FEASIBILITY STUDY OF AIR CATCHER FOR NATURAL VENTILATION APPLICATION

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For the souls of my father.my mother and my brother Hassan, for all my brothers and sisters, and for my wife. Allah S.W.T bless you all.

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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 mengunakan 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

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LIST OF SYMBOLS AND ABBREAVIATION

A	Area
C_{ax}	Chord Axial Length
C_D	Discharge Coefficient
Clo	Clothing Insulation
C_p	Pressure Coefficient
D	Diameter
g	Gravitational Acceleration
Gr	Grashof Number
H	Height
HVAC	Heating, Ventilation and Air and Air Conditioning
L	Litter
MRT	Mean Radiant Temperature
$\dot{m}_{eff}$	Effective Mass Flow Rate
$\dot{m}_{nom}$	Nominal Mass Flow Rate
Nu	Nusslet Number
P	Pressure
Pr	Prandtl Number
Q	Mass Flow Rate

Re	Reynolds Number
T	Temperature
Top	Operative Temperature
U	Wind Speed
V	Air Velocity

Greek Symbols

α	Angle of Attack
ρ	Air Density
μ	Dynamic Viscosity

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 α (0°,10°,20°) will be considered for each airfoil.

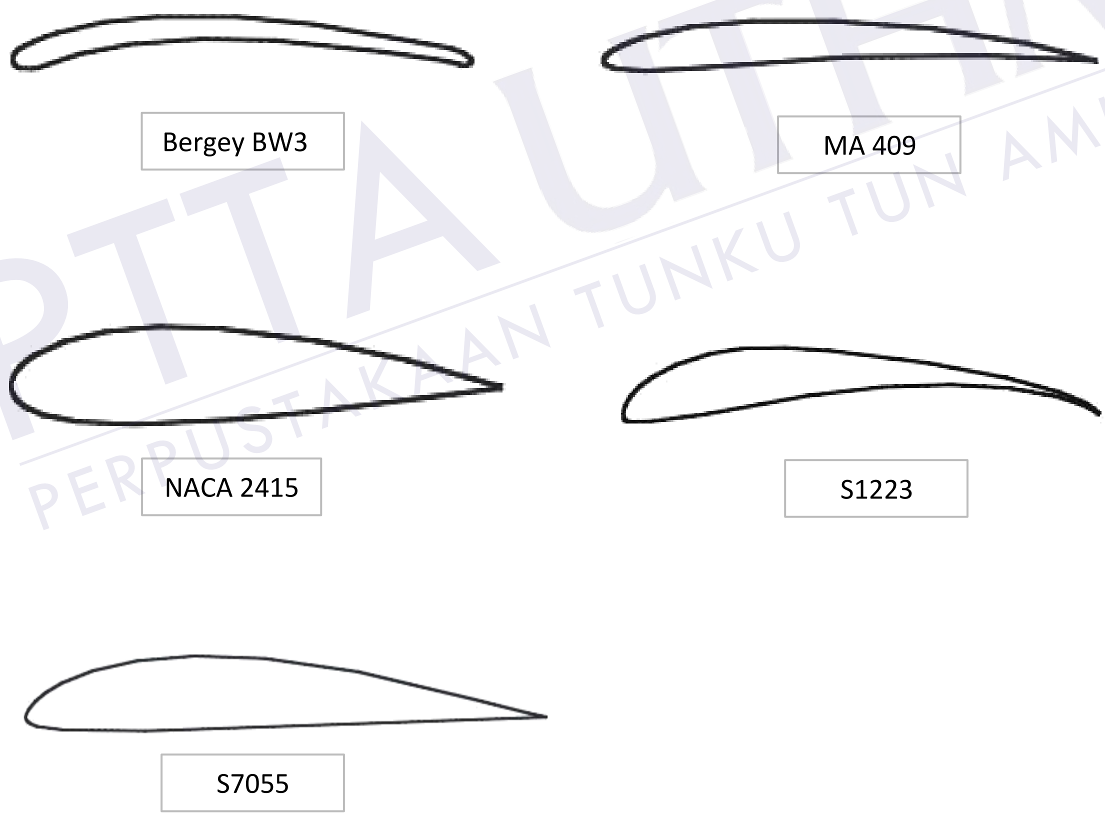

Figure 1.1: Five airfoils at angle of attack α=0°.

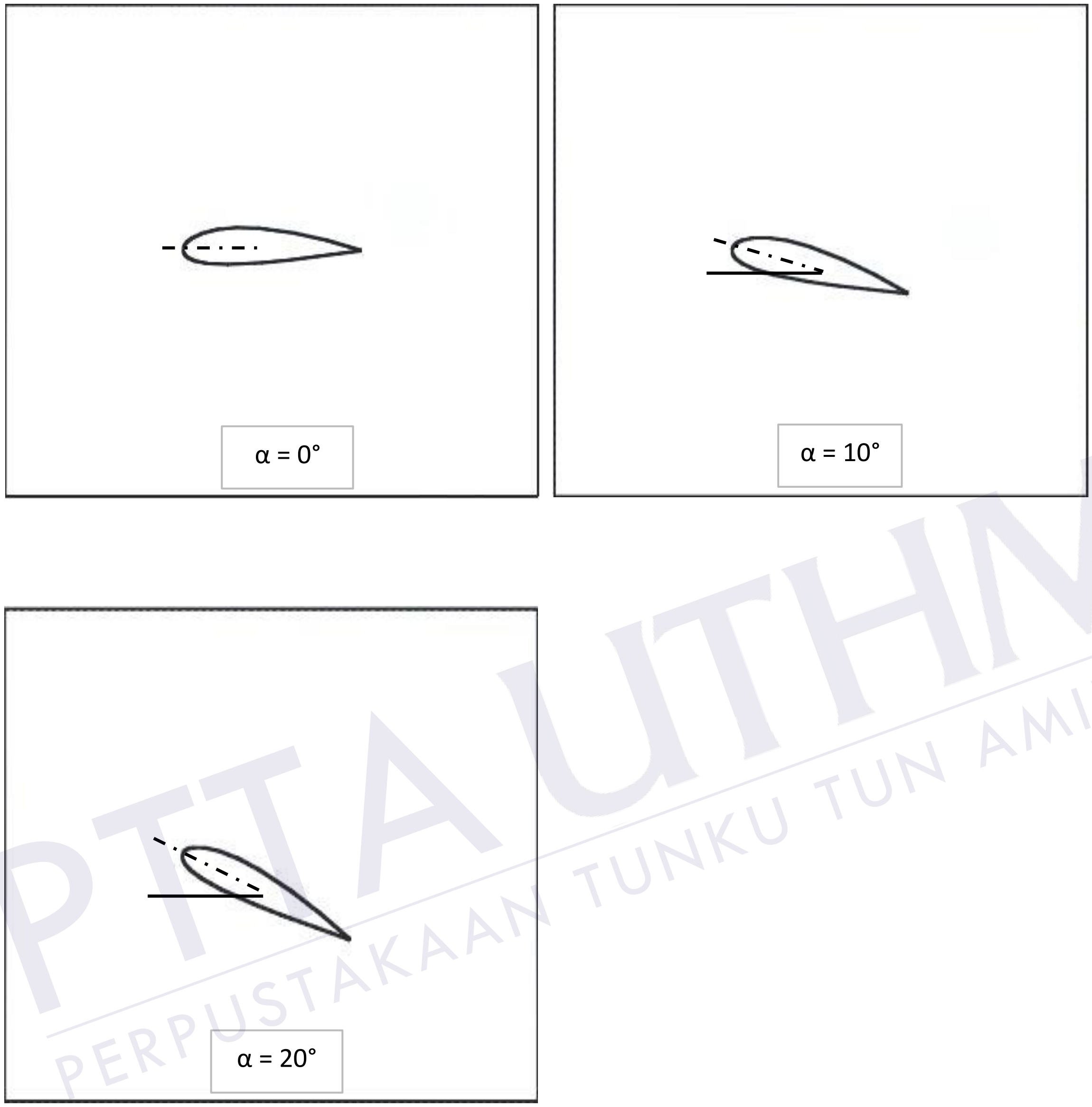

Figure 1.2: Examples of the airfoil at different angles of attack.

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].

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