DISTRIBUTION OF PRESSURE COEFFICIENT ALONG THE EXTERNAL PROFILE OF RURAL HOUSE EXPOSED TO WINDSTORM IN MALAYSIA USING COMPUTATIONAL FLUID DYNAMICS (CFD)

SITI NORATIKAH BINTI CHE DERAMAN

UNIVERSITI SAINS MALAYSIA

2019

DISTRIBUTION OF PRESSURE COEFFICIENT ALONG THE EXTERNAL PROFILE OF RURAL HOUSE EXPOSED TO WINDSTORM IN MALAYSIA USING COMPUTATIONAL FLUID DYNAMICS (CFD)

by

SITI NORATIKAH BINTI CHE DERAMAN

Thesis submitted in fulfillment of the

requirements for the degree of

Doctor of Philosophy

February 2019

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulilillah, all praises to Allah, the Almighty for providing me this opportunity and granting me the capability to complete this study successfully. I would like to express my utmost gratitude and appreciation to my primary supervisor, Prof. Dr. Taksiah A Majid and my second supervisor, Dr. Shaharudin Shah Zaini for their invaluable guidance, supervision, professional expertise, patience, commitment and encouragement throughout these years.

A heartfelt appreciation is also dedicated to Dr. Mohd Azmi Ismail, Khairi and Hafiz, who patiently taught me about ANSYS Fluent and Gambit 2.4.6 as well as solving the problems occurred in both software. Their knowledge, experience and expertise have made a significant contribution in all aspects of my research, and I am tremendously grateful for that.

I would not have been able to concentrate and accomplish my goals had it not been for the love and support from my lovely parents, Che Deraman Che Wil and Sobariah Ab Rahman and also my siblings, Hazwani, Azizul, Farhanah, Shahidan, Syahmi and Syahrul for their endless love, prayers, understanding, patience, financial support and encouragement. Allah bless all of you for the bits and pieces you have helped me with. I love you!

I would like to extend my thanks to the members of Wind Group for sharing their academic knowledge, friendship and cooperation during my study. I am indebted to them for their assistance during my journey. I would also want to express my special thanks to my close friends from team Syabiha, Farah, Aziemah, Hasyimah, Ain, Rafidah, Fatihah, Aina, Hilmah, Azrin, Khairiyah, *'Geng Surau'*, *'Kawan Sekolah'*, *'The Legendary'* and *'Gadis Murai'* Group for their advice and support throughout the ups and downs. The same appreciation also goes to the Hydraulic Group, staffs from School of Civil Engineering, staffs from School of Mechanical Engineering, academic staff from School of Material and Mineral Resources, academic staffs from Universiti Malaysia Kelantan, all postgraduate student in School of Civil Engineering, members of Doctorate Support Group who directly or indirectly help me throughout these years, thank you.

Finally, I would like to thank the Ministry of Education Malaysia for sponsoring my PhD studies under MyBrain15 program. I am also grateful for the financial support from the Fundamental Research Grant Scheme (FRGS) provided by the Ministry of Higher Education (203.PAWAM.6071317) and the APEX Delivering Excellence Grant DE2012 from Universiti Sains Malaysia.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	Three-dimensional
ABL	Atmospheric Boundary Layer
ANOVA	Analysis of Variance
CFD	Computational Fluid Dynamics
CD	Computational Domain
CWE	Computational Wind Engineering
DOE	Design of experiment
FVM	Finite Volume Method
FFD	Full Factorial Design
GH	Gap height
GSA	Grid Sensitivity Analysis
LES	Large Eddy-Simulation
MAE	Mean Absolute Error
MET	Malaysian Meteorological Department
NAE	Normalized Absolute Error
OV	Overhang
PBL	Planetary boundary layer
RANS	Reynolds Averaged-Navier Stoke
RKE	Realizable $k - \varepsilon$
RMSE	Root Mean Square Error
RNG	Renormalization Group
RP	Roof pitch
SEB	Silsoe Experimental Building
SIMPLE	Semi-Implicit Method for Pressure-Linked Equation

SKE	Standard $k - \varepsilon$
TKE	Turbulence Kinetic Energy
TDR	Turbulence Dissipation Rate
UDF	User Define Function
WTT	Wind Tunnel Test

LIST OF SYMBOLS

B	Constant
C_S	Roughness constant
C_P	Pressure coefficient
C_{Pmin}	Maximum negative peak pressure
C_{Pmean}	Mean suction
C_{Prms}	Root Mean Square value of pressure coefficient
C_μ	Kolmogorov constant
E	Empirical constant
H	Target building
H_C	Height of core house
H_e	Height of the eaves
H_K	Height of kitchen house
H_S	Height of surrounding building
h_g	Height of ABL
K_S	Roughness height
L_z	Length of the line
N	Interval count
R_e	Reynolds Number
T	Reference temperature
u	Wind velocity
u_*	Friction velocity
u^+	Dimensionless velocity
U_∞	Constant velocity distribution

V	Upstream velocity at the height of the building
V_Z	Wind velocity at height z
V_1	Wind velocity at reference height z_1
y^+	Dimensionless distance from the wall
z_0	Roughness length
z	Height above ground
z_0	Roughness length
z_P	Center of first cell
ε	Turbulence dissipation rate
κ	Von Karman constant
k	Turbulence kinetic energy
ρ	Air density
μ	Dynamic viscosity of air
α	Power-law exponent
δ	Boundary layer thickness
μ	Kinematic viscosity
$\bar{\rho}$	Mean density
$\bar{p}$	Mean pressure
τ_ω	Shear stress at the wall

TABURAN PEKALI TEKANAN DI SEPANJANG PROFIL LUAR RUMAH LUAR BANDAR YANG TERDEDAH KEPADA RIBUT DI MALAYSIA MENGGUNAKAN PERKOMPUTERAN DINAMIK BENDALIR (CFD)

ABSTRAK

Kajian terhadap kesan aliran angin di sekeliling rumah luar bandar menjadi fokus di dalam kajian ini. Kajian lapangan selepas angin ribut menunjukkan banyak kerosakan bumbung pada rumah dapur dan bukan hanya pada rumah ibu. Walaubagaimanapun, kajian-kajian lepas terhad kepada bangunan tinggi dan rendah tanpa ruang tambahan (rumah dapur) berbanding rumah luar bandar di bahagian Utara di Semenanjung Malaysia. Kajian berangka menggunakan simulasi Perkomputeran Dinamik Bendalir dijalankan untuk mensimulasikan aliran angin terhadap rumah luar bandar, seterusnya menghasilkan taburan tekanan di sekeliling rumah dan disahkan dengan keputusan ujian terowong angin. Oleh itu, kajian ini dijalankan untuk mengkaji kesan juntaian, sudut bumbung, ketinggian jurang dan kedudukan rumah dapur ke atas aliran angin di sekeliling rumah luar bandar menggunakan Perkomputeran Dinamik Bendalir. Persamaan RANS menggunakan model bergelora RNG $k - \varepsilon$ diperkenalkan untuk menyelesaikan masalah aliran dalam kajian ini. Sedutan tertinggi di batas bumbung (C_P =-2.28) telah direkod untuk model rumah dapur berada di tengah. Pekali tekanan yang tertinggi di tinggi sela telah direkod menjadi 0.97 untuk model dengan 0.25 m sela. Sementara itu, model yang bersudut bumbung 17° telah membangunkan sedutan tertinggi di batas bumbung dengan nilai pekali tekanan -2.28. Kesan sedutan tertinggi berlaku di juntaian bumbung dengan nilai pekali tekanan bersih dikira menjadi -2.35 dan tidak berlaku di batas bumbung. Akhir sekali, keputusan dari rekabentuk ekperimen menunjukkan juntaian bumbung dan sudut bumbung memberi kesan kuat

kepada nilai C_P sedangkan juntaian bumbung, sudut bumbung dan kedudukan rumah dapur menyumbangkan kesan interaksi yang kuat.

DISTRIBUTION OF PRESSURE COEFFICIENT ALONG THE EXTERNAL PROFILE OF RURAL HOUSE EXPOSED TO WINDSTORM IN MALAYSIA USING COMPUTATIONAL FLUID DYNAMICS (CFD)

ABSTRACT

The study of effects of wind flow surrounding the rural house become the focus of the present study. Post windstorm site-survey shows that most damages part of the roof is over the kitchen house and not only core house. However, the previous studies are limited to the high-rise building and low-rise building without extended room (kitchen house) rather than the rural house in the Northern region of Peninsula Malaysia. The numerical study using CFD simulation was performed to simulate the wind flow toward rural house, resulting a pressure distribution surrounding the house and validated with the wind tunnel test. Therefore, the study is conducted to investigate the effect of house features namely overhang, roof pitch, gap height and position of kitchen house on the wind flow surrounding the rural house using CFD. The steady-RANS equation using RNG $k - \varepsilon$ turbulence models were introduced to solve the flow problems for this study. The highest suction at the roof ridge (C_P = -2.28) was recorded for the model with kitchen house located at the center. The highest pressure coefficient at the gap height was recorded to be 0.97 for model with 0.25 m gap. Meanwhile, the model with 17° roof pitch developed the highest suction at the roof ridge with the value of C_P -2.28. The highest suction effect occurred on the roof overhang with the values of net C_P calculated to be -2.35 and not at the roof ridge. Finally, the results using Design of Experiment show that overhang roof and roof pitch cause the most significant influence to the C_P values whereas the roof overhang, roof pitch and kitchen house position contributed to the strong interaction effect.

CHAPTER ONE

INTRODUCTION

1.1 Overview of windstorm induced damage

Most high winds are produced by severe storms such as hurricanes, tornadoes, thunderstorm, downburst (Liu, 1991), tropical cyclone, monsoon and gale (Henderson and Ginger, 2008). The same types of severe storms such as hurricanes, typhoons and cyclones are termed differently based on the geographical region and in Asia is known as cyclones (Liu, 1991). Cyclones generally impacted the coastal regions in the tropics, and can extend hundreds of kilometers in land. Therefore, this type of storm has the potential to cause the most damage such as roof blown off, uprooted trees, building collapse, injuries and deaths of human or animals. Figure 1.1 shows the damage caused by a strong wind event in Mourilyan, Australia.

Figure 1.1: Damage in Mourilyan from tropical cyclone Larry (Henderson and Ginger, 2008)