ANALYSIS OF WIND PRESSURE EFFECT ON GAMBREL ROOF OF A LOW-RISE BUILDING USING COMPUTATIONAL FLUID DYNAMIC (CFD)

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SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
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By

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ABL	Atmospheric Boundary Layer
ANOVA	Analysis of Variance
CFD	Computational Fluid Dynamics
DNS	Direct Numerical Simulation
LES	Large Eddy Simulation
MAE	Mean Absolute Error
NAE	Normalized Absolute Error
RANS	Reynolds Averaged-Navier Stoke
RNG	Renormalization Groups
WTT	Wind Tunnel Test
OH	Overhang
GH	Gap height
UDF	User Define Function

LIST OF SYMBOLS

V_s	Minimum basic wind speed (m/s)
$M_{z,cat}$	Terrain multiplier
M_h	Hill shape multiplier
Cp	Pressure Coefficient
$V_{x,\,free}$	Mean velocity at the reference height (m/s)
y	Height along vertical axis (m)
δ	Reference height (m)
α	Terrain coefficient
k	Turbulence kinetic energy (m^2/s^2)
Ks	Equivalent sand-grain roughness height (m)
Z_o	Aerodynamics roughness length (m)
U_*	Friction Velocity (m/s)
Z	Height above the ground surface (m)
V	Wind speed function of height (m/s)
a	Constant value depending on terrain category
$Zref$	Reference height at 10 m above the ground surface (m)
ρ	Air density (kg/m^3)
$Pref$	Reference pressure
U_{he}	Velocity (m/s)
Z_g	Vertical wind speed (N/m^2)
C_s	Roughness Constant

RAMALAN TEKANAN ANGIN TERHADAP BUMBUNG JENIS 'GAMBREL' PADA BANGUNAN RENDAH MENGGUNAKAN CFD.

ABSTRAK

Ribut angin adalah punca kerosakan harta benda yang besar, kecederaan diri, dan juga kematian, selain kerugian ekonomi. Semasa ribut angin, bangunan bertingkat rendah, terutamanya yang mempunyai struktur bumbung, menghadapi risiko paling besar untuk musnah. Bumbung struktur tertakluk kepada jumlah beban angin yang paling besar jika dibandingkan dengan komponen lain bangunan. Hasil simulasi dinamik bendalir pengiraan (CFD) yang dijalankan dengan objektif untuk menentukan pengaruh tekanan angin pada struktur bertingkat rendah dengan pelbagai padang bumbung yang berbeza. Menggunakan simulasi dinamik bendalir pengiraan (CFD), penyelidik telah menjalankan sejumlah besar eksperimen selama bertahun-tahun untuk menganalisis kesan angin. Sebahagian besar kajian pula dijalankan dengan mengambil kira persekitaran tiga dimensi dan bentuk muka bumi di sekeliling bangunan satu tingkat. Di sisi lain, terdapat kajian yang menggunakan simulasi CFD dalam persekitaran dua dimensi tetapi dengan beberapa jenis bumbung, seperti bumbung '*gable*', bumbung rata dan padang bumbung yang berbeza-beza darjah. Daripada data yang diperoleh, saiz dan trajektori aliran angin boleh ditentukan. Tahap -*Cp* yang lebih tinggi mendatangkan lebih banyak kemudaratan disebabkan oleh peningkatan sedutan dan kawasan pusaran yang lebih luas. Sudut bumbung boleh ubah juga mempunyai kesan yang ketara ke atas pengagihan aliran udara. Kehadiran '*overhang*' pada bumbung gammbrel memberikan lebih kekuatan daripada ketiadaan *'overhang'*.

ANALYSIS OF WIND PRESSURE EFFECT ON GAMBREL ROOF OF A LOW-RISE BUILDING USING COMPUTATIONAL FLUID DYNAMIC (CFD)

ABSTRACT

Windstorms are the cause of enormous amounts of property damage, personal injury, and even death, in addition to economic loss. During windstorms, low-rise buildings, particularly those with roof structures, are at the greatest risk of being destroyed. The roof of a structure is subjected to the greatest amount of wind load when compared to the other components of a building. The results of computational fluid dynamics (CFD) simulations carried out with the objective of determining the influence of wind pressure on low-rise structures with a variety of different roof pitches. Using computational fluid dynamics (CFD) simulations, researchers have conducted a great number of experiments over the course of many years in order to analyse the wind impact. The vast majority of studies, on the other hand, were carried out by taking into account the three-dimensional environment and topography around the single-story buildings. On the other side, there are studies that use CFD simulations in a two-dimensional environment but with several kinds of roofs, such as gable roofs, flat roofs, and roof pitches of varying degrees. From the acquired data, the size and trajectories of the wind flows may be determined. Higher -*Cp* levels inflict a great deal more harm owing to increased suction and a wider vortex region. Variable roof pitch also has a significant impact

on the airflow distribution. The presence of an overhang on a gambrel roof provides more strength than the absence of an overhang.

CHAPTER 1: INTRODUCTION

1.1 Background

Wind is the movement of air above the earth's surface. Air movement is connected to the difference in atmospheric pressure and air temperature. Because hot air has a low density, it causes low pressure in the atmosphere above the earth's surface, and vice versa. Air with low pressure prefers to migrate to locations with high pressure, and the speed of wind movement is determined by air pressure variations (Duncan *et al.,* 2018). Windstorms arise when a fast shift in pressure over a short distance creates a significant pressure gradient. Windstorms are a complicated natural disaster that may have a huge effect and endanger the environment.

Thunderstorms arise when warm, wet air travels rapidly to colder portions of the atmosphere in a tremendous updraft, generating layers. The liquid condenses in the updraft, generating huge cumulonimbus clouds and, finally, precipitation. Thunderstorms may bring hail, heavy rain, lightning, and strong gusty winds. High winds have the ability to inflict significant harm (Bachok *et al.,* 2015). In structures with pitch roofs, cladding, purlin, and rafter are prone to windstorm damage. A structure that is not constructed in accordance with any design code suffers significant harm (Abdullah *et al.,* 2019). The amount of the forces acting on the home, known as suction (uplift) and pressure, also has an impact on the degree of damage. Figure 1.1 depicts the impact of thunderstorms on a low-rise structure.

Figure 1.1:Damages related to roofing system of a low rise building during windstorm event in Ipoh, Perak (The Malay Mail, 1 February 2022)

1.2 Roof Types of Low-rise Buildings

Throughout history, there has been a gradual expansion in the variety of roof types available. The layout of the roofs in each area is distinctive on account of the varying conditions imposed by the local geography, topography, and atmosphere. The three most common forms of roofs are gable, hip, and shed roofs. Gable roofs are the most common type. In contrast, the gambrel roof will get an in-depth investigation from this inquiry. A healthy roof protects the structures from the elements, conserves energy, avoids severe leaks, enhances the building's curb appeal and value, and may even encourage a healthy resident to remain in the building.

1.2.1 Gable Roof

Traditional and modern architecture around the world use gable roofs, which are basically a structural roof covering design of steeply pitched slopes rising to a peak where two sides' slopes meet at the pitched surfaces at the central ridge down to the walls with a gentle slope to protect the design from water leakage cottages. This kind of roof design allows for the lower pitch of the gable roof to extend beyond the vertical centerlines of the home. Additionally, the higher pitch of the gable roof extends beyond the lower pitch, which creates two vertical regions on each side of the house (Owens, 2019).

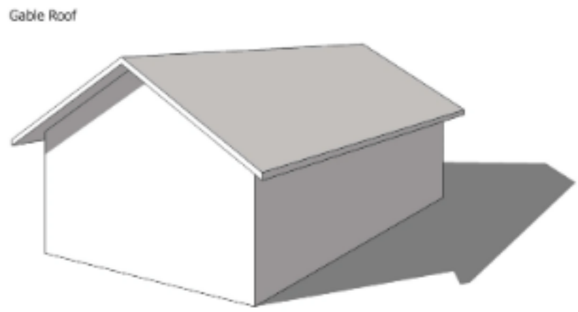

Figure 1.2:Gable roofs

1.2.2 Hip Roof

The walls of the home are situated under the overhanging eaves that run down either side of the hip roof, which is a kind of roof style. Hip roofs are sometimes referred to as gable roofs and shed roofs. A hip roof has no vertical ends along its edges. If the structure is square, it has slopes on all four sides and a central peak. It may also incline the ends inward so that they meet a ridge created by the adjacent sides. The word "hip" refers to the outer angle formed by the intersection of two adjacent sides. Hip roof construction costs are more than gable roof construction costs owing to the intricacy of the hip roof's design and construction requirements (Iko, 2021).

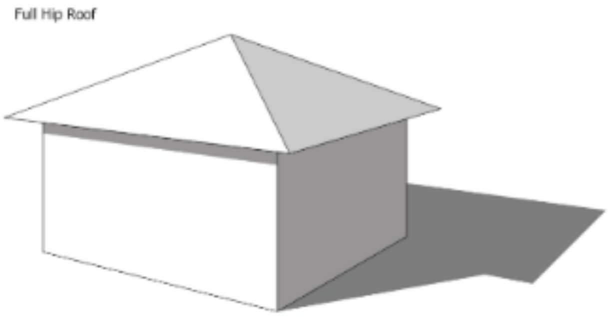

Figure 1.3:Hip roofs

1.2.3 Shed Roof

A shed roof is characterised by having a single steeply sloping roof with an acute pitch. It is also known as a skillion roof or a pent roof, and it gets rid of corners and low spots on the walls, which results in a substantial amount of additional space that can be used inside. The pitch of the roof is often between 10 and 30 degrees, depending on the specific design (Owens, 2019). Flat roofs are more susceptible to the force of wind than shed roofs, although only marginally. However, in regions prone to storms, they must still be anchored down to the walls in a very safe manner.

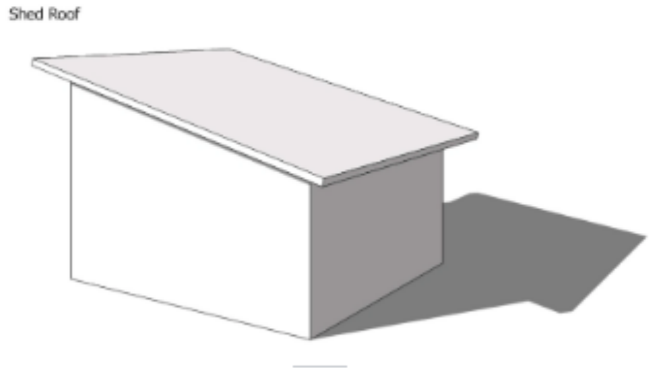

Figure 1.4:Shed roofs

1.2.4 Gambrel Roof

A gambrel roof is a symmetrical two-sided roof that has a slope that is steeper on one side and a slope that is more shallow on the other side. Consider the gambrel roof that most people are most familiar with, which is the roof of a barn. This is also a typical roof pattern in Dutch colonial homes, and some historians think that early Dutch merchants in Southeast Asia studied the style and brought it with them when they moved. This is a theory that is supported by the fact that the design is prevalent. The peak of a basic gambrel roof is typically constructed at an angle of 30 degrees, and the second slope is typically constructed at an angle of 60 degrees; however, this can be altered according to the wants and preferences of the individual builder, as is the case with so many other aspects of construction. Gambrel roofs are not only easier to build, but they also provide more storage space than the more conventional pitched roofs (the triangular roof shape). In addition, they use less material than roofs that have extra support beams and columns to hold them up (Medeeks, 2019). Because it provides more space, the gambrel roof is often seen on structures such as barns, sheds, and other buildings of a similar kind.

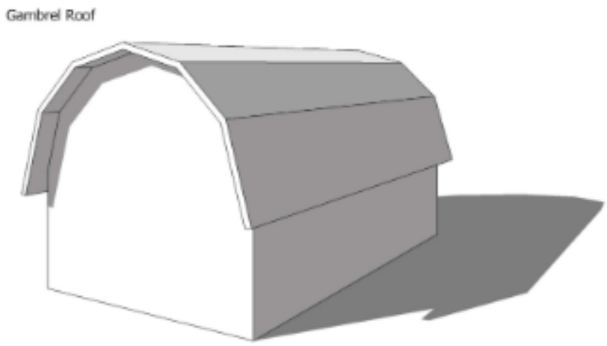

Figure 1.5:Gambrel roofs

1.3 Problem Statement

Windstorms are the cause of enormous amounts of property damage, personal injury, and even death, in addition to economic loss. During windstorms, low-rise buildings, particularly those with roof structures, are at the greatest risk of being destroyed. The roof of a structure is subjected to the greatest amount of wind load when compared to the other components of a building. CFD simulations were carried out with the objective of determining the influence of wind pressure on low-rise structures with a variety of different roof pitches. Using computational fluid dynamics (CFD) simulations, researchers have conducted a great number of experiments over the course of many years in order to analyse the wind impact. For example, Tominaga *et al.,* (2015) and Ozmen *et al., (*2016b) used only gable roofs as their simulations model. The vast majority of studies, on the other hand, were carried out by taking into account the three-dimensional environment and topography around the single-story buildings. On the other side, there are studies that use CFD simulations in a two-dimensional environment but with several kinds of roofs, such as gable roofs, flat roofs, and roof pitches of varying degrees as shown in Figure 1.6. As a result, the air flow pattern and wind design data for a building on other type of roofs are not largely found in the open literature. To fill in the gaps left by previous researchers, these studies focus on the gambrel roof as the primary roof structure with a distinct kind of roof pitch and flat terrain features. In the past, there was a lack of different roof type assessments, particularly employing gambler roof as the primary structure. In order to explore pressure distribution, these experiments use the gambler roof as the primary roof structure and expand the research area by adding another form of roof.

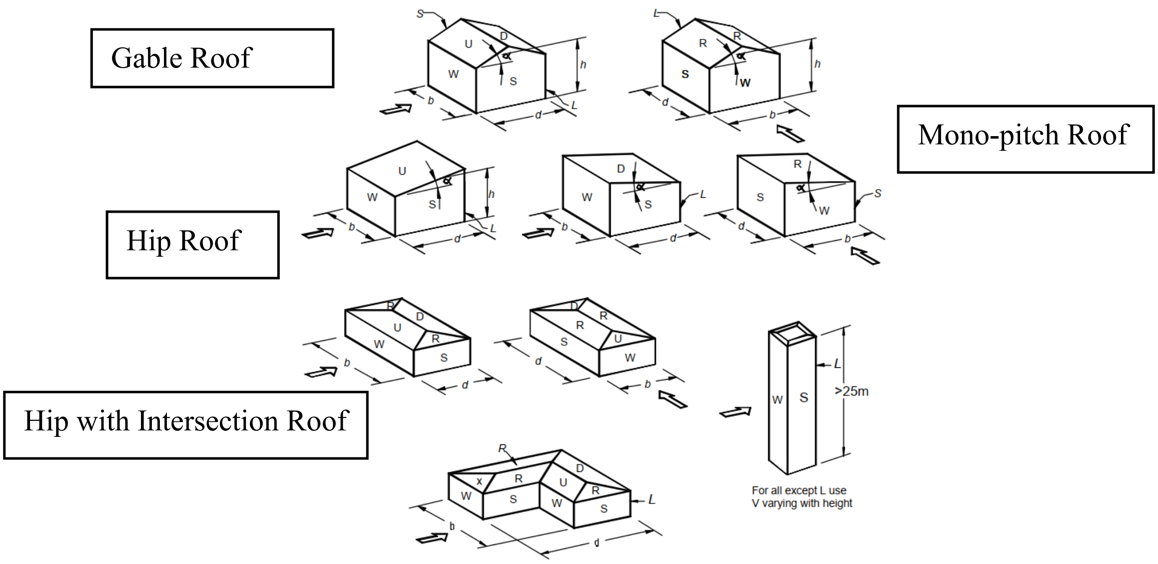

Figure 1.6:Common roof types of a low-rise building

1.4 Objectives

The objectives of this research are listed as below:

1. To evaluate the distribution of pressure coefficient along the profile of a low-rise building with a gambrel roof.

2. To determine net pressure acting across the overhang roof.

3. To evaluate the effect varying the gambrel roof pitch for low-rise houses.

1.5 Scope of Study

This research examines the distribution of pressure coefficient (*Cp*) and streamlines pattern for a low-rise model on single and combination terrain features. In the case of a level terrain, the impact of modifying the slope angle of the combined upstream and downstream terrain is examined. It is vital to analyse because the existence of an overhang at the roof structure affects the net pressure operating over the roof structure. The 2-D numerical simulations are carried out with the assistance of ANSYS Fluent 14 and the Computational Fluid Dynamics method.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In Malaysia, the magnitude of the devastation caused by the wind is not yet known. On the other hand, in the year 2022, there were a number of reports of windstorms around the nation. This may occur as a result of the changing climate throughout the world. As a direct effect of climate change, Malaysia is seeing a much higher frequency of windstorms that are not typical for the region (Majid *et al.,* 2012). As a direct consequence of this, inadequate thought was put into the planning, design, and construction of roof structures that could withstand a windstorm.

According to prior research conducted by Wan Chik et al. (2014), Malaysia has seen 74 windstorms and has caused million-ringgit losses. The roof pitch and slope have an impact on the forces that the roof will encounter. Most of the damage occurred on the roofing system, and the occurrence is associated with the formation of high local suction and high-pressure fluctuations around the proof structure. According to Ozmen et al. (2016), a 15° roof pitch creates higher critical suction on the roofs than gable roofs with 30° or 45° roof pitches. Figure 2.1 illustrates the air flow pattern around building of a low-rise building with gable roofs models with smoke wire technique

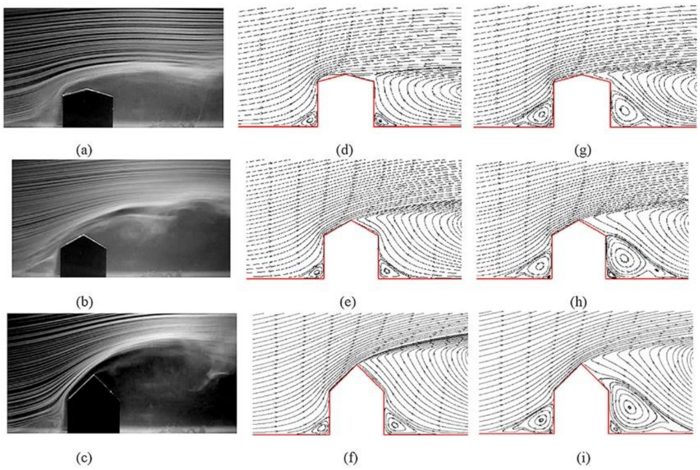

Figure 2.1:(a,d,g) roof pitch of 15°, (b,e,h) roof pitch of 30°, (c,f,i) roof pitch of 45°. *(Ozmen et al., 2016)*

2.2 Wind Disaster in Malaysia

The Southwest Monsoon and the Northeast Monsoon are the two monsoon seasons that Malaysia experiences on an annual basis. These monsoon seasons typically last from late May to September and from October to March, respectively. According to reports, the Northeast Monsoon is responsible for more precipitation than the Southwest Monsoon (Suhaila *et al.,* 2010). On Malaysia, the basic wind speed is defined as the peak gust wind speed recorded at 10 metres above ground level in open terrain that has a properly uniform long fetch in all directions. This measurement is taken at the same altitude as the ground level. (MS 1553:2002). The recent report from the Malaysian Meteorology Department (2017) indicates that the typical speed of a gust of wind is three seconds. Nevertheless, during the Northeast Monsoon, steady winds of 10 to 20 knots (5.2 to 10.3 m/s) prevail. The wind over the east coast states of Peninsular Malaysia may reach 30 knots (15.4 m/s) or higher during this time, with significant surges of cold air from the north. During this time, there are also significant surges of cold air from the north (Nizamani *et al.,* 2018). This specific monsoon has a considerable effect on the northern section of Peninsular Malaysia, in especially on rural regions with open terrain like paddy fields (Wan Chik *et al.,* 2014) and waterbodies. The influence of wind on low-rise buildings distributed around the area may generate severe and/or extended loads on low-rise structures, both of which can be hazardous to the structure and the people living in it. Wind can also cause damage to low-rise buildings (Bresowar *et al.,* 2016). Figure 2.2 shows Bernama report on an event involving a windstorm disaster in Dengkil, Selangor on February 21, 2021, which caused a tree to collapse and damage to 20 cars underneath it.

Figure 2.2:Tree fallen on 20 cars underneath it in Dengkil, Selangor

Bachok et al. (2012) did a research on the frequency of windstorms from the years 2000 to 2012, during which time they found that the frequency changed substantially from year to year. It's possible that this is because to changes in the climate on a worldwide scale, which have led to a rise in the frequency of erratic windstorms in Malaysia. In 2009, there were 110 windstorms, which is the most number ever recorded; the year 2003 had the fewest number of windstorms ever recorded. The progression of windstorm occurrences is seen in Figure 2.3. This graph indicates that windstorms are something that happens on an annual basis in Malaysia.

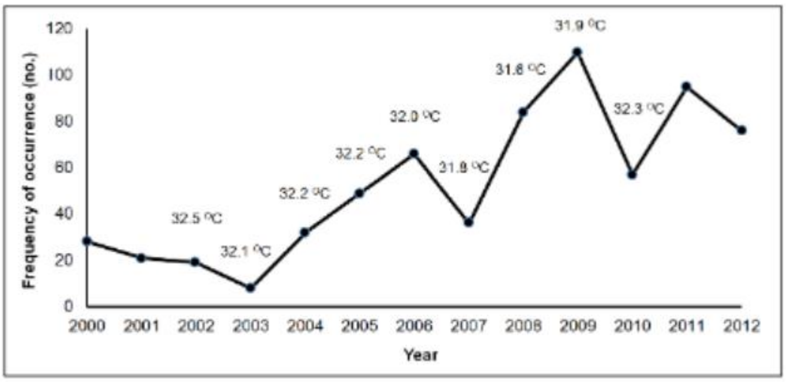

Figure 2.3:Frequencies of windstorm in Malaysia from 2000 until 2012 (Bachok *et al.,* 2012)

In addition, based on data obtained from Disaster Research Nexus (DRN) and Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang from 2009 to 2012 shows that most of the windstorm damages occurs in Northern side of Peninsular Malaysia. Figure 2.4 shows the graphical data of windstorm and damages occurrences in Malaysia from 2009 until 2012. Based on the figure, Perlis and Kedah that encounter the most damages due to windstorm in 2010 and 2009.

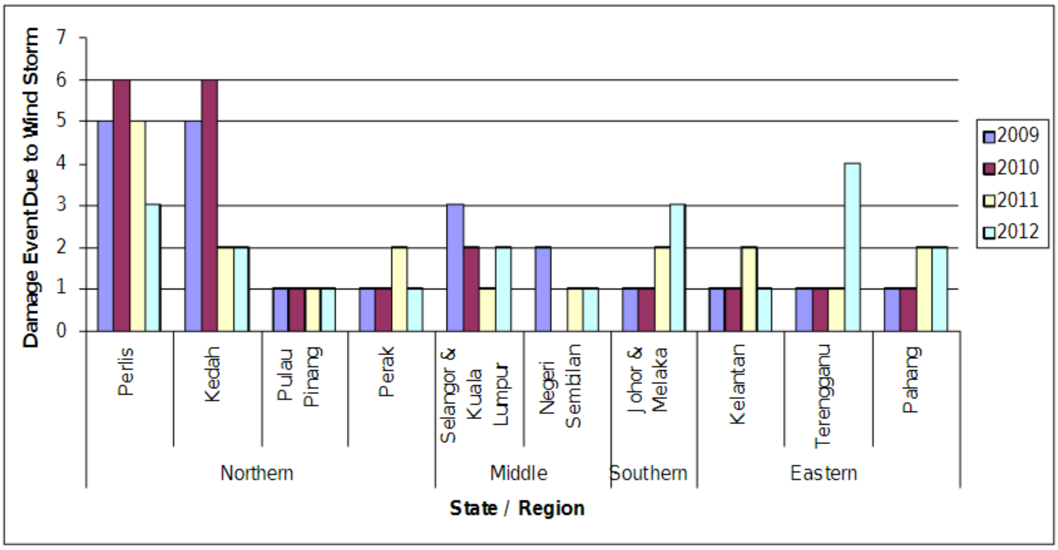

Figure 2.4:Statistic of damage due to windstorm for Peninsular Malaysia from Jan 2009 until June 2012 (Majid *et al.,* 2012)

2.3 Factors Affecting the Wind Induced Damages

One of the most important factors that plays a role in the degradation of roofs is the kind of roof that is on the building. Overhang, roof pitch, roof geometry interference, and surrounds are some of the factors that have been the focus of a number of different research projects that have been conducted on the subject of wind flow around low-rise structures. Wind load studies on low-rise structures were made somewhat more difficult as a result of the influence of a number of different elements (Irtaza *et al.,*2015). On low-rise buildings, the form of roof that is most often encountered is called a gable roof. A gable roof is the name given to the section of a wall that is triangular in shape and is located between the boundaries of crossing roof pitches. Gable roofs may be troublesome in areas with heavy wind, particularly if the structures that support them are of low quality. Winds may generate uplift pressures under a roof if there is an overhang, which can result in the roof being detached from the walls and the materials being blown away from the building. On the other hand, hip roofs are more reliable than gable roofs in terms of stability. Hip roofs are distinguished by their four inward-sloping sides, which contribute to the roof's increased stability and longevity. The slope of the roof will allow any water that accumulates there to simply run off.

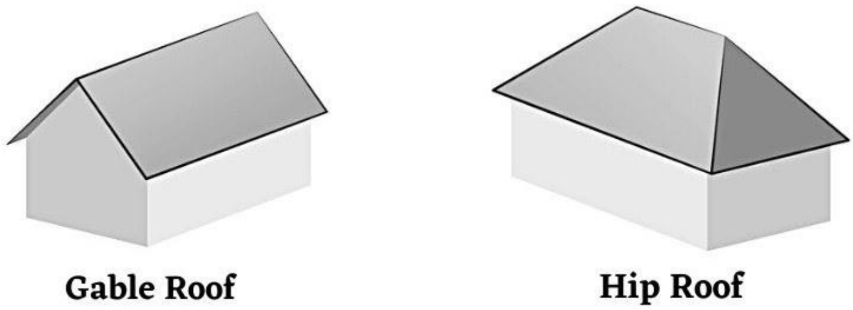

Figure 2.5:Gable roof and hip roof

Overhang has a significant impact on the wind load on roofs. The effect of overhang was revealed in a study conducted by Narayan and Gairola (2010) utilizing the Boundary Layer Wind Tunnel Test. The effect of roof pitches vs varied overhang lengths is the topic of this research. The windwars eaves may be highly loaded due to the variation on the lower eave surface, which promotes the high suction on the upper eave surface soon after separation flow, they reported. Peak pressure coefficients for overhang zones are much greater for roof slopes of 10^0.

According to Ahmad and Kumar (2002b) and Tominaga *et al.,* (2015) the roof pitch has a significant impact on the surrounding flow. The influence of roof pitch has been studied extensively using both numerical and experimental simulations. Ahmad and Kumar (2002b) studied at how different roof pitches affected wind pressure distribution. Seven different hip roofed building models (10^0, 15^0, 20^0, 25^0, 30^0, 35^0 and 40^0) were tested. The experiment was conducted in a wind tunnel. According to the findings, the 40^0 roof pitch produced the most suction at the roof corner of the seven roofs evaluated. As a result, steeper roofs result in higher roof suctions.

2.4 Wind Flow Surrounding a Low-rise Building

The wind flow surrounding across building model is subjected to upstream wind as shown in Figure 2.6 (Liu,1991). Recirculation region was formed between windward wall and ground. Recirculation of air flow within this vicinity is also known as standing vortex (Kutter *et al,* 2017).

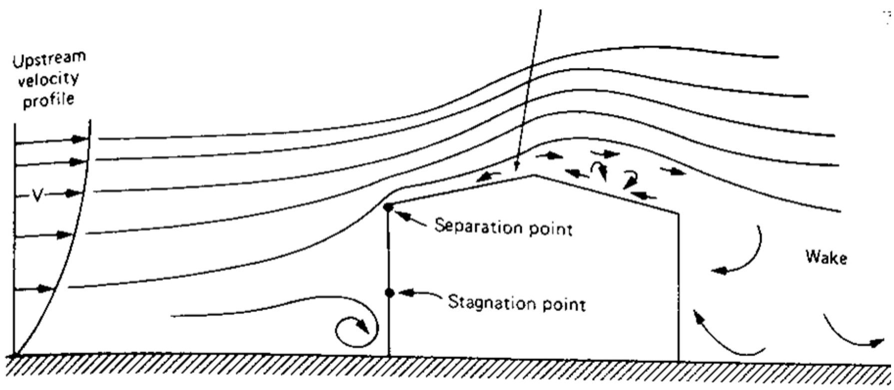

Figure 2.6:Pressure Distribution around a Low-rise Building (Liu,1999)

As the flow approaches the ridge on the windward side, a separation zone forms near the surface of the roof due to the development of backflow. Generally, the air pressure at the separation zone is lower than the ambient pressure, resulting in suction fluctuations. Behind the leeward wall, a wake or vortex (pocket of flow trailing a building) forms, causing suction on the surfaces in this region.

The influence that pressure and suction have on a structure is commonly represented by the local mean pressure coefficient, which is denoted by Cp . The pattern of pressure distribution that is often seen along the transverse profile of a low-rise structure is shown in Figure 2.7. A surface is said to be experiencing negative pressure (also known as suction) when the wind is blowing away from it, whereas positive pressure implies the opposite. Many researchers have decided to focus their efforts on increasing the amount of suction rather than increasing the amount of pressure that is exerted on the roof. This is owing to the fact that intense suction has the potential to harm the structure (Baskaran *et al.,* 2007; Lin *et al.,* 2008; Silva *et al.,* 2010).

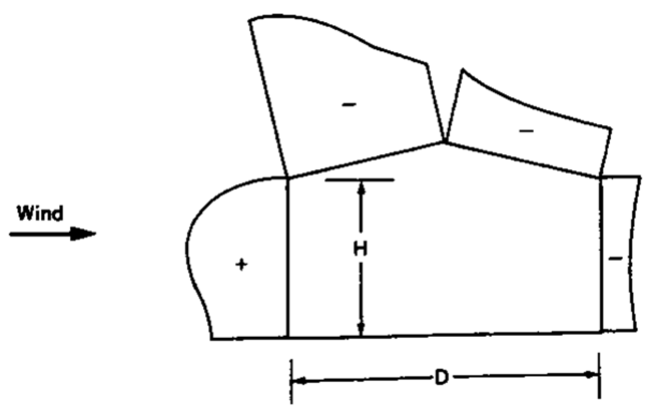

Figure 2.7:Pressure Distribution around a Low-rise Building (Liu,1999)

As can be seen in Figure 2.8, the point on the roof that has the greatest amount of -*Cp* is located at the ridge of a low-rise gable roof structure that has a steep slope. (Tominaga *et al.,* 2015). In addition to this, the majority of the windward roof's regions that had higher slopes presented a +*Cp* value (Tominaga *et al.,* 2015; Liu, 1991).

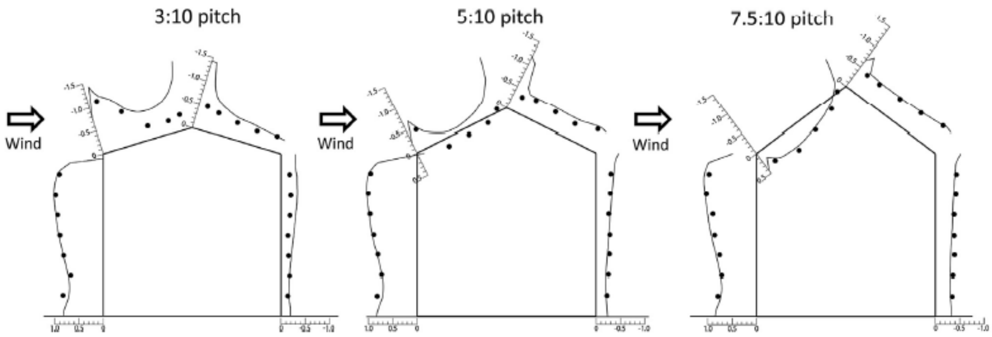

Figure 2.8:Distribution of pressure coefficient for an isolated low rise building with varying roof pitch (Tominaga *et al.,* 2015)

A stagnation point is defined as the maximum pressure being formed before the wind is deviated to four mainstreams which have lower pressure zones (Abohela *et al.,* 2013; Murakami and Mochida, 1998), namely:

i. The first stream is deviated over the building
ii. The second stream is deviated down the windward façade
iii. The other two streams deviate to the two sides of the building

A stagnation point formed in the middle of the windward surfaces at the height of approximately 0.7H (H= height of the building model). Figure 2.9 shows the location of stagnation point and wind stream.

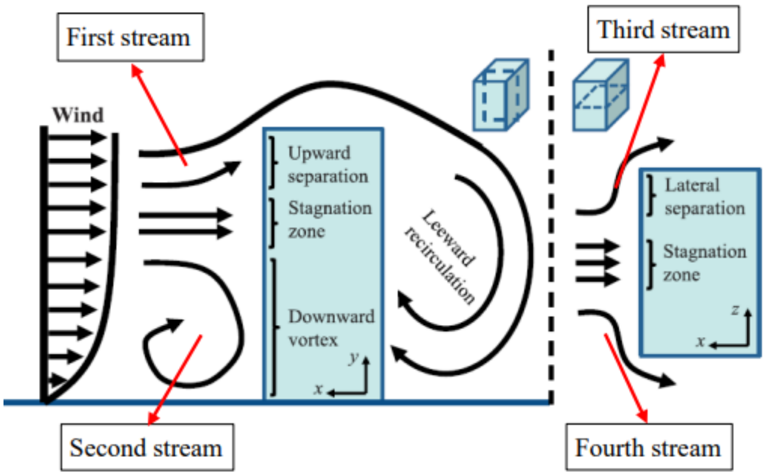

Figure 2.9:Air Flow Surrounding Rectangular Building (Jin *et al.,* 2015)

2.5 Type of Wind Analysis

Performing an analysis of the wind may be done using either an experimental or a computational technique. In contrast to airbox and other types of tests conducted on a smaller scale, wind tunnel testing is often carried out as part of the research process. In the meanwhile, the computational technique often included the use of software like that used for Computational Fluid Dynamic simulations.

2.5.1 Wind Tunnel Test

A wind tunnel is a device that is used to investigate the effects of air flow passing through or around an item. Studies of aerodynamics, such as those conducted in the aerospace industry, the automotive industry, and the construction of tall buildings, typically make use of wind tunnels as an instrument. According to Geurts and Bentum (2007), essentially current design coefficients are based on wind tunnel tests. [Citation needed]

The Atmospheric Boundary Layer (ABL) wind tunnel is used during the majority of the investigation. This kind of wind tunnel has a test chamber that is large enough to accommodate a scaled-down replica of the building that is being evaluated together with its surroundings. Roughness components are positioned upstream of the structure being evaluated in order to provide an environment that is an accurate representation of the required wind profile. Figure 2.10 presents a photograph of the test chamber of an ABL wind tunnel. In addition, Zaini et al. (2008) claimed that they were able to successfully employ another form of wind tunnel called as an educational wind tunnel to examine the flow of air around a low-rise home (refer to Figure 2.11).

Figure 2.10:Atmospheric Boundary Layer Wind Tunnel (Matuella *et al.,* 2016)

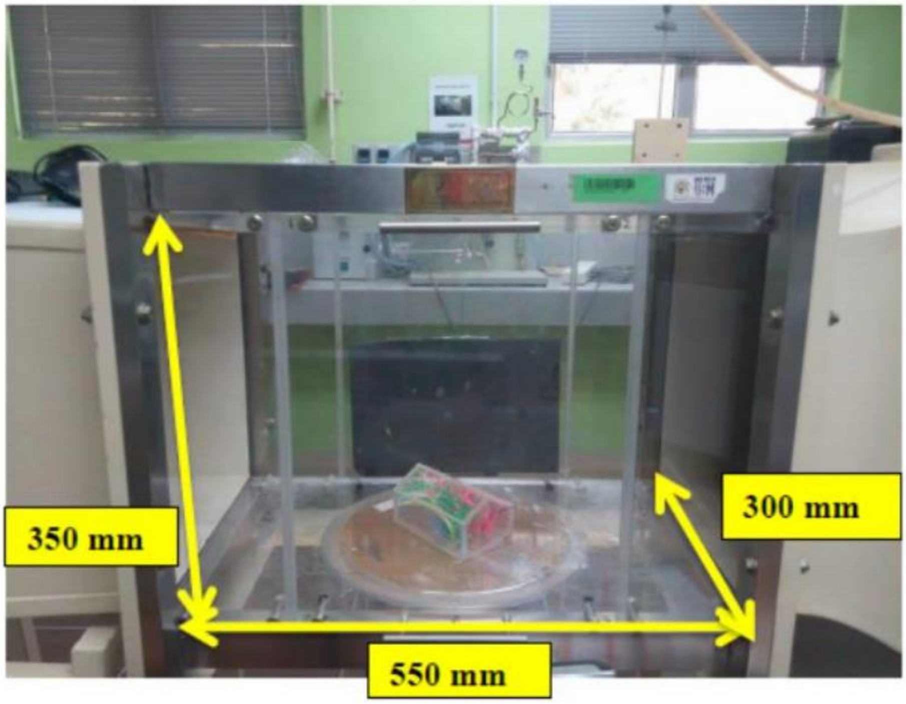

Figure 2.11:Educational Wind Tunnel (Zaini *et al.,* 2018)

2.5.2 Computational Fluid Dynamic

In today's world, computational fluid dynamics (CFD) simulations have become the go-to method for investigating the flow of wind around structures (Silva *et al.,* 2018). The cheap operating costs, the flexibility to choose from a broad variety of shapes, and the significant amount of time savings offered by a CFD approach are all advantages of using this method. CFD, on the other hand, needs an in-depth grasp of the applicability range and the limits in order to function properly. This is due to the numerical approximations and assumptions that are incorporated within the method. The Direct Numerical Simulation (DNS), the Large Eddy Simulation (LES), and the Reynolds-Averaged

Navier-Stokes (RANS) equations are the three methods that are used by Computational Fluid Dynamics, often known as CFD, to provide predictions about turbulent flows.

The RANS k-ε turbulence model may be used to provide predictions about the turbulent flow that will occur in CFD while analysing a low rise building. Dhunny et al. (2017) investigated the flow of wind through very challenging terrain for the purpose of selecting places for wind farms. They found that the RNG k- turbulence was able to satisfy the second order convergence criteria, which were determined by the convergence rate and index. In addition, Liu and Niu (2016) discovered that the RNG k- model exhibited a higher performance on the accuracy prediction of flow field and concentration diffusion in the wake zones than the Standard k- model and the Realizable k- model. This was found to be the case after comparing the RNG k- model to both of the aforementioned models. In a similar vein, (Tominaga *et al.,* 2015) stated that the numerical findings demonstrate that the Realizable k- turbulence model exhibited superior agreement at the prediction of mean velocity and turbulence kinetic energy in comparison to other turbulent models. This was stated in reference to the fact that the model was able to more accurately predict mean velocity and turbulence kinetic energy.

2.5.3 Turbulence Model

The computational fluid dynamics (CFD) approach is an effective tool for simulating the turbulent flow and pollutant dispersion around buildings. There are several other options available outside CFD, such as stable RANS, URANS, LES, and a hybrid URANS/LES model. Details in the geometrical representation of buildings, the size of the computational domain, the boundary conditions, the computational grid, the discretization schemes, the initialization of data, the time step, and iterative convergence criteria are all being considered in order to select the model for simulation that will prove to be the most effective (Blocken *et al.,* 2012).

When it comes to computational fluid dynamics (CFD), one of the most important decisions to make is which turbulence model to use in order to describe the physics of the flow field. The Reynolds-averaged Navier Strokes (RANS) model approach is one that is often used for practical engineering computations due to the fact that it is both straightforward and effective. The RANS equations are a kind of transport equation that models turbulence on all scales, however they only describe mean flow values. The amount of work that must be put into computing is drastically cut down when using the tactic of permitting a solution for the mean flow variables. If the mean flow remains the same, then the governing equations do not need to include any temporal derivatives, and it will be possible to implement an economically viable steady-state solution (Fluent, 2001).

Xing et al. (2018) investigated how the presence of several roof slopes affected the mean pressure distributions around single-family homes situated on level ground and subjected to a variety of wind directions. This analysis made advantage of the wind tunnel test facilities that are available. In addition, they used three-dimensional stable Reynolds-averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) turbulent models in their computational investigation. During the course of their experiment, they used all three of these various roof pitches: 1:5, 2:5, and 3:5. The findings demonstrated that the

RANS model had a high degree of concordance with the experimental pressure distribution data. On the other hand, when it came to the prediction of flow fields near buildings, choosing LES over RANS was responsible for a significant improvement. They also suggested, as is shown in Figure 2.12, that the formation of high suction pressures was more essential on structures with a lower roof pitch than on buildings with a higher roof pitch.

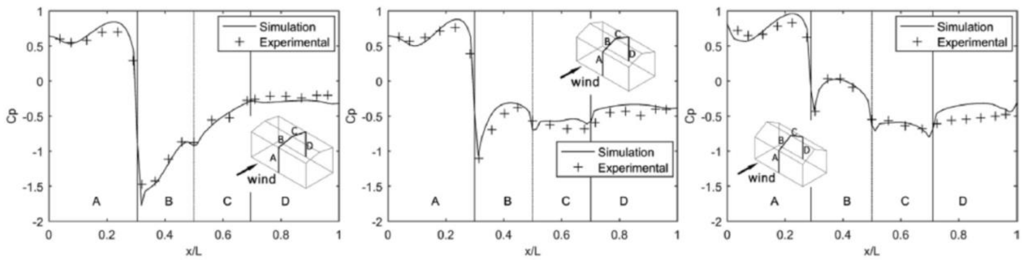

Figure 2.12:Pressure Coefficient comparison results from the simulation and wind tunnel test on buildings under wind direction 90° with a roof pitch of: (a) 1:5, (b) 2:5, (c) 3:5 (Xing *et al.,* 2018)

2.6 Summary

Tables 2.1 provide a summary of previous research effort. Much research have been undertaken utilising Computational Fluid Dynamics models to study the wind effect. The majority of the experiments, however, were conducted in a 3-D environment and primarily evaluated flat terrain conditions. As a result, there is very little information available in the open literature about pressure distribution along a house's wall and roof profile. CFD simulations in a 2-D setting, on the other hand, can be found in many articles, but no attempt has been made to integrate a house model in the research.

Table 2.1:Summary of previous research

No.	Author	Model	Parameter	Method
1	(Tominaga *et al.,* 2015)	Isolated building (gable roof)	Roof pitch (3:10), (5:10), (7.5: 10)	WTT & CFD
2	(Ozmen *et al.,* 2016b)	Gable roof of a low-rise building	Roof pitch (15º, 30º and 45º)	WTT & CFD
3	(Irtaza *et al.,* 2015)	Hip Roof Building	Wind direction (0°, 45° and 90°)	CFD
4	(Liu *et al.,* 2016)	3-D hills and 2-D ridge	Turbulence statistics, power spectrum, and Reynolds stress ratios	WTT & CFD
5	(Zaini *et al., 2018)*	Single Storey House	Different topographic characteristics	CFD
6	(Yahya *et al., 2019*)	Isolated Rural House	Rural House with Kitchen House	CFD
7	(Aly and Bresowar, 2016)	Low Rise Building	Corner Adjustment	CFD
8	(Abohela *et al.,* 2013)	Rectangular Building	Air Flow Surrounding Rectangular Builing	CFD
9	(Blocken *et al.,* 2012)	Decentralized power generation (Complex Hilly Terrain)	Types of topography (irregular hills and valley)	WTT & CFD
10	(Wu *et al.,* 2017)	Rectangular low rise building	Types of terrain	CFD