UNIVERSITI PUTRA MALAYSIA

EFFECTS OF SYMMETRICAL ROOF SHAPE ON PRESSURE COEFFICIENT DIFFERENCE IN ISOTHERMAL CONDITION

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By

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Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in fulfilment of the Requirements for the Degree of Master of Science

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DEDICATED

To

My dearest parents

For their extensively love and their endless care

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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October 2015

Chairman : Assoc. Prof. Nuraini Abdul Aziz, PhD
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Wind driven ventilation techniques mainly rely on the design and geometry of the roof and structure. Venturi shaped roof uses two airfoil like cross section, one mounted on top of the other, to increase the wind speed in the venturi contraction thus reducing the static pressure. This negative pressure induces natural ventilation in building by sucking the air out through a duct connected to the roof.

The influence of the contraction resistance referred as wind blocking effect is the most important effect for reducing the venturi effect of the roof. If the passage width decreases more wind will only flow around and over the roof. Hence the roof is extremely dependent on its geometrical characteristics for its optimum performance. The objective of this study is to conduct a study on the geometric characteristics of the roof and investigate the impact of various geometries and configurations to propose an optimum venturi roof geometry suitable for the hot and humid regions of Malaysia. To achieve this, three models with different roof shapes were chosen and tested in the wind tunnel.

This study compares performance of different roof models shape 1 (Shallow ellipse), shape 2 (ellipse) and shape 3 (hemisphere) in low speed wind tunnel and compares the pressure coefficient (C_p) values at the center of the roof at its contraction, as an indication for higher performance and ventilation flow rates.

The results show that shape 1 (Shallow ellipse) outperformed shape 2 (ellipse) and shape 3 (hemisphere). However when the upper part of the roof is unmounted, the hemisphere without the upper part performs the best and shape 2 without upper part of roof and shape 1 without the upper part of roof perform the worst. This is important at conditions that narrow supporting is not possible for the upper disc. Shape 3 without the upper part also called the simple dome shows 70% of the performance of shape 1(shallow ellipse). When commissioning of shape 1 is not possible, the dome would be the best option since there is no upper part and no supporting pillars are required thus

alleviating construction. The results of this experimental study is believed to aid architects and designers of tall buildings with roof designs in order to get the most out of the wind for natural ventilation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

KESAN BENTUK BUMBUNG SIMETRI TERHADAP PEMBEZAAN PEKALI TEKANAN DALAM KEADAAN ISOTERMA

Oleh

MOHAMMADMAHDI BOROOJERDIAN

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Teknik pengalihudaraan berasaskan angin yang utama bersandarkan bentuk dan geometri bumbung dan strukturnya. Bumbung berbentuk Venturi menggunakan dua buah bahagian melintang seakan airfoil, dengan satu bahagian berada di atas satu sama lain, bertujuan untuk meningkatkan kelajuan angin di dalam venturi menyusut (contraction) maka menyebabkan pengurangan tekanan statik. Tekanan negatif ini mengaruh pengalihudaraan semulajadi di dalam bangunan dengan menyedut udara keluar melalui sesalur yang disambung ke bumbung.

Pengaruh rintangan bahagian menyusut (contraction) ini dinamakan kesan menyekat angin (wind blocking effect) adalah kesan paling utama untuk pengurangan kesan venturi bumbung. Jika kelebaran laluan berkurangan maka lebih banyak angin akan mengalir di sekeliling dan di atas bumbung. Oleh itu ciri geometri bumbung sangat-sangat mempengaruhi prestasi optimum bumbung. Objektif kajian adalah untuk menjalankan kajian ciri geometri bumbung dan mengkaji kesan berbagai geometri dan konfigurasi bumbung untuk mencadangkan geometri bumbung venture yang optimum dan sesuai untuk kawasan panas dan humid seperti Malaysia. Untuk mencapai tujuan ini tiga model berbagai bentuk telah dipilih dan diuji di dalam terowong angin. Perbandingan prestasi model bumbung bentuk 1 (shallow ellipse), bentuk 2 (ellipse) dan bentuk 3 (hemisfera) dalam keadaan halaju angin rendah di dalam terowong angin dengan membuat perbandingan nilai pekali tekanan (C_p) di tengah-tengah bumbung pada bahagian venturi menyusut, sebagai aras prestasi dan kadar alir pengalihudaraan yang lebih tinggi.

Keputusan kajian menunjukikan bahawa bentuk 1 (Shallow ellipse) menandingi bentuk bentuk 2 (ellipse) dan bentuk 3 (hemisfera). Walaubagaimana pun apabila bahagian atas bumbung dikeluarkan, bentuk hemisferea tanpa bahagian bumbung atas memberi hasil terbaik manakala bentuk 1 tanpa bahagian atas menghasikan prestasi paling rendah. Keadaan ini adalah penting kerana sokongan yang sempit tidak dapat dibuat untuk bahagian atas bumbung. Semtara itu bentuk 3 tanpa bahagian atas atau dome mudah menunjukkan prestasi 70% daripada prestasi bentuk 1(shallow ellipse). Apuntuk kerja tugasmula bentuk 1 tidak mungkin dibuat, maka bentuk dome menjadi

pilihan terbaik kerana tidak ada bahagian bumbung atas dan tiada tiang sokong yang memudahkan kerja binaan. Dipercayai bahawa hasil kajian dapat membantu arkitek dan pereka bangunan tinggi mendapat kebaikan pengalihudaraan semulajadi sepenuhnya.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as partial fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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a	Acceleration (m/s^2)
A	Area (m^2)
F	Force (N)
g	acceleration due to gravity (m/s^2)
m	mass (kg)
M	mach number
p_{abs}	absolute pressure (N/m^2)
p_{gauge}	gauge pressure (N/m^2)
p_{atm}	atmospheric pressure (N/m^2)
p_s	surface pressure (N/m^2)
Q	Volume flow rate (m^3/s)
R	Gas Constant (J/(kg.K))
R_o	Universal Gas Constant (J/(kg.mol.K))
ρ	fluid density (kg/m^3)
s	specific volume (m^3/kg)
u	fluid velocity (m/s)
v	fluid velocity (m/s)
τ	shear stress (N/m^2)
μ	dynamic viscosity (Pa.s)
ν	kinematic viscosity ($m^2.s^{-1}$)
∞	A position upstream
E	energy
W	work
Q	heat energy
PD	pressure difference due to stack effect in inches of water (in H_2O)
t_i	inside air temperature in degrees F
t_0	outside temperature in degrees F
P_{out}	the air pressure outside in (kg/m^3)
P_{in}	the air pressure inside in (kg/m^3)
h	overall height at the exhaust port in (m)
h_{npl}	height of the neutral pressure line (m)
V(z)	wind speed at required height

$V(z_{ref})$	wind speed measured at the refrence height (ft)
Z	elevation of the desired wind speed
Z_0	the roughness length of the terrain
Re	Reynolds number
L	Length
V_{tunnel}	the speed of wind in the tunnel, measured in m/s.
P_{dyn}	Dynamic Pressure.
P_{static}	Static pressure in the tunnel
V_{∞}	Wind speed in the tunnel
P_{Roof}	The static pressure at the center of the two parts of the roofs.
V_{Roof}	Wind speed at the center of the roof
Kpcl	amplification factor in passage centerline,
Kc	amplification factor along corner stream at outer building corner

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CHAPTER 1

INTRODUCTION

1.1 Background

As stated in the American Society of Heating Air conditioning and Refrigeration Engineers (ASHARE), natural ventilation is ventilation provided by thermal, wind, or diffusion effects through doors, windows, or other intentional openings in the building [1]. Historically many buildings in the past used natural ventilation. . There are lot of variety of mosque roof designs but in general, there are two distinguished characteristics of overall mosque designs in Malaysia which are the domed and pitched roof mosques. The significant variation on the design of the mosques is strongly evident more in the roof design than in the spatial layout which shows the importance of the roof design in natural ventilation of buildings.

Shape and size of the openings and roof dramatically influences the air change in the naturally ventilated spaces as the wind speed and the temperature difference cannot be controlled. The three types of openings are eave, ridge and wall openings. These three types of openings are shown in the figure 1.1.

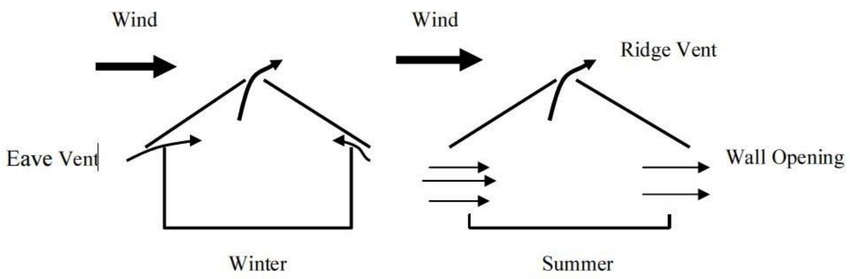

Figure 1.1 : Typical openings used for natural ventilation of dairy buildings [2]

The shape of the roof and its slope also plays an important role and is quoted as follows "The vertical separation between the eave and ridge openings has a significant impact on the pressure differences generated by the chimney effect. Therefore, the roof slope is an important consideration in the design of a naturally ventilated building." [2].

1.2 The purpose of ventilation

Buildings are ventilated for two basic purposes [3-5]. First is to achieve an acceptable indoor air quality and the other is to provide thermal comfort. Indoor air quality is based on removing or dilution of indoor pollutant concentration by supply of fresh air. Accordingly ventilation is not for oxygen supply in buildings nor to get rid of carbon dioxide [6]. The reason is that it is hardly possible to consume the oxygen to an extent that there is a need to increase the oxygen level, and even harder to reach levels of carbon dioxide which are harmful to us. However they are good indicators of the other contaminants such as odour and moist which are produced by human body.

Optimum indoor air quality is defined as "air which is free of pollutants that cause irritation, discomfort or ill health among occupants" [3].

- Typically Pollutants are:
- Odour and moisture from humans and human activities.
- Emissions from building materials, furnishing, fittings, equipment, detergents etc. (Volatile organic and chemical compounds, e.g. formaldehyde).
- Environmental Tobacco smoke (ETS) and pollution from combustion processes (e.g. CO and NOx).
- Radon and pollution from outdoor sources [6].

Besides providing good indoor air quality, ventilation also helps to achieve thermal comfort. ISO 7730 states that "Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment" [7]. Unwanted heating or cooling of all body or parts of the body causes discomfort and dissatisfaction. As far as thermal comfort is concerned there are three objectives of natural ventilation in daytime [3]:

- Cooling of the building structure
- At times when the outdoor temperatures are lower than the indoor temperature the air can be replaced or diluted.
- Direct cooling of occupants by means of evaporation and convection.

The cooling of building structures at night time can also result in the cooling of the interior of the building. In this case the mass of the building is used as a thermal storage during the cooler times and acts as a heat sink during the next day [6].

1.3 Comparisons between Natural and Mechanical Ventilation

There are more benefits to have natural ventilation than mechanical ventilation. Some of these benefits are cooling energy savings, better comfort, productivity and occupant health. The following are some comparisons between using mechanical and natural ventilation in buildings.

1.4 Occupant Health, Comfort and Productivity

Based on research in both European and North American countries, there are lower symptoms in the naturally ventilated buildings compared to mechanically ventilated and air-conditioned buildings [8]. Natural ventilation systems can provide more healthy, comfortable, and productive environments than mechanical systems. Architects have accepted natural ventilation as one of several objectives of high quality sustainable design [9]. In cooling the building mechanically, fans become one of the mechanical means which use a significant amount of the energy [9].

Heating Ventilating and Air conditioning (HVAC) equipment cost and space requirements mechanical heating, ventilating, and air conditioning equipment often are one of the large cost of construction of new buildings and the renovation of existing buildings. These costs may be expected to range from 35% to 45% of construction costs in larger office and institutional buildings [9]. Consequently, by replacing or at least reducing mechanical systems for ventilation and cooling, one of the potentially quite large costs can be saved.

Mechanical air handling equipment including fans, filters, heating and cooling coils, vertical distribution shafts and ducts, horizontal distribution duct networks, dampers, supply diffusers and return grilles consume vast amounts of space. Therefore, mechanical equipment's consume about 20% to 40% of the total volume of the building. Natural ventilation systems recover much of this volume as occupied space for the spatial interior of the building. This recovered space (volume) may be used for formal architectural objectives or for daylight distribution [10].

1.5 Ambient Air Quality

Another important issue in natural ventilation systems is the impact of ambient air quality. Typical natural ventilation systems do not use filtration. The filtration in mechanical ventilation systems does not remove all contaminants from the outdoor air. It generally includes some form of particle filtration. Natural ventilation helps improve indoor air quality. Also, it can control indoor humidity and airborne contaminants which are health hazards. So, the acceptability of having a better ambient air quality in natural ventilation systems must be considered [10].

1.6 Advantages of Natural Ventilation Systems

Advantages of natural ventilation are as follows [9].

- Removal of mechanical air handling systems.
- Reducing cooling energy consumption.
- Eliminating the use of fan power required.
- Providing quantitative health, comfort, and productivity advantages.
- Providing qualitative advantages of 'fresh air' in the minds of most occupants.
- Having better control of their environments and less restrictive comfort criteria.

• Reducing significant fraction costs of conventional mechanical ventilation systems in commercial buildings.

• Eliminating the large spatial requirements that conventional mechanical systems demand.

• Avoiding the duct cleanliness dilemma, and its attendant costs.

1.7 Uniform building by-law 1984

Malaysia Uniform Building by Laws 1984 states minimum requirements for air wells in buildings for natural ventilation purposes as follows:

1. For buildings up to 2 storeys in height: 7 square meters;
2. For buildings up to 4 storeys in height: 9 square meters;
3. For buildings up to 6 storeys in height: 11 square meters;
4. For buildings up to 8 storeys in height: 13 square meters;
5. And for buildings more than 8 storeys in height: 15 square meters

The minimum width required in any direction will be 2.5 meters.

1.8 Problem statement

Roof being the most exposed part of the building to winds, has the ability to extract the air out of the building. In a design by Bronsema the building uses two airfoils, one located above the other at the roof to create a contraction resembling the venturi, and according to Bernoulli's principle creating a negative pressure at the center of the contraction which is supposed to aid the natural ventilation by sucking the air out of the building through a central air channel or duct (Figure 1.2).

However if the disc is placed too close to the extraction points the element could constrict the air flow between the disc and roof to a point where the oncoming winds would stack up at the cap thus creating a dead zone without pressure of velocity. In a sense if the constriction is too much a Venturi "disc" can become a windbreak also referred to as wind blocking effect which shows the extreme importance of the geometry of roof.

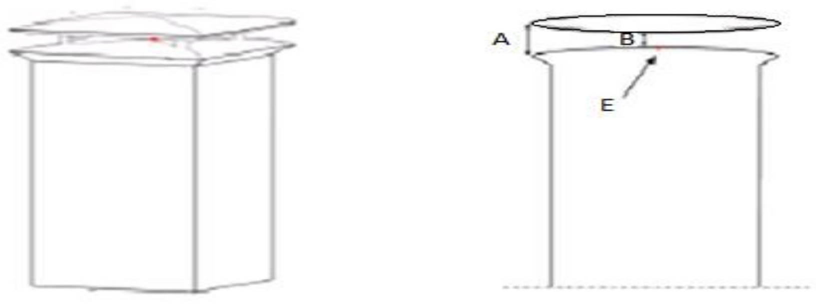

Figure 1.2 : VENTEC roof designed by Bronsema[11]

Later studies on the venturi roof has focused on the geometrical features that can possibly affect the performance of the roof. Adding guiding vanes, width of the building and vertically translating the full square disc, but the geometry of the roof was not changed. There is no reported studies on how can different roof shapes affect the performance of the roof.

A study conducted in the UKM university on a full scale model have reported that venturi shaped roofs have created significant air changes in the hot and humid regions of Malaysia equivalent to the wind towers of the middle east. However no parametric study has been done on the roof geometry and its effect on ventilation. No explanations are given in terms of the criteria of implementing this roof design. The so called venturi tower shown in figure 1.3 has obvious contradictions in the roof design with the reports of an optimized roof performed on Bronsema's venturi roof and raises the controversial issue of which is an optimized roof geometry for the climate of Malaysia. The low wind speeds of Malaysia and the requirement of high ventilation rates and air movement, highlights the need for and optimized roof design which cannot be achieved without the knowledge on the influence of roof geometrical on the performance of the roofs.

Figure 1.3: Full scale model at UKM University[12]

Studies on venturi roofs show that there is a fine balance between the venturi effect and the wind blocking effect which are influencing the performance of the roof and even insignificant geometrical characteristics like the pillars or the support of the upper roof can hinder its performance. Being more precise any venturi looking roof does not necessarily mean that the venturi effect is taking place in the roof. Every roof design needs to be investigated for this effect and cannot be generalized or predicted. Therefore is a need to quantify a suitable venturi roof for the hot and humid climatic conditions of Malaysia in a separate study.

1.9 Objective

The objective of this study is to fabricate three roofs with different shapes and experimentally identify how different geometries influence the performance of the roof, and find the optimum configuration that creates the highest negative pressure at the roof center. This optimum configuration is mathematically referred to as contraction ratio and is affected by both variation in geometry of roof and the distance between the two parts of the roof.

According to the literature, in wind tunnel experiments, the negative pressure at the center of the roof also known as pressure coefficient (Cp) is the major criteria for comparing the performance of the roof and consequently knowing whether the venturi effect is taking place or the wind blocking effect is the governing phenomena. The center of the roof where the highest contraction is present yields the lowest pressure coefficient and the specific location for the tap measurement.

The specific objectives of this study are to:

1) Measure the pressure coefficient (Cp) for Bronsema's design for validation
2) Determine suitable geometric shape and gap between the two roof parts, best suitable for the hot and humid regions of Malaysia.

1.10 Significance of study

This work contributes to knowledge in green building technology where roof can have a major impact on inducing natural ventilation. The study can be of concern to architects and professions of those related to green buildings, as it intends to give an insight on the effect of different geometrical shapes on the performance of the roof and introducing a geometrical shape of roof, preforming efficiently in the climatic conditions of Malaysia.

1.11 Scope and limitations

This study has considered a number of roof configurations that are likely to present a good performance in the hot and humid climate of Malaysia. All parameters that are believed to influence the results are kept constant (i.e. wind speed, height of the building) and the effect of roof shape and the optimum distance between the two parts of the venturi roof in terms of venturi versus wind blocking effect is studied. The pressure coefficient at the roof center is considered as the criteria of determination of the performance of the roof. The roofs are fabricated from high density polyethylene (HDPE). The scale ratio of the models are 1:50 as the roofs are assumed to be applicable to be mounted on buildings or towers at heights above 25 meters.

As this experiment is conducted using wind tunnel and models have to be fabricated for change in any geometrical parameter. Except experimental errors, a drawback of this method is number of models that can be fabricated as it can be time consuming and expensive. This reduces the ability of a thorough parametric study. Numeric simulation can be helpful in such cases however the limitations of a licensed CFD software and instruments and equipment's of the wind tunnel required for validating the CFD results at the time of the study suggests the wind tunnel experimental method.

It is also not clear to what extent the difference in pressure coefficient at the roof center will affect the natural ventilation of the building. Also the building is considered standing alone and the effect of other building upstream is ignored.

1.12 Thesis layout

Chapter 1 introduces the topic on ventilation principals, venturi roof design and their definitions. Chapter two presents the literature review. Chapter three presents research methodology using wind tunnel. Chapter four presents the results and discussions and finally chapter five presents the conclusions and recommendations for future work.

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