants include an enormous range of substances and biological organisms generated by the building materials, human activities, office equipment and also activities outside the building from the outdoor environment. The common air contaminants include airborne particles, volatile organic compounds, tobacco smoke, asbestos, formaldehyde, radon, combustion gases, ozone, micro-organisms, respiratory products and body odors [4].

2.3 Indoor Thermal Environment

Thermal comfort is defined in ISO 7730 as “that condition of mind which expresses satisfaction with the thermal environment.” Dissatisfaction may be caused by warm or cool discomfort of the body as a whole. But thermal dissatisfaction may also be caused by an unwanted cooling or heating of one particular part of the body. Local discomfort may also be caused by an abnormal high vertical temperature difference between head and ankles, by too warm or cool a floor or by too high a radiant temperature asymmetry.
Thermal neutrality is the first comfort condition. It means that a person feels neither too warm nor too cold. When the skin temperature falls below 34 °C, the cold sensors of the human body begin to send impulses to the brain. If the temperature continues to fall, the impulses increase in number. The number of impulses is also a function of how quickly the skin temperature falls, the faster temperature drop the greater the number of impulses being sent. Similarly, the heat sensors in the skin send impulses to the brain when the temperature exceeds 37°C, and the number of impulses increased with temperature increases, the number of impulses increase. It is believed that it is the signals from these two sensor systems that form the basis for human body evaluation of the thermal environment.

Due to individual differences, it is impossible to specify a thermal environment that will satisfy everybody. There will always be a percentage of dissatisfied occupants. But it is possible to specify environment predicted to be acceptable by a certain percentage of the occupants.

Thermal comfort is affected by the thermal interaction between the body and surrounding environment. There are six primary factors that affect this thermal interaction:

(a) Air temperature.
(b) Relative Humidity.
(c) Air speed.
(d) Mean radiant temperature (MRT).
(e) The operative temperature.
(f) Metabolic rate.
(g) Clothing insulation.

The first four factors define the conditions of the surrounding environment while the latter two factors represent “personal” variables that can vary between people exposed to the same environmental conditions [5].
2.3.1 Air Temperature

It is one of the basic IAQ measurements that have a direct impact on perceived comfort. According to ASHRAE Standard 55, the recommended air temperature that is perceived as comfortable is ranges from 22.8 °C to 26.1°C in the summer and 20°C to 23.6 in the winter [6].

2.3.2 Relative Humidity

Too little humidity in a space may create static build-up and people will sense that their skin feel dry. Too much humidity will make people feel sticky. According to ASHRAE Standard 55, indoor humidity levels should be maintained between 30% and 65% for optimum comfort.

2.3.3 Air Speed

One of the first checks in a comfort study is making sure that sufficient air is moving in a space. Air movement can affect human comfort level in that too fast air is perceived as drafty or chilly and too slow may create a sensation of stuffiness.

2.3.4 Mean Radiant Temperature, T_{mrt}

The amount of radiant exchange between a person and the surrounding will be effective on comfort. Cold walls or windows may cause a person to feel cold on certain sensitive
parts of the body (such as back of neck, knee and ankle) even though the surrounding air may be at a comfortable level. Likewise warm surfaces such as stove or fire places may cause a person to feel warmer than the surrounding air temperature would indicate. This phenomenon is known as “local cooling or local heating.”

The basic index to describe the radiative condition in an environment is the mean radiant temperature, the mean temperature of individual exposed surfaces in the environment. The mean radiant temperature is commonly measured using a Vernon’s Globe Thermometer, which consists of a hollow sphere 6 inches in diameter, flat back paint coated, and a thermocouple or thermometer bulb at its surrounding. The equilibrium temperature was assumed by the globe (globe temperature) result from a balance in the convective and radiative heat exchange between the globe and its surroundings. The mean radiant temperature is estimated by combining the globe temperature, air temperature and velocity.

\[
T_{mrt}^4 = T_g^4 + CV^{1/2} (T_g - T_a)
\]  

(2.1)

where \(T_{mrt}\) : Mean radiant temperature K

\(T_g\) : Globe temperature

\(T_a\) : Ambient air temperature K

\(C\): 0.247 \times 10^9

\(V\): Air speed m/s

2.3.5 The Operative Temperature, \(T_{op}\)

The operative temperature is the average of the mean radiant temperature and ambient air temperature, weighted by their respective practical applications; it is the mean of the radiant and dry bulb temperature and is sometimes referred to as the adjusted dry bulb temperature. It is the uniform temperature of an imaginary enclosure with which and
individual exchanges the same heat by radiation and convection as in the actual environment. The effective and operative temperatures are used in defining comfort condition in ASHRAE Comfort Zone.

\[
T_{op} = \frac{T_a + T_{mrt}}{2}
\]  

(2.2)

2.3.6 Metabolic Rate

Human activity levels can be expressed in term Metabolic Rate and measured in (met) units. Table 2.1 presents probable metabolic rates for various typical activities by ISO 7730.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Metabolic Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W/m²</td>
</tr>
<tr>
<td>Reclining</td>
<td>46</td>
</tr>
<tr>
<td>Seated, relaxed</td>
<td>58</td>
</tr>
<tr>
<td>Sedentary activity (office dwelling, school, laboratory)</td>
<td>70</td>
</tr>
<tr>
<td>Standing, light activity (shopping, laboratory, light industry)</td>
<td>93</td>
</tr>
<tr>
<td>Standing, medium activity (shop assistant, domestic work, machine work)</td>
<td>116</td>
</tr>
<tr>
<td>Walking on the level:</td>
<td></td>
</tr>
<tr>
<td>1 km/h</td>
<td>110</td>
</tr>
<tr>
<td>2 km/h</td>
<td>140</td>
</tr>
<tr>
<td>3 km/h</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 2.1: Metabolic Rates according to ISO 7730.
ASHRAE standard 55-1992 assumed an average adult effective surface area for heat transfer of 19.6 ft\(^2\). And as 1 met = 18.4 BTU/(hr.ft\(^2\)), therefore will dissipate approximately 360 BTU/hr. (106 W) when functioning in a quite seated manner.

2.3.7 Clothing Insulation

The other personal variable that affects comfort is the type and amount of clothing that a person is wearing. Clothing insulation is usually described as a single equivalent uniform layer over the whole body. Its insulating value is expressed in term (clo) units: 1 clo = 0.155 m\(^2\).°C/W. A heavy two-piece business suit with accessories has an insulation value of about 1 clo, whereas a pair of shorts has about 0.05 clo.

2.4 Fresh Air Requirement

One of the most important factors in delivering comfort is freshness of the conditioned air. If the same air were circulated over and over again it would become staled and make the occupants very uncomfortable. ASHRAE Standard 62 – 1999 specified that the minimum fresh air supplied to each person in a building, should be at least 15 cfm (8 l/s) of fresh air. Table 2.2 shows the amount of fresh air to be supplied based on the type of space and level of activity.
Table 2.2: Fresh air ventilation requirement (ASHRAE 1999).

<table>
<thead>
<tr>
<th>Application</th>
<th>cfm per person</th>
<th>l/s per person</th>
</tr>
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<tbody>
<tr>
<td>Dining room</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Hotel room</td>
<td>30 per room</td>
<td>15 per room</td>
</tr>
<tr>
<td>Offices, conference room</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Public smoking lounge</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>Auditorium</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>School classroom</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Hospital room</td>
<td>25</td>
<td>13</td>
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Table 2.3: Guideline on Minimum Ventilation Rates [7].

<table>
<thead>
<tr>
<th>Air space per person (m³)</th>
<th>Fresh air supply per person (L/s)</th>
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<tr>
<td></td>
<td>Minimum</td>
<td>No smoking</td>
</tr>
<tr>
<td>3</td>
<td>11.3</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>7.1</td>
<td>10.7</td>
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<tr>
<td>9</td>
<td>5.2</td>
<td>7.8</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
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</tbody>
</table>
2.5 Natural Ventilation

Natural ventilation relies on pressure differences to move fresh air through buildings. Pressure differences can be caused by wind or the buoyancy effect created by temperature differences or a combination of these two [8]. The flow of air through a building depends on the following factors:

(a) The temperature difference between the air inside and outside the building.

(b) The difference in height between the air inlet and the exhaust vents.

(c) Convection currents rising from heat sources (e.g. people, computers, lighting).

(d) The rate at which heat is produced or released inside the building.

(e) The size, position and construction of the building.

(f) Wind speed and direction.

2.5.1 Wind Driven Natural Ventilation

Wind can blow air through openings in the wall on the windward side of the building, and suck air out of openings on the leeward side and the roof. Wind causes a positive pressure on the windward side and a negative pressure on the leeward side of buildings. To equalize pressure, fresh air will enter any windward opening and be exhausted from any leeward opening (Figures 2.1 and 2.2).
The pressure created by the wind on the building is calculated by multiplying a non-dimensional pressure coefficient ($C_p$) with the dynamic pressure.
\[ P_{\text{wind}} = C_p \cdot \frac{1}{2} \cdot \rho_e \cdot U_{\text{ref}}^2 \]  \hspace{1cm} (2.3)

where \( P_{\text{wind}} \): wind induced pressure [Pa]

\( C_p \): pressure coefficient \([-]\)

\( \rho_e \): is the outdoor air density [kg/m\(^3\)]

\( U_{\text{ref}}^2 \): is the wind speed at a reference height [m/s]

The \( C_p \) coefficient is determined by the shape of the building, the wind direction and the surrounding terrain.

The pressure difference between the inside and the outside of the building can be calculated as:

\[ \Delta P_{\text{wind}} = C_p \cdot \frac{1}{2} \cdot \rho_e \cdot U_{\text{ref}}^2 - P_i \]  \hspace{1cm} (2.4)

where \( P_i \): is the pressure inside the building [Pa].

There are two types of wind driven natural ventilation: single – sided ventilation and cross – ventilation [9]. In a single – sided ventilation, opening(s) is/are only installed on one side of the chamber. Fresh air enters and exhaust air exits on the same side (Figure 2.3), sometimes through the same single opening. Turbulence often plays an important role in single – sided ventilated enclosure.

![Figure 2.3: Single – sided ventilation.](image-url)
For cross ventilation, air moves from the windward façade through opening on two sides of the enclosed space (Figure 2.4). There is a simple rule of thumb stating that cross ventilation can perform well in the width of the enclosed space is less than five times the ceiling height.

![Cross ventilation diagram](image)

**Figure 2.4: Cross ventilation.**

### 2.5.2 Buoyancy Driven Natural Ventilation

Since many studies have shown that wind effect is far dominant than temperature buoyancy (stack effect) in inducing air flow [10], the application of natural wind driven ventilation is always the preferred choice by the architects and building designers to generate indoor air movement and improve their building thermal environment. However, nowadays in the conditions of warmer climate and denser built environment or in building surrounded by thick trees, the conventional concept of wind driven ventilation does not always successfully apply. The main solution could lie on providing effective outlet area at the top of the building and use a stack ventilation strategy to induce vertical air movement. In buoyancy driven natural ventilation, the pressure difference created by different densities in the warm and cold air inside and outside a building and in different zones inside the same building. The exchange of air will happen through one or more opening in the roof or outer wall (Figure 2.5). In addition,
this type of natural ventilation could be done in single – sided and cross – ventilation designs.

Figure 2.5: Buoyancy (stack) ventilation.

2.5.2.1 Calculation of Buoyancy Driven Natural Ventilation

Natural ventilation by thermal buoyancy is the air exchange between two or more zones with different densities due to different temperatures. Ventilation by air exchange implies openings between the zones and the opening arrangement can either be separate openings in different levels or it can be a single large vertical or horizontal opening. The temperature differences can occur due to heating one or more of the zones.

The external and internal pressure distribution can be described as below [11]:

\[ P = P_0 - \rho_0 \cdot g \cdot H \]  \hspace{1cm} (2.5)

where

- \( P \) : the external or internal pressure [Pa]
- \( P_0 \) : the pressure at a reference level (floor) [Pa]
- \( \rho_0 \) : the external or internal air density at a reference level [kg/m\(^3\)]
- \( g \) : the gravitational acceleration [m/s\(^2\)]
\[ H : \text{the height above the reference level} \ [\text{m}] \]

Thus, the buoyancy – induced pressure difference \( \Delta P \) across an opening at height \( H \) can be calculated as following where expressions (i) for internal and (e) for external:

\[ \Delta P = P_{e,0} - P_{i,0} - (\rho_e - \rho_i) \cdot g \cdot H \]  \hspace{1cm} (2.6)

At the neutral plane \( (H = H_0) \) where \( \Delta P = 0 \), expression (2.6) becomes:

\[ P_{e,0} - P_{i,0} = (\rho_e - \rho_i) \cdot g \cdot H_0 \]  \hspace{1cm} (2.7)

From the Equation of state it can be found that

\[ \frac{\rho_e - \rho_i}{\rho_i} \approx \frac{T_i - T_e}{T_e} \]

and

\[ \frac{\rho_e - \rho_i}{\rho_e} \approx \frac{T_i - T_e}{T_i} \]  \hspace{1cm} (2.8)

And Eq. (2.7) can therefore be rewritten to:

\[ P_{e,0} - P_{i,0} = P_i \cdot g \cdot H_0 \cdot \frac{T_i - T_e}{T_e} \]  \hspace{1cm} (2.9)

Likewise the pressure in the height \( H_1 \) where \( \Delta P \neq 0 \) can be found as

\[ \Delta P_{H=H_1} = P_{e,0} - \rho_i \cdot g \cdot H_1 \cdot \frac{T_i - T_e}{T_e} \]  \hspace{1cm} (2.10)

If equation (2.9) is inserted into equation (2.10) the pressure difference in \( H_1 \) can be expressed only from the internal and external temperatures, the gravitational acceleration and the density of air. Positive values of the pressure difference in equation (2.10) \( (H_1 \) below the neutral plan) shows that the pressure outside the building is higher than inside.

\[ \Delta P_{H=H_1} = \rho_i \cdot g \cdot H_0 \cdot \frac{T_i - T_e}{T_e} - \rho_i \cdot g \cdot H_1 \cdot \frac{T_i - T_e}{T_e} \]

\[ = \rho_i \cdot g \cdot (H_0 - H_1) \cdot \frac{T_i - T_e}{T_e} \]  \hspace{1cm} (2.11)
From Eq. (2.11) it is seen that the pressure difference is increased with increasing height difference and increasing temperature difference.

From the pressure difference the airflow can be found:

\[ Q = C_D \cdot A \cdot \sqrt{\frac{2 |\Delta P|}{\rho}} \]  \hspace{1cm} (2.12)

where \( C_D \) is the discharge coefficient and in the area between 0.6 and 0.75.

2.5.3 Combination of Buoyancy and Wind

When both mechanisms are operating, they both create pressure differences across the building. Depending upon actual conditions, the pressure created across any aperture will may be additive or opposite. The flow rate and direction through and aperture will depend upon the sum of pressures cross the aperture. Calculation of the combined effects is complex, even for a simple building, but calculating the flow rate for each mechanism separately and taking the larger Figure may make a reasonable approximation of the total ventilation rate.

Most often the pressure in natural ventilation will be created as a combination of thermal buoyancy and wind. The total pressure across an opening is found as a summation of the pressure created by buoyancy and wind.

\[ \Delta P = \Delta P_{wind} + \Delta P_{buoyancy} \]  \hspace{1cm} (2.13)
2.5.4 Examples of Naturally Ventilated Buildings

Natural ventilation has been the dominant way to ventilate residencies since the ancient times. Successful example can be traced in the wind catchers in the architecture of the Middle East, Pakistan and India, which exhibit the impact of the traditional Persian architecture on these regions (Figure 2.6). Wind catcher is placed and oriented in the wind direction, and it has two opening in opposite directions. Air moves in from one opening, circulating down and then go out form the opposite opening.

![Figure 2.6: Wind catchers in Yazd City.](image)

There is a trend for more buildings to incorporate natural ventilation as a scheme for cooling and ventilating part of or a whole building. Some of these buildings emphasize design characteristics making them stand out in a typical streetscape, while others lean toward a more traditional building façade. Both strategies work and examples of each are presented here for comparison. Most naturally ventilated buildings are located in Europe, and the examples here are from the United Kingdom and the Netherlands [12].

Of the examples, one in particular accentuates the design characteristics on the façade of the building, the home of the British Research Establishment (BRE). This building incorporates stack vents into the ventilation scheme, and makes them
pronounced in the architecture of the building. The BRE, designed by Fielden Clegg and built in 1997, is well known for its low energy usage and efficient design. It combines the use of thermal mass, cross ventilation and stacks to passively cool the building. The building’s stacks not only are a prominent feature in its façade, but also assist in driving buoyancy and stack driven air flow. They are constructed of glass block, shown in Figure 2.7, creating a greenhouse effect that warms up air within the shaft which as it rises, draws in cooler air through other openings on the façade. The occupants have control over the lights and window openings as shown in Figure 2.8.

Figure 2.7: BRE Office Building Facades with Stacks. Figure 2.8: Building interior.

### 2.6 Wind Lens

Wind lens is a diffuser shroud equipped with a brim. The concept of wind lens technology is that if local wind speed can be accelerated by capturing and concentrating the wind with some mechanism, there will be a hope for utilizing the wind power in a more efficient way [13]. This is because a low pressure region due to a strong vortex formation behind the broad brim draws more mass flow to the diffuser (Figures 2.9, 2.10).
2.6.1 Air Catcher

Air catcher is the proposed geometry that will be used in present study to enhance the buoyancy driven natural ventilation (Figure 2.11). Air catcher is an airfoil shaped cross sectional area design to be used in this study by using five different airfoils to study the hydrodynamics over these airfoils at different angels of attack. The principal of air...
catcher is similar to aerodynamics of an airplane wing. As a result of the airflow pattern over the wing, decelerated and accelerated zones are developed. The flow induced positive pressure below and negative pressure above the wing in what is called the Bernoulli Effect (Figure 2.12).

Figure 2.11: Air catcher

Figure 2.12: Bernoulli effect.
REFERENCES


