THE IMPACT OF WIND LOADS ON CURTAIN WALL DESIGN

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By

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FINAL PROJECT REPORT

Submitted to the Civil Engineering Programme
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Universiti Teknologi Petronas
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved:

AP Ir. Dr. Mohd. Shahir Liew
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Munirah Binti A. Jabar

ABSTRACT

Building façade is a major aesthetical feature of a particular building as it sets the theme for the rest of the building. It introduces visitors and passersby to the identity of the building and its characteristics distinguish one building from another. One of the most common features of building façade is curtain wall. It carries its own dead load and transfers the live loads that act upon it. A great knowledge and understanding regarding forces and pressures which the curtain wall is subjected to, may require a major attention when it comes to the design of curtain wall. The primary concern is the dynamic or live loads that induce movement in the curtain wall structure.

Comprehensive analysis of wind pressure acting upon a curtain wall seldom has been practice in Malaysia. Generally, curtain wall design is under the concern of architect whereby the wind pressure distribution acting on curtain wall is not well-predicted. The design is more likely to be carried out based on a uniform wind pressure. On the other hand, the assessment of curtain wall design shall be zoned based on the actual design of known wind codes and standards, which is under the expertise of engineers. This paper reviews and analyzes the impact of wind loads in designing a curtain wall. In addition, it demonstrates an appropriate way in designing the wall glazing with respect to the pressure distribution acting upon the curtain wall.

American Society of Civil Engineers (ASCE) 7-05 provides guidance in designing wind loads for overall stability of a building, which encompasses the design for Main Wind Force Resisting System (MWFRS) and Components and Cladding (C & C). Curtain wall is considered as a cladding system and hence, the analysis of wind loads acting on it shall be done based on C & C procedures.

This paper distinguishes between two (2) approaches of curtain wall design, namely: the proposed method based on the ASCE 7-05 versus the "traditional" method based on the current consultancy practices in Malaysia. Subsequently, the cost impact of both approaches had been analyzed by implementing Parametric Cost Estimate Method.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASCE	American Society of Civil Engineers
C & C	Components and Cladding
MWFRS	Main Wind Force Resisting System

CHAPTER 1
INTRODUCTION

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1.1 Background of Study

Building façade is a major aesthetical feature of a particular building as it sets the character and theme for the rest of the building. It introduces visitors and passersby to the identity of the building and its characteristics distinguish one building from another.

Figure 1 shows a modern type of building façade which is Burj Khalifa, completed in 2010 and formerly known as Burj Dubai. It is the tallest building in the world with a height of more than 800 m and located in Dubai, United Arab Emirates. It has accomplished a world record for the highest installation of an aluminum and glass façade in a timely manner.

The Burj Khalifa was designed by Skidmore, Owings and Merrill (SOM), which is a Chicago-based architectural and engineering firm and has been recognized as one of the largest Architects and Engineers (AE) firm in the world. The Burj Khalifa was designed to maximize human comfort and safety under adverse loading conditions. Extensive wind tunnel testing had been performed to the building in order to allow the tower to resist high wind loads from the Gulf while minimize lateral vibrations, displacement and fulfilling human comfort criteria.

More than forty (40) wind tunnel testing had been conducted to study the wind effects towards the tower as well as its occupants. These include verification of atmospheric boundary layer in Dubai, analysis of structural models of the tower, the responses of façade and so forth.

Figure 1: Burj Khalifa - current world tallest completed building

On the other hand, Kellie's Castle is an example of a classic-ancient type of Victorian building façade shown in Figure 2. Located in Batu Gajah, Perak, it was owned by a Scottish planter, Kellie Smith and was built in 1915 and remains a national heritage until today.

Figure 2: Kellie's Castle in Batu Gajah, Perak

Façade may come in many different types and materials. One of the most important features of façade is the curtain wall. Vigener, PE & Brown (2009) defined curtain wall as a thin framed wall which is usually made from aluminum, containing glass infills, metal panels or thin stone. The framing is attached to the building structure and it does not carry both floor and roof loads of the building.

The design of curtain wall involves a process of designing and selecting the proper materials to be used. Main aspects that shall be considered and properly executed by the designers are comprised of the building's integrity, environmental friendliness and aesthetic appeal. These aspects are to ensure that the building is architectural attractive, structurally sound and energy efficient (Curtain Wall and Façade Design Forum, 2009).

In general, curtain wall systems can be classified in accordance of their method of installation, namely: stick system, unitized system, unit-and-mullion system, panel system and so forth. The two (2) main components of curtain wall are frames and infills. Infills or better referred as glazing is made from various materials like glass, stone veneer as well as metal panels. Glass is the most prevalent infill used in curtain wall design due to its versatility. It can be made into many shapes and colors in order to fit with the design requirement. Resistance of glass with respect to loads impose on it decreases with age, load duration and with increasing area (Dalgliesh, 1998). Its strength also can vary widely within a set of identical specimens.

Curtain wall carries its own dead load and transfer ambient live loads that act upon it. Apart from acting as a frontage of a particular building, curtain wall shall be designed to withstand all loads imposed on it as well as to keep air and water from penetrating into the building interior.

The dead load of curtain wall is made up of the weight of the structural elements which consist of the weight of the mullions, anchors, infill materials and other structural components. Aside from seismic load, thermal load and blast load, the wind load that imposed on the curtain wall acts as a main contributor in designing a curtain wall.

1.2 Problem Statement

A well-designed curtain wall with attractive glazing is definitely remarkable aesthetically. Nevertheless, the aesthetic characteristics are just one of the remarkable attributes of curtain wall. A great knowledge and understanding regarding forces and pressures which the curtain wall is subjected to, may require a major attention when it comes to the design of curtain wall. The primary concern is the dynamic or live loads that induce movement in the curtain wall structure.

Many building failures are associated with failure of the curtain wall due to high pressure of wind. In many situations, glass shattering cause enormous damage to the surrounding of a particular building, which in a worst case could cause death of inhabitants. Thus, loss of lives is a typical risk and exposure to the vicinity of the building when the curtain wall fails. Figure 3 and Figure 4 illustrate some of building failures due to high wind pressure.

Figure 3: Building failure, adopted from "Design Consideration for Withstanding Hurricane Forces" by Bennardo

Figure 4: Window failure, adopted from "Design Consideration for Withstanding Hurricane Forces" by Bennardo

Smith (2009) had described in Whole Building Design Guide (WBDG), the types of building component damages that typically experience by buildings due to impact of wind pressure. Followings are the types of damage in descending order of frequency of occurrence:

- Roof covering damage – including rooftop mechanical, electrical and communications equipment, as illustrated in Figure 5.
- Exterior wall covering and soffits.
- Structural damage – is the number one type of damage during strong tornadoes. Some of the examples include the collapse of exterior bearing walls or major portions, or collapse of the entire building.

Figure 5: Roof covering damage

The consequences of the above types of damage include:

- Property damage. Some might require extensive repair or replacement of the damaged components or replacement of entire facility. This would in return affect financially.
- Interrupted use. Due to the property damage, it can take days, months or even more than a year to repair or replace the damage. The duration of the repair is depending on the magnitude of the wind.
- Injury or death. Building occupants or people in the vicinity of the building could get injured or killed when struck by collapsed building components. Apart from that, debris such as roof aggregates, HVAC equipment, or wall coverings blown from office could damage automobiles and other buildings in the vicinity of the building.

Hence, the behavior and complexities of wind pressure should be kept in mind when designing a building as well as its cladding system. Nevertheless, comprehensive analysis of wind pressure acting upon a building, precisely on curtain wall is seldom practiced in Malaysia. Generally in Malaysia, curtain wall design is under the concern of architects whereby the wind pressure distribution acting on the curtain wall is not well-analyzed. In the United States, the assessment of curtain wall design is zoned based on the actual design of known wind codes and standards which is under the scope and preview of engineers.

As the wind pressure varies with height in accordance to the power law or logs law, the characteristics of a curtain wall design vary as well. Poor understanding of this aspect has cause an inefficient design of a curtain wall.

One of the important aspects in designing curtain wall is the determination of the glazing thickness with respect to the wind pressure distribution. In Malaysia practices, architects are more likely to design the thickness based on a uniform wind pressure. This action will eventually cause an uneconomical and non-optimize design of curtain wall. Thus, this project presented herein will emphasize on the importance of the wind pressure variation towards the design of curtain wall.

1.3 Objectives

The objectives of this project are as follows:

1) To understand the effects of the wind atmospheric boundary layer on curtain wall design.
2) To provide in-depth perspective on the treatment of external and internal pressure coefficients towards the components and cladding of buildings.
3) To compute the dimensions of curtain wall due to wind pressure using advent rational method proposed by the American Society of Civil Engineers (ASCE) 7-05, which generally considered an advanced method in wind engineering.
4) To compare the economics of curtain wall design based on the proposed scientific method versus the "traditional" practices in Malaysia.

1.4 Scope of Study

The scope of study encompassed the following:

1) Familiarize with the fundamental knowledge of wind loads and its impact towards the design on curtain wall. This was attained from various reading sources.
2) In-depth understanding of wind loads design for a high rise building with the guidance of ASCE 7-05 and the examples of calculation which were adopted from the Malaysian Structural Steel Association (MSSA) ongoing training for practicing engineers, prepared by AP Ir. Dr. Mohd. Shahir Liew.
3) Design and compare the wind pressure for a known dimension of a building using detailed analysis of ASCE 7-05 versus the "traditional" practices in Malaysia.
4) Design the curtain wall and compare the economic impact, based on detailed analysis of ASCE 7-05 versus "traditional" practices in Malaysia.

CHAPTER 2
LITERATURE REVIEW

2.1 Background of Study

Development of modernized curtain wall system came into attention during the year 1911 whereby the Fagus Factory, a shoe factory located in Alfed an der Leine in Germany was constructed, as illustrated in Figure 6. This example of façade was designed by renowned German architect, Walter Gropius together with his employee, Adolf Meyer. Even though Gropius and Meyer only designed the facade, the glass curtain walls of this building demonstrated the modernist principle that form reflects function.

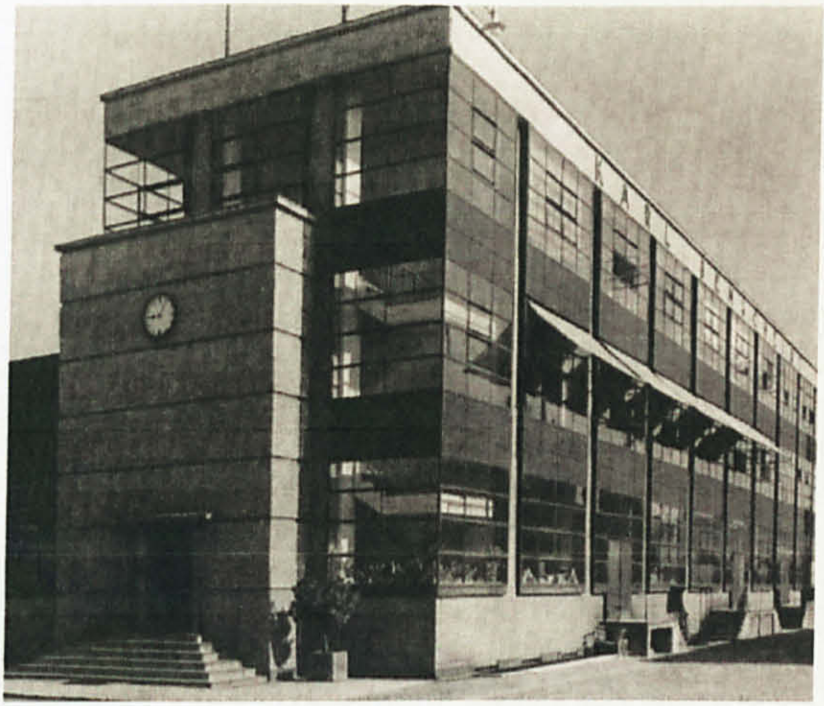


Figure 6: Illustration of Fagus Factory (1911-1925) at Alfed an der Leine, Germany

Another example of historic design of curtain wall is the Hallidie Building, as illustrated in Figure 7, which is an office building located in San Francisco. It was credited as the earliest building to feature glass curtain wall. It was built around 1917-1918 and designed by an American architect, Willis Polk.

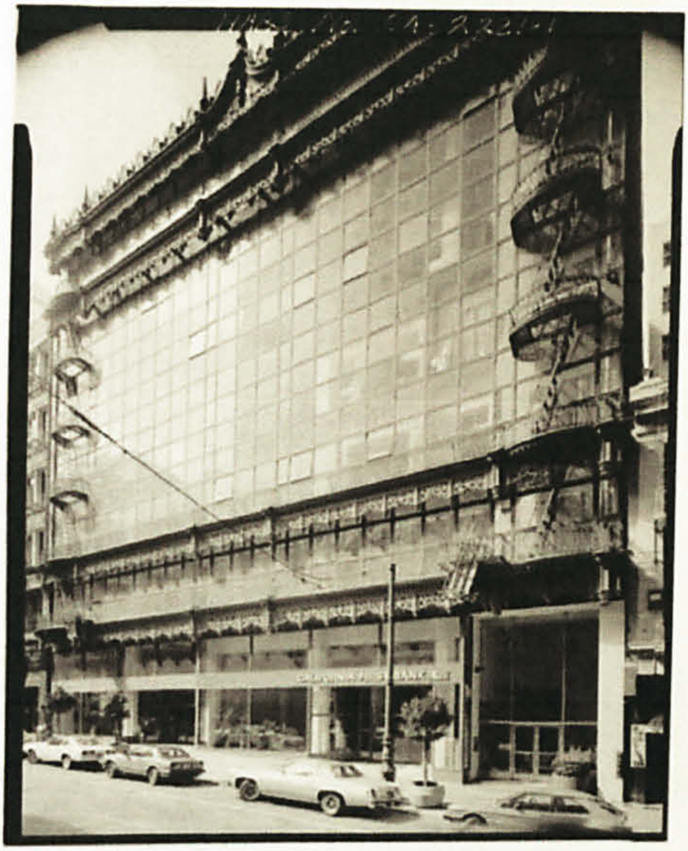


Figure 7: Illustration of the Hallide Building (1917-1918) in San Francisco

In these days, curtain wall design is far more sophisticated and challenging. Nevertheless, the basic principles of high quality curtain wall system have not changed. As these principles have grown with experience and time, the curtain wall industry has continued to improve its performance and reliability.

2.2 Nature of Wind

Wind is a term used in conjunction of movement of air. It consists of huge array of eddies with different sizes and rotational characteristics which move along the earth's surface. These eddies produce gusty or turbulent behavior. Thus, wind and wind gust are totally different parametrically.

Wind speed tends to vary with different heights in accordance with power law. A retarding effect occurs in the wind layers near the ground, which is affected by frictional drag of the air stream over the terrain. At greater height above ground, the frictional effects are reduces and eventually will become negligible at certain height, as shown in Figure 8, with different terrain roughness value, z_o.In a nutshell, we can say that wind speed increases with height above the ground.

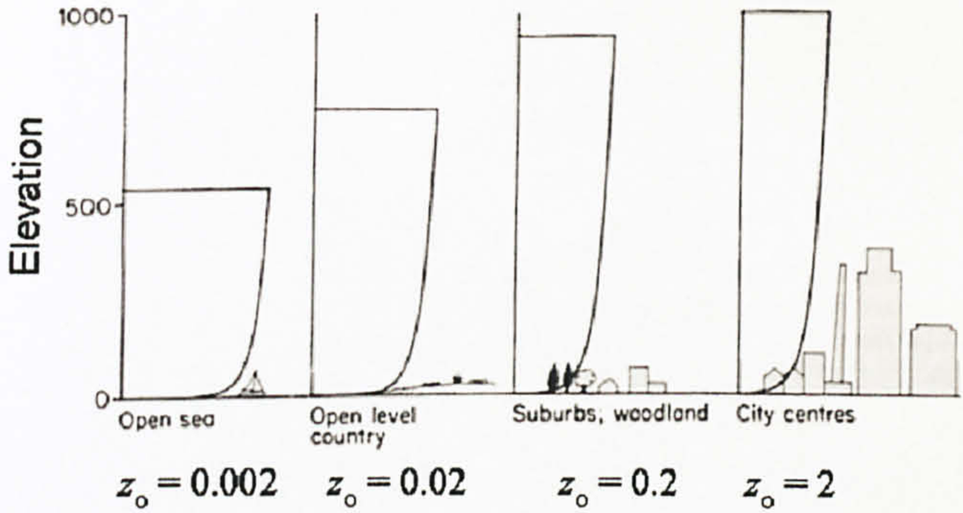


Figure 8: Mean wind profiles for different terrains, adopted from "*Wind Loading on Tall Buildings*" by Mendis et al. (2007)

The height at which velocity ceases to increase is called the gradient height, and the corresponding velocity is the gradient velocity (Taranath, 2005). The height in which the wind speed is affected by the surface terrain is known as atmospheric boundary layer.

2.3 Design of Wind Loads – Types of Wind Design

The behavior of wind pressures on a particular building depends on the characteristics of the approaching wind, the geometry of the building under consideration and the proximity of the structures upwind (Mendis et al., 2007). The pressure is not steady and fluctuates in time due to the gustiness of the wind. It is also because of the local vortex shedding developed at the edges of the buildings. This fluctuation can result in fatigue damage to the building and in dynamic excitation, if the building happens to be dynamically wind sensitive. The wind pressure also is not uniformly distributed over the surface of the building, but vary in position.

Generally, wind sensitive buildings shall consider these three (3) basic wind effects:

2.3.1 Environmental Wind Studies

This study is use to investigate the wind effects on surrounding environment due to the erection of a particular building. It is also important to assess the impact of wind on pedestrians, vehicles and architectural features within the vicinity of the building.

2.3.2 Wind loads for façade

In order to design cladding system for a building, the assessment of design wind pressures throughout the surface area shall be done. According to Mendis et al. (2007), wind tunnel testing is used to assess design loads for cladding which is now a normal industry practice in the aim to minimize initial capital costs and more significantly, to avoid expensive maintenance costs associated with malfunctions due to leakage and structural failure

2.3.3 Wind Loads for Structures

This consideration is to determine the design wind load for designing the lateral load resisting structural system of a particular structure in order to satisfy various design criteria.

2.4 Interaction of Wind Loads with Buildings

Generally, wind pressure exerted on a structure would depend on the speed of the wind as well as the interaction between the air flow and the structure (Dalgliesh & Schriever, 1968). The distribution of wind pressures and suctions over a building depends on how it disturbs the air flow.

When wind strikes a face of a building (windward face), the air flow in line with the building is forced to diverged and pass around the edges, as shown in Figure 9. This will eventually cause the direction and the magnitude of the original wind velocity to be changed and thus will alter the wind pressure. It is found that the stagnation pressure is produced near the center of the building with increasingly steep pressure gradient towards the edges of the building.

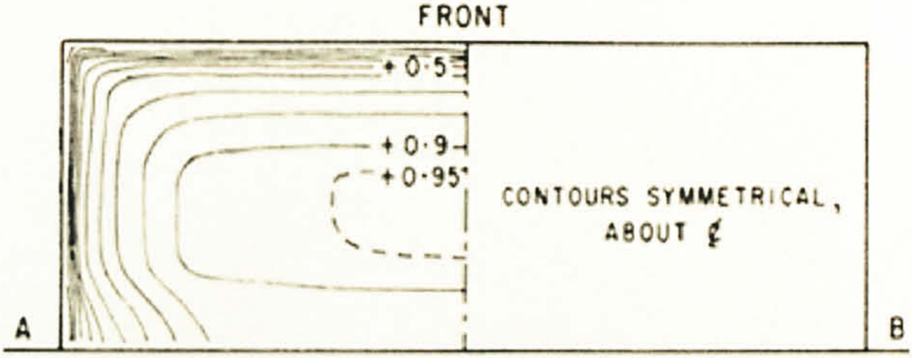


Figure 9: Example of pressure contours and coefficients on a wall at right angles to wind direction, adopted from "*Wind Pressure on Buildings*" by Dalgliesh & Schriever (1968)

In comparison with the wind behavior behind the building (leeward face), the air flow is unable to combined together immediately due to the inertia of the air and create a wake region. Air from this region will be "suspended" by the fast flow lines and thus, creating "suction", resulting negative pressures as shown in Figure 10.

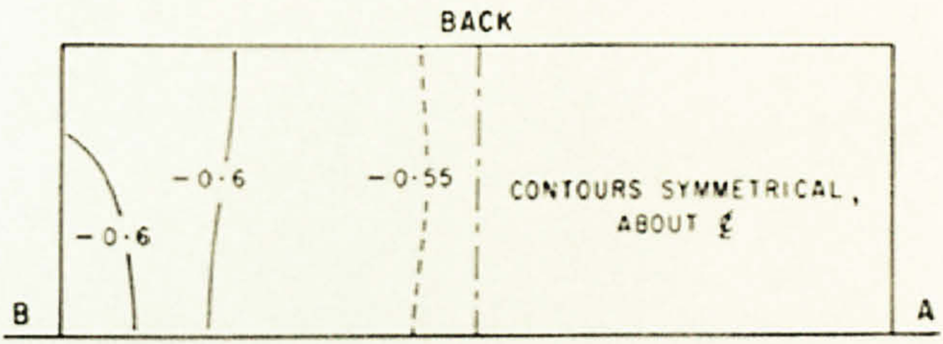


Figure 10: Example of pressure contours and coefficients on a leeward face of a wall, adopted from "*Wind Pressure on Buildings*" by Dalgliesh & Schriever (1968)

2.5 Variables Affecting Pressure Distribution

As discussed in Section 2.2, wind speed tends to vary with height above ground. Aside from that, there are some other variables that would affect the wind pressure distribution. Some include:

- **Building Region and Shape**

  Wind pressure acting on certain regions of a structure is rather sensitive than the others. For instance, the wind pressure acting on roof is remarkably greater than the wind acting on windward face of a building. Aside from that, the suction on the windward roof slope vary considerably with the slope of the roof, the ratio of height to width as well as the ratio of width to length of a building (Dalgliesh & Schriever, 1968). Shape details such as parapet walls and large chimneys may also contribute to the wind pressure distribution.

- **Openings**

  Generally, building types with regard to openings can be segregated into three (3) types, namely: open building, fully enclosed building and partially enclosed building. The size and location of openings (windows and doors) would influence the determination of internal pressure of a building. The values of internal pressure tend to exceed the values appropriate to the exterior of the wall in which the openings predominate.

- **Wind Direction**

  The effect of wind is not only depending on the magnitude of the wind speed, but also the corresponding wind direction as well. It is associated with the direction of where it originates. The wind pressure distribution is affected by the orientation of a building towards the direction of wind, particularly at near the leading edges of roofs where the suction pressure is considerably high.

- **Shielding**

  Shielding contributed by other buildings, trees and structures in the vicinity of a particular building would disrupt and interfere the wind flow acting on the building. These neighboring structures may either increase or decrease the flow-induced forces on the building, depending on some other considerations such as the geometry of these structures, the orientation with respect to wind direction of wind and upstream terrain conditions (Khanduri et al., 1996)

2.6 The Impact of Wind Pressure on Curtain Wall Design

"The design of a building and its cladding system is very much a function of the extreme wind induced pressures that are expected to occur within its lifetime. These pressures therefore have a significant impact on the cost of the structure" (Smith, 1994).

In order to have a rational and effective design of a building and its façade, it is important to have a good knowledge of wind pressures acting on it. ASCE 7-05 provides guidance in designing wind loads for overall stability of a building, which encompasses the design for Main Wind Force Resisting System (MWFRS) and Components and Cladding (C & C).

ASCE 7-05 defines MWFRS as "assemblages of structural elements assigned provide support and stability for the overall structure. The system generally receives wind loadings from more than one surface." Thus, the MWFRS loads are the assembly of elements that transfer loads acting on the structure to the ground (Dexter, 2009).

In building construction, cladding acts as a control element which provides a layer or skin to manage the infiltration of weather elements, aside from providing aesthetical purposes. It is basically a process of applying one material over another. ASCE 7-05 defines C & C as "elements of the building envelope that do not qualify part of MWFRS."

Components receive wind loads from cladding and will be transferred to MWFRS. Some of the examples of components are fasteners, purlins, studs and roof trusses where as claddings include wall covering, curtain wall, exterior windows and doors and roof coverings.

2.7 Wind Tunnel Test

There are many situations where assessments of wind loads cannot be done purely based on analytical method where wind tunnel test is deployed. While this adds to the design cost, it has been proven to be cost effective in most cases. It provides a solid basis for the design that may affect savings over analytical method (Nashed, 1996).

It is particularly useful for structures with complex shape resulting in complex wind flows and patterns where by determination of wind forces using code provision is inadequate. This is allowed in the code when analytical procedures cannot adequately when complex shape.

Wind tunnel testing provides detailed study of the natural effect of wind on a particular structure. Some of the aspects that can be determined from the wind tunnel test include the effects of boundary layer profiles that are a function of land terrain, the pressure distribution on the buildings as related to vortex shedding and flow separation, the dynamic response of the building and loads on cladding (Smith, 1994).

2.8 Types of Curtain Wall

Curtain wall is generally classified based on the method of installation. Some include stick system, unitized system, panel system, rainscreen principle and so forth. Figure 11 show several types of curtain wall installation.

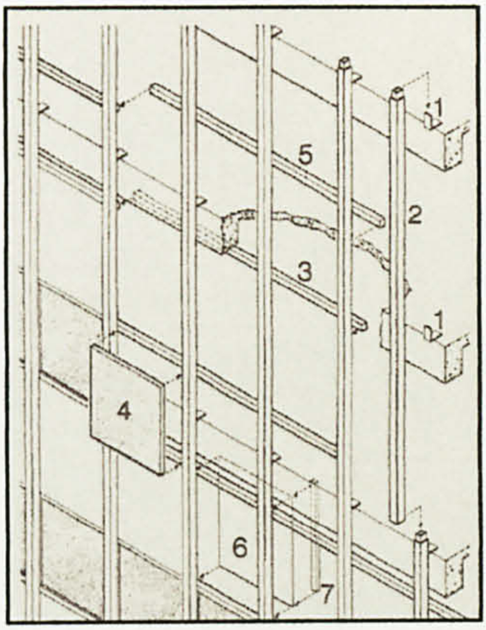
With the changing design philosophies and economics, more sophisticated types of curtain wall are available in the market. However, the most common types of curtain wall are stick system and unitized system, which further discussed as follows:

- **Stick System**

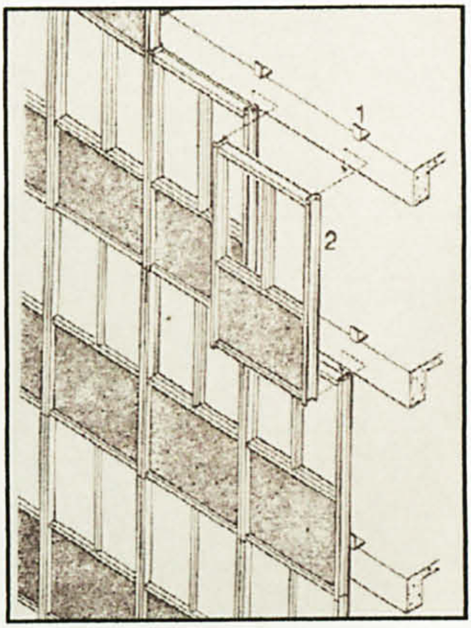
  It is among the earliest technology of curtain wall installation, where by the wall is installed in pieces which referred as 'sticks'. In general, the mullion members (vertical members) are installed first followed by the horizontal rail members. Finally, the glazing or window units will be positioned. Even though it was used extensively in early years, this type of curtain wall is still widely used in greatly improved versions (Wong, 2007). Unit-and-mullion system as well as column cover and spandrel system, also implement this type of installation method.

- **Unitized System**

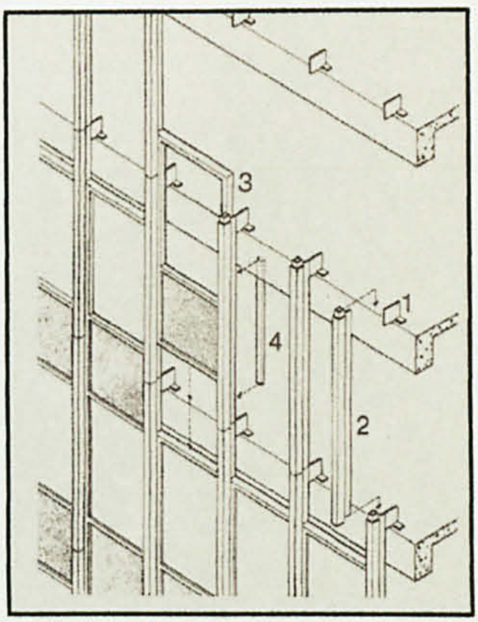
  The components of the curtain wall (for instance, the glazing and aluminum framing) are fabricated and assembled in factory. The completed units are hung on the building structure to form the building enclosure. Unitized system offers various advantages such as; quality control in assembling the components, lower cost in field installation as well as speed up the site construction time.



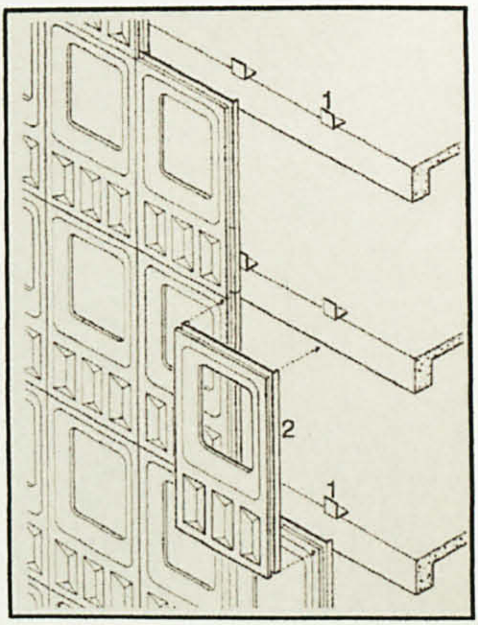
(a): Stick System



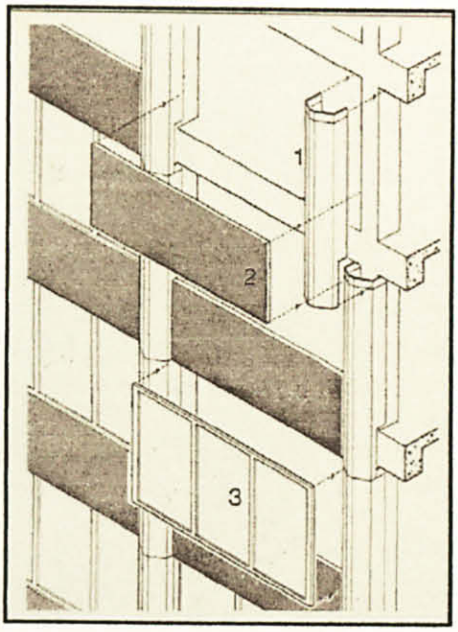
(b): Unitized System



(c): Unit-and-Mullion System



(d): Panel System



(e): Column Cover and Spandrel System

Figure 11: Different types of curtain wall installation, adopted from "*Exterior Wall Design*" by Nashed (1995)

2.9 Curtain wall glazing

Glazing is one of main components in curtain wall. It is generally fixed, meaning there is no access to the exterior except through doors. Nonetheless, ventilation system typically incorporated with the curtain wall system in order to provide aeration or operable windows.

Glass is the most prevalent types of glazing used in curtain wall design due to its versatility. The term 'glass type' is referred to the basic composition of glass. It differs with the applied secondary processes such as added chemicals, as to produce a better type of glass (Nashed, 1995). Some common types of glass are as follows:

- **Sheet Glass**

  It is known to be the least expensive type of glazing. It is produced by melting the raw materials which are mainly sand, lime and soda in a melting tank. This molten glass is then drawn into a tin sheet or film. It is commonly used in residential construction as windows, glass door and transparent wall.

- **Float Glass**

  As the name implies, this type of glass is fabricated by floating the glass on top of molten tin, as it is emerged from a melting tank. It is then spread out and formed level parallel surfaces. The thickness of float glass is controlled by the speed at which the solidifying glass is drawn off the molten tin bath. Typically, this float glass will undergo annealing process, which will produced annealed glass, before it can finally be cut. Figure 12 illustrates the process of producing float glass.

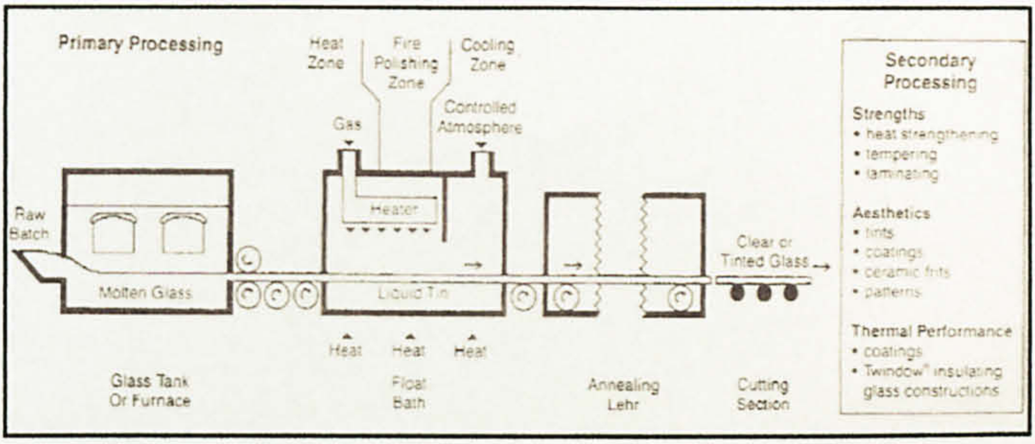


Figure 12: Float glass manufacturing process, adopted from *Exterior Wall Design*" by Nashed (1995)

- **Annealed Glass**

  Formerly produced from float glass, annealed glass is heated in order to change the properties by annealing process. It is then carried on rollers through temperature-controlled kiln or known as 'Lehr', as illustrated in Figure 12. This glass is then subjected to slow cooling without being quenched, in order to release internal stress after it is formed.

Glass usually experiences secondary processes in order to enhance the quality of the glass. The following is the description of different types of secondary processes applied for glass.

- **Heat-strengthen Glass**

  This type of glass is formed by heating the annealed glass at high temperature, which is approximately 1150°F. Both top and bottom surfaces are subjected to rapid cooling. Due the enhanced process it goes through, heat-strengthen glass is approximately twice as strong as float glass. It is typically found in large window panels and being used in areas with high wind pressure.

- **Tempered Glass**

  The tempering process is quite similar to heat-strengthening, except that the cooling process in more abrupt. It is made by processes which create balanced of internal stresses (compressive and tensile stresses) which provide strength to the glass. Due to the abrupt cooling, it is suitable to be used for safety glazing subjected to sudden impact. Tempered glass is approximately four times stronger as for float glass.

- **Laminated Glass**

  Laminated glass is consisted of two or more layers of glass that held together by interlayer using heat and pressure, as illustrated in Figure 13. It is durable, high performance and provides a range of benefits and functions such as:

  - Safety and security

    When it is subjected to high impact, the bond between the glass and interlayer would absorb the force of the impact. Should the impact is considerably high to cause breakage; the resulting fragments of glass would remain intact to the interlayer (G. James, 2000).

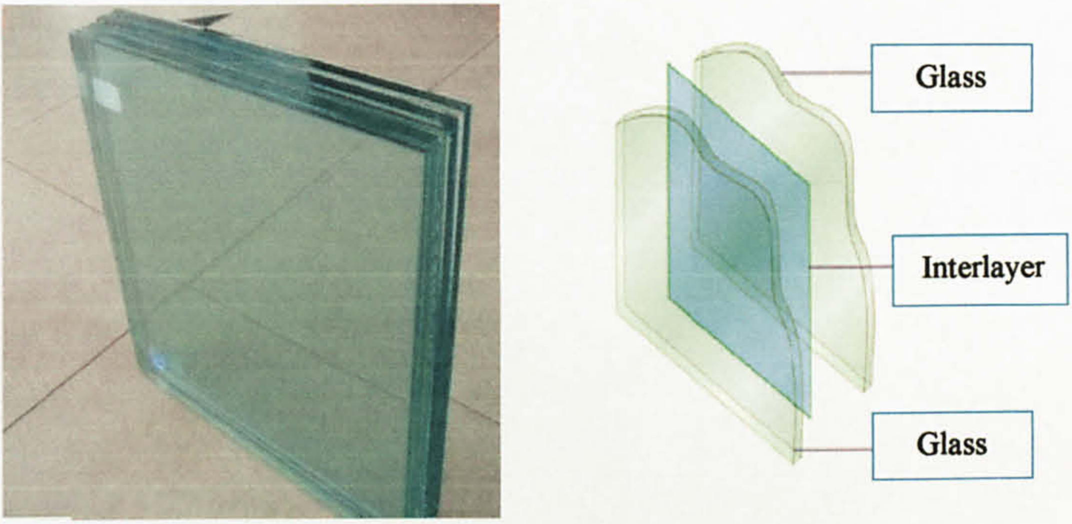
  - Sound Reduction

    In many cases, laminated glass is able to reduce the noise transmission through the glass. It is due to the properties of the interlayer than tend to dampen and adsorb the noise. Hence, laminated glass is considered as an effective and low cost method in sound reduction.

  - Use for overhead glazing, skylights and roof-lights

- Use for jails, embassies and security vehicles

- Use for aquariums and zoos



(a) Multi-layered of laminated glass

(b) Schematic diagram of laminated glass

Figure 13: Laminated Glass

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

In order to achieve the objectives of the project as discussed and outlined in section 1.3, Figure 14 shows the summary of the project flow.

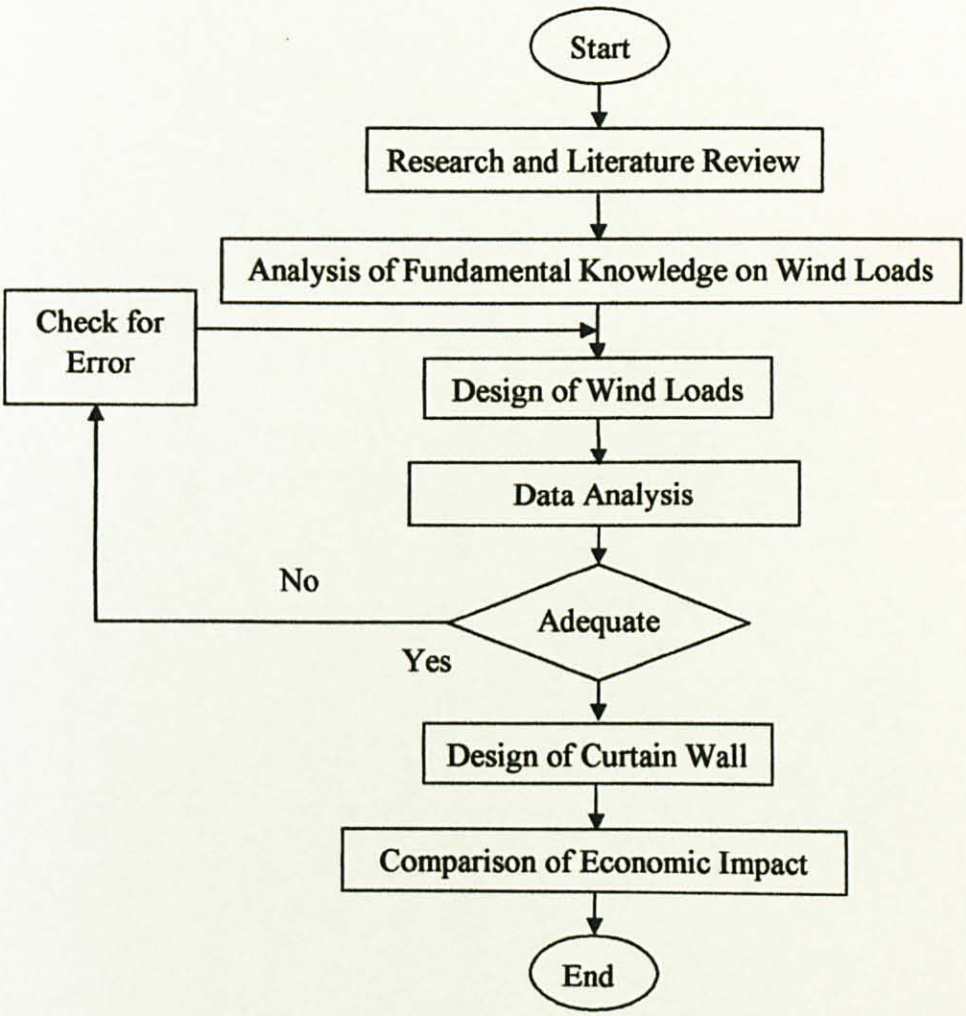


Figure 14: Project Flow Chart

3.2 Proposed Project Activities

3.2.1 Research and Literature Review

The theories and the concepts of curtain wall as well as the nature of wind loads acting on structures were extensively attained by detailed research and review on previous established literatures. Sources are comprised of journals, technical articles and related reference books.

3.2.2 Analysis of Fundamental Knowledge on Wind Loads

In-depth understanding of the design of wind loads was analyzed with reference to ASCE 7-05. The standard segregates and provides provision for the design of wind loads for MWFRS and C & C. As discussed in Section 2.6, curtain wall is considered as a cladding system of a building. Hence, the analysis of wind loads acting on curtain wall shall be done based on C & C procedures.

Design of wind loads for C & C is divided into three (3) methods, namely:

- Method 1: Simplified Procedure
- Method 2: Analytical Procedure
- Method 3: Wind Tunnel Procedure

Hence, this project presented herein adopted Method 2 for both analysis as well as the computation of wind loads, which will be further discussed in Chapter 4.

Apart from that, examples of wind pressure calculations, prepared by AP. Ir. Dr. Mohd. Shahir Liew which was adopted from the Malaysia Structural Steel Association (MSSA) ongoing training course notes for practicing professional engineers had been examined in details. This task was to enhance the knowledge in the design of wind pressure on structures, particularly on curtain walls, and in the understanding of external and internal pressure coefficient.

3.2.3 Design of Wind Loads

By considering a known dimension of a basic rectangular building as shown in Figure 15, the wind pressure distribution was determined for all building faces (windward face, sidewall face and leeward face), by the means of the above standard and calculation references. The computation distinguished between two (2) approaches of curtain wall glazing design, namely: the proposed method based on ASCE 7-05 versus the "traditional" method based on current consultancy practices in Malaysia. Local wind speeds data were adopted from the Malaysian Meteorological Services (Jabatan Kajicuaca Malaysia). From the computation, wind pressure contours for critical face (windward face) were developed in order to identify the variation of wind pressure which considerably essential in optimizing the design of curtain wall.

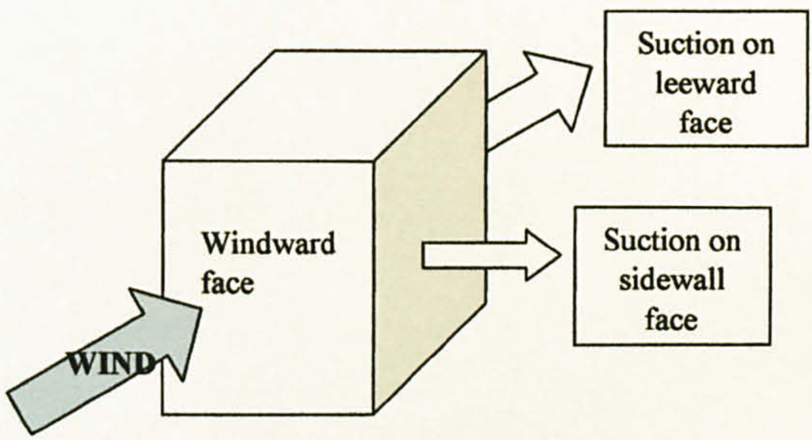


Figure 15: Illustration of windward face, leeward face and side wall face for a basic rectangular building

3.2.4 Data Analysis

The reliability of expected wind pressure computation was analyzed based on ASCE 7-05 and other related calculation references. Any indicated errors were examined and alteration of the computation was taken into account.

3.2.5 Design of Curtain Wall

The design of curtain wall emphasizes on the determination of the glazing thickness. It is assumed that the glass thickness is directly proportional to the corresponded wind pressure acting on the glass. From the estimated wind pressure contours, they were then zoned into a block pressure diagram. This diagram consisted with several zones with different wind pressures, which subsequently determine the corresponding curtain wall glazing design. For simplicity, the design of curtain wall only focuses on the critical face (windward face) as the design would be similar for other faces, depending on the wind pressure distribution.

On the other hand, curtain wall design applied for the current consultancy practices simply adopted a single thickness of glazing with respect to a uniform wind pressure acting on the curtain wall. Subsequently, the difference in the curtain wall design based on the proposed method using ASCE 7-05 versus the "traditional" method based on current consultancy practices was then achieved by analyzing the economic impact of both approaches.

3.2.6 Comparison of Economic Impact

The design of curtain wall glazing was then translated into economic studies by using Parametric Cost Estimate Method. Apart from determining the cost difference of both approaches, the comparison of economic impact would determine the reliability and efficiency of the rational design based on ASCE 7-05 standard.

3.3 Project Schedule

Gantt Charts in Table 1 and Table 2 illustrate the work breakdown of the project schedule for the Final Year Project (FYP).

Table 1: The key milestone of the project activities (FYP I)

NO	DETAILS / WEEK	1	2	3	4	5	6	7	8	9	Mid-semester Break	10	11	12	13	14
1	Selection of project topic															
2	Preliminary research work															
3	IEM Talk															
4	IRC Workshop & Technical Writing Workshop															
5	Technical Writing Workshop (Part II)															
5	Submission of journal papers															
6	Project work:															
	i. Review on literature															
	ii. Analyze the fundamental knowledge of wind loads															
	iii. Study examples of wind load calculation															
7	Submission of progress report															
8	HSE Talk															
9	Referencing Workshop															
10	Project work continuation															
11	Submission of interim report final draft															
12	Oral presentation															

Table 2: The key milestone of the project activities (FYP II)

NO	DETAILS / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14	
1	Recheck and polish up wind pressure calculation (FYP I)								Mid-semester Break								
2	Research on write up materials																
3	Block pressure sketch preparation																
4	Discussion with glass specialists and consultants																
5	Design of curtain wall																
6	Cost comparison – "analytical" method vs. "traditional" practices																
7	Progress Report I & II preparation																
8	Progress Report I & II submission																
9	Dissertation preparation and drafting																
10	Poster preparation and exhibition																
11	Preparation and submission of dissertation – soft bound																
12	Oral preparation and presentation																**8/6**
13	Hard bound of dissertation preparation and submission																**25/6**

CHAPTER 4
RESULTS / FINDINGS

4.1 Major Findings

ASCE 7-05 has specified that "all buildings and other structures, including Main Wind Force Resisting System (MWFRS) and all Components and Cladding (C & C) shall be designed and constructed to resist wind loads". Hence, the analysis of MWFRS and C & C shall be determined separately. In contrast, the design of wind pressure acting on a building which has been practiced by engineering consultancy in Malaysia would only depend on the evaluation of the velocity pressure. This generally includes the combination of MWFRS and C & C.

The analysis of wind pressure distribution performed in this project had segregated into two (2) parts, namely; Detailed Analysis using ASCE 7-05 and Current Consultancy Practices, as illustrated in Figure 16.

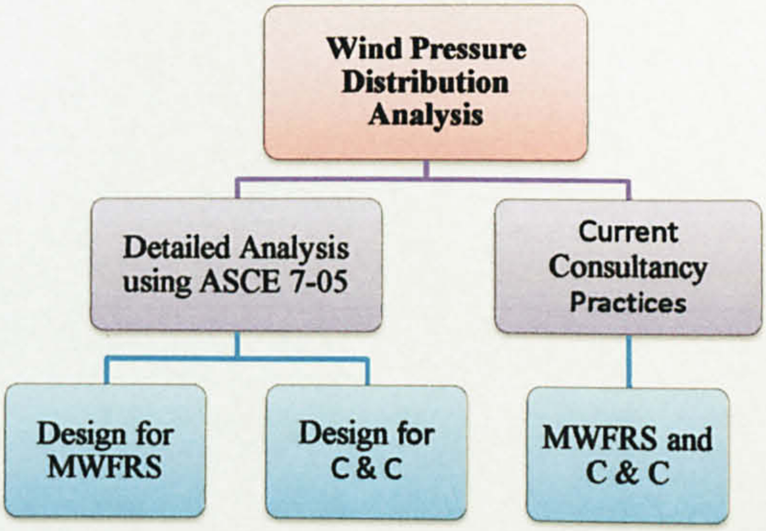


Figure 16: The hierarchy of wind pressure distribution analysis

For this purpose, the author adopted the dimension and characteristics of Twin-Bistari Condominium located in Kuala Lumpur, as illustrated in Figure 17.

Figure 17: Illustration of Twin-Bistari Condominium located in Kuala Lumpur

As discussed in Section 2.6, curtain wall is considered as a cladding system. Hence, the wind pressure distribution acting on the building's curtain wall shall be examined based C & C procedures which will be elaborated in section 4.2.1.2. By taking into account that the building is fully glazed, the analysis of wind pressure distribution will be followed by the design of curtain wall, which will be elaborated in Section 4.3.

Subsequently, the cost comparison of curtain wall design for both approaches (detailed analysis and current consultancy practices) will be evaluated in Section 4.4, as to distinguish the economic impact of utilizing both approaches.

4.2 Design of Wind Loads

The data of Bistari Condominium are as follows:

- Dimension: 60 m (B) x 40 m (W) x 175 m (H)
- Terrain: Open and flat terrain
- Location: Kuala Lumpur
- Basic Wind Speed (based on 3-second gust): 32.1 m/s – acted on 60 m face

Based on ASCE 7-05, the velocity pressure q_z was evaluated at every height z of the building by the following equation:

$$q_z = 0.613\ K_z K_{zt} K_d V^2 I \qquad \textit{(ASCE 7-05: Eq. 6 - 15)}$$

where K_z = velocity pressure coefficient

K_{zt} = topographic factor

K_d = wind directionality factor

V = basic wind speed based on 3-second gust

I = importance factor

0.613 = constant related to density of air mass at specified atmospheric pressure and temperature

The velocity pressures variation acting upon the building is shown in Figure 18, as follows:

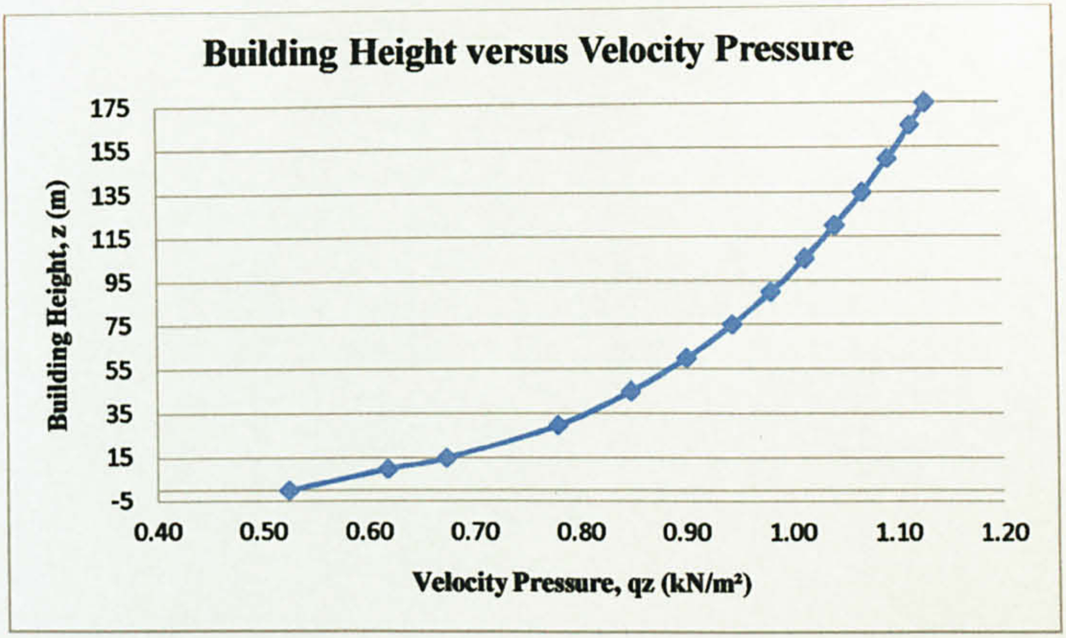


Figure 18: The variation of velocity pressure acted on the Bistari Condominium

4.2.1 Proposed Design of Wind Pressure Distribution - Detailed Analysis

4.2.1.1 Design for Main Wind Force Resisting System (MWFRS)

The design of wind pressure for the MWFRS was determined by the following equation:

$$p = qG_fC_p - q_i(GC_{pi}) \qquad \textit{(ASCE 7-05: Eq. 6 - 19)}$$

where q = q_z for windward walls

q = q_h for leeward walls, side walls and roofs

qi = q_h for windward walls, side wall, leeward walls, and roofs for negative internal pressure

qi = q_z for positive internal pressure evaluated where height z is defined as the level of the highest opening

G_f = gust effect factor for rigid building and structure

C_p = external pressure coefficient

GC_{pi} = internal pressure coefficient

The summary of the design wind pressure distribution for MWFRS is shown in Figure 19, as follows:

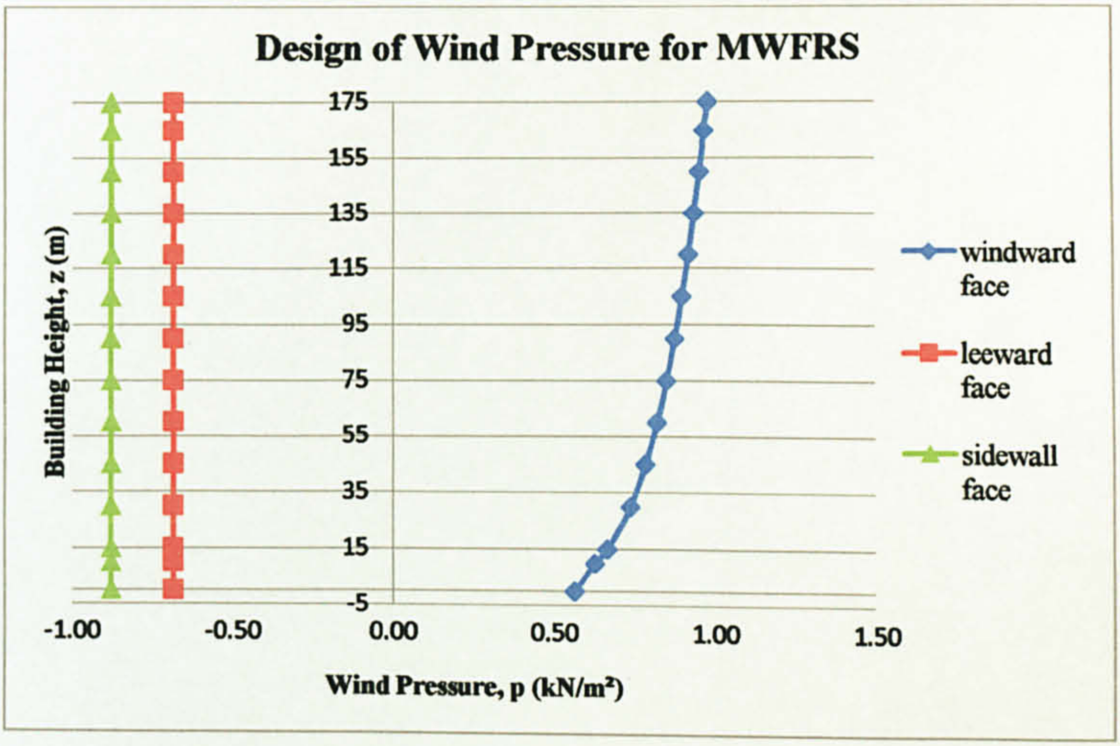


Figure 19: Design wind pressure distribution for MWFRS

4.2.1.2 Design for Components & Cladding (C & C)

The design of wind pressure on C & C was determined from the following equation:

$$p = q(GC_p) - q_i(GC_{pi}) \qquad \textit{(ASCE 7-05: Eq. 6-23)}$$

The design of wind pressure distribution for C & C is shown in Figure 20 and Figure 21, as follows:

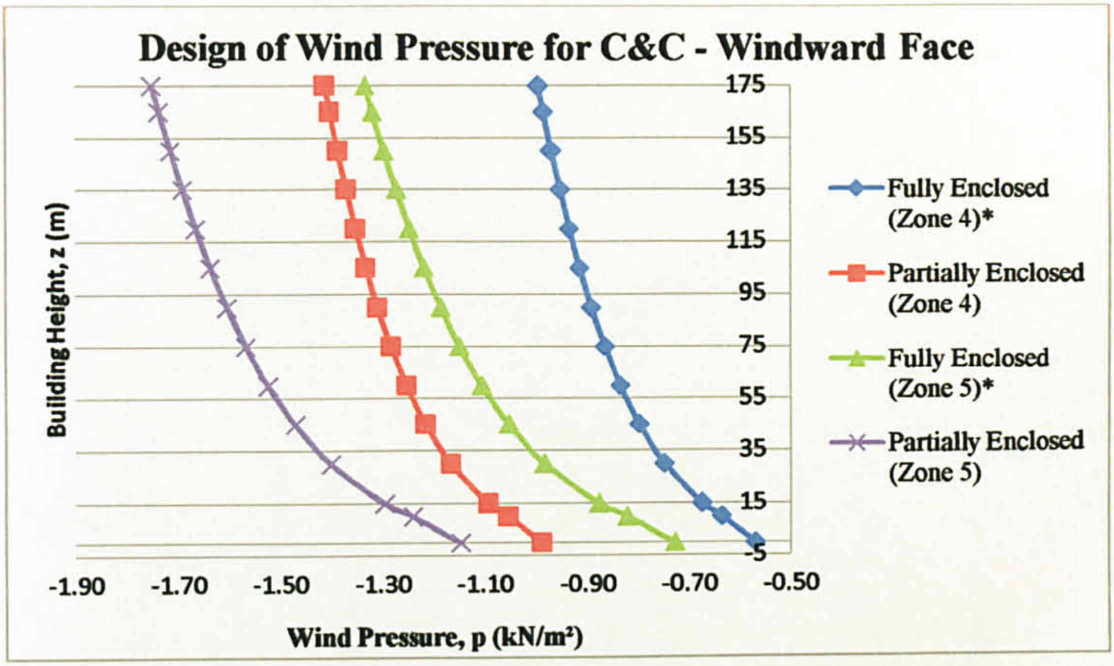


Figure 20: Design wind pressure distribution for C & C acted on the windward face

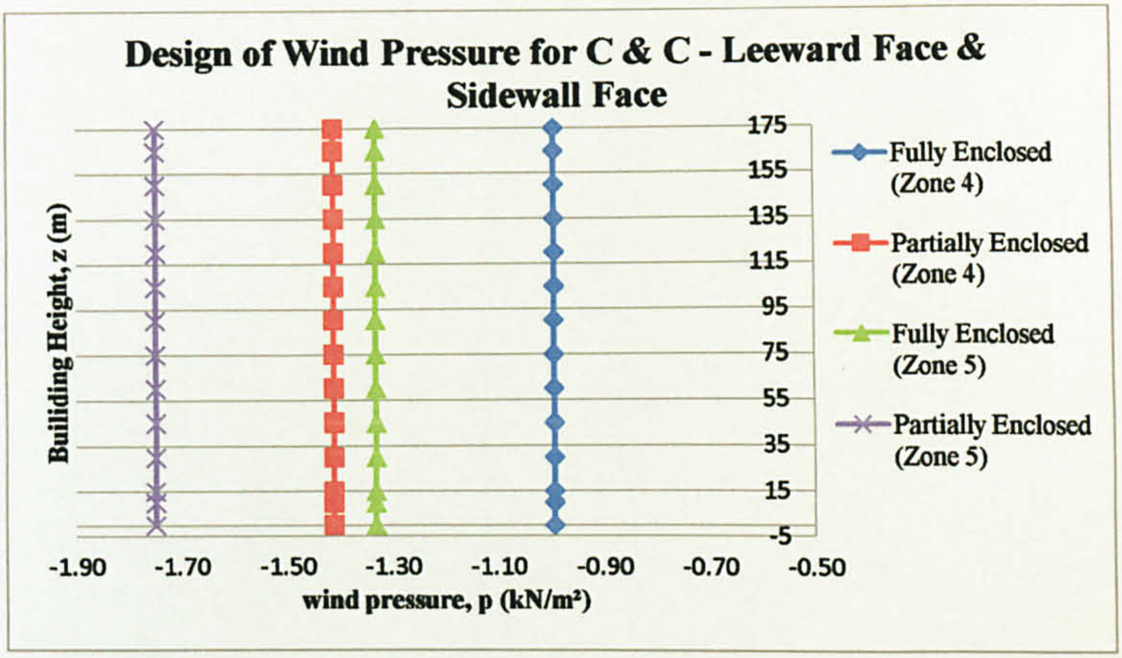


Figure 21: Design wind pressure distribution for C & C acted on the leeward face and sidewall face

Note that, positive pressures acting towards the surface of the building where as negative pressures acting away from the internal surface (suction).

**Please refer to Figure 26 in Appendix A for the illustration of Zone 4 and Zone 5*

4.2.2 Wind Pressure Distribution for Current Consultancy Practices

In current consultancy practice, the design of wind pressure acting on a building depends only on the evaluation of the velocity pressure. This approach generally includes MWFRS and C & C without differentiating the effect of internal pressure coefficient. From the discussion with existing consultants, it was indicated that they generally apply a uniform pressure only on one critical face of a building ranging from 0.5 to 1.0 kN/m². Typically, the velocity pressure was determined by the following equation:

$$q_z = 0.613\,V^2$$

The summary of the design of wind pressure is shown in Table 3, as follows:

Table 3: The analytical design wind pressure distribution

z (m)	V^2	q_z (N/m²)	q_z (kN/m²)	q_z used (kN/m²)
0-175	1030.41	631.64	0.63	1.0

The comparison of the design of wind pressure acting on the windward face (critical face) of the building is shown in Table 4, as follows:

Table 4: Comparison of design wind pressure between the detailed analysis and current consultancy practice

z (m)	Detailed Analysis using ASCE 7-05 (kN/m²)			Current Consultancy Practice (kN/m²)
	MWFRS	C & C (Zone 4)	C & C (Zone 5)	MWFRS and C & C
0	0.56	-0.57	-0.73	1.00
10	0.63	-0.64	-0.82	1.00
15	0.66	-0.67	-0.88	1.00
30	0.74	-0.75	-0.98	1.00
45	0.78	-0.80	-1.05	1.00
60	0.82	-0.83	-1.10	1.00

Table 4 (con't): Comparison of design wind pressure between the detailed analysis and current consultancy practice

z (m)	Detailed Analysis using ASCE 7-05			Current Consultancy Practice
	MWFRS	C & C (Zone 4)	C & C (Zone 5)	MWFRS and C & C
75	0.85	-0.86	-1.15	1.00
90	0.88	-0.89	-1.18	1.00
105	0.90	-0.91	-1.22	1.00
120	0.92	-0.93	-1.25	1.00
135	0.94	-0.95	-1.27	1.00
150	0.95	-0.97	-1.30	1.00
165	0.97	-0.98	-1.32	1.00
175	0.98	-0.99	-1.33	1.00

Note: Detailed computation of the design of wind pressure distribution is shown in Appendix A.

4.3 Design of Curtain Wall

To determine the impact of wind pressure on curtain wall design, the wind pressure contours acting on the critical face of the building (windward face) were estimated as illustrated in Figure 22(a). Generally, the pressure contours are generated from wind tunnel testing. However, in order to observe the behavior of wind pressure applied throughout the building face, the estimation of pressure contours were done by interpolating the values of wind pressure as shown in Table 4 using standard Microsoft Software.

The pressure contours were then zoned into a block pressure diagram which will determine the glazing design presented herein, as illustrated in Figure 22(b). The block diagram consisted of five (5) zones with different pressures. This difference in pressures indicates the difference in characteristics of curtain wall.

As discussed in Section 1.2, one of the important aspects in designing curtain wall is the determination of the glazing thickness with respect to the wind pressure distribution. Several prominent specialists in different backgrounds (façade consultants and glass manufactures) had been approached in order to get comprehensive recommendations in the design of curtain wall glazing.

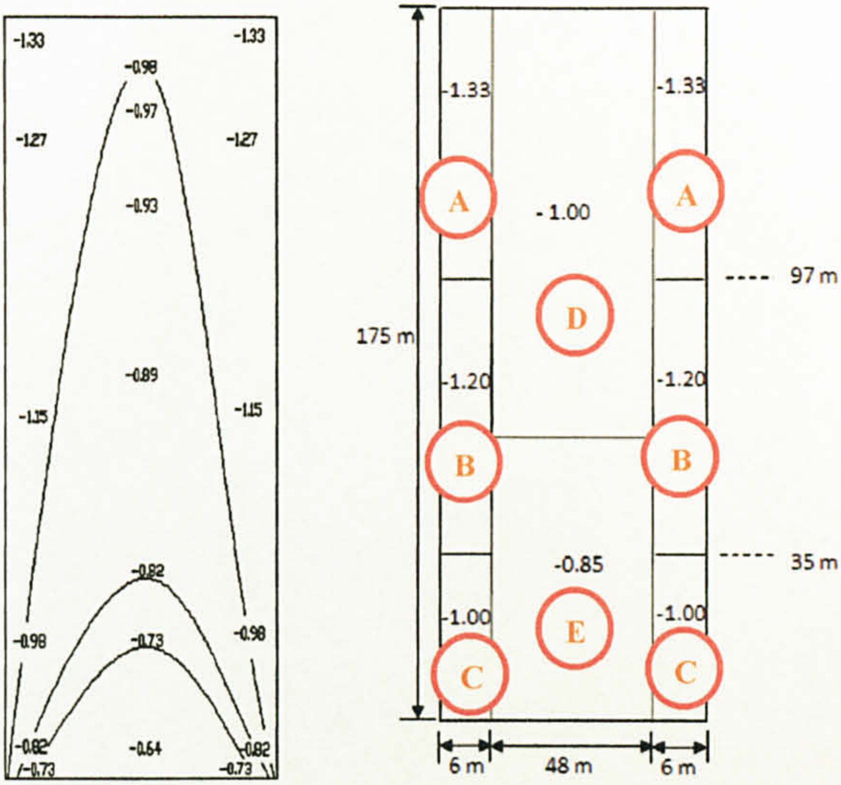


Figure 22: (a) Wind pressure contours acted on windward face; (b) Wind block pressure acted on windward face

From the discussion made, it was found that the design of curtain wall as well as its glazing system is very much subjective. It depends on many factors and considerations which include:

- **Type of glass and process requirement**
  Some common types of glass available in the market comprise of floating glass, tempered glass and laminated glass. In order to choose the best type of glass, some factors which are taken into account include the strength of the glass to withstand the applied environment forces, the effects of glass failure towards the vicinity of the building and the compatibility of the glass towards the whole structure. Typically in Kuala Lumpur, Dewan Bandaraya Kuala Lumpur (DBKL) requires either three (3) types of glass for high level of curtain wall, namely: tempered glass, laminated glass or wired glass (Bebington, 2010).

- **Available glass size**

  The size of glass is basically dependent on the material prices, size of project, complexity of design and commercial pricing decisions by curtain wall specialist. The common dimensions of a glass panel for a typical building in Malaysia are found to be either 2 m x 3 m or 8 ft x 4 ft (2.4 m x 1.2 m).

  Brown (1970) stated that from the past decades, information regarding glass strength as well as wind pressure characteristic is available considerably. Hence, it is possible to incorporate this information together with improved procedures in determining appropriate glass thickness for curtain wall glazing of different sizes which subjected to different pressures.

  Aside from that, manipulation of glass type and its strength would also determine different types of thickness that can be used for curtain wall design. Normally, buildings in Malaysia adopt 8 mm and 12 mm glass thicknesses, which are applied throughout the entire building face.

- **Glass visual appearance**

  Aside from wind pressure distribution, visual appearance or the color of the glass would also influence the glazing thickness. Typically, architects and clients would prefer to have an overall visual appearance. The intensity of colored glass is rather in proportion to the variation of thickness of the glass. Subsequently, clear glass would significantly be chosen comparative to colored glass in the design of curtain wall glazing.

- **Framing system**

  Normally, the framing of curtain wall is made from aluminum. The design of this framing is dependent on the design wind loads, spanning requirement (floor to floor height), deflection requirement, section size and so forth. (Bebington, 2010).

Hence, the variation of these considerations would affect the cost of the curtain wall design. The cost also would change day to day depending on the glass manufacturers themselves.

In order to determine the difference in curtain wall design based on the proposed design using the ASCE 7-05 versus the "traditional" design based on the current consultancy practices, the cost comparison between both approaches had been analyzed using Parametric Cost Estimate Method, which will further discussed in Section 4.4.

4.4 Cost Estimation – Parametric Cost Estimate Method

Due to the complexity of analyzing the curtain wall design as discussed in Section 4.3, this approach presented herein had been adopted in order to determine the difference in curtain wall design based on proposed design using ASCE 7-05 versus the "traditional" design based on current consultancy practices. This approach is unbiased and remains objective in its content.

Two (2) types of assumptions have been taken into account:

- Technical assumptions – weight and density of glass are assumed to be fixed and uniformity of the glass thickness is directly proportional to wind pressure.
- Procurement assumptions – price of glass is fixed and bulk discount and goodwill are not considered herein.

Therefore, the estimated cost for designing the curtain wall glazing is based on the following formula:

$$\boxed{\text{Cost} = \text{size of parameter} \times \text{cost per unit parameter}}$$

where:

Size of parameter = thickness x area

The cost difference between both approaches is tabulated in the
Table **5**, as follow:

Table 5: Cost comparison by using Parametric Method

Zone	Area	Total Area	Wind Pressure		Thickness Factor		Cost		% difference (by zone)
			ASCE 7-05	"traditional" Method	ASCE 7-05	"traditional" Method	ASCE 7-05	"traditional" Method	
A	468	936	1.33	1.00	1.33t	t	1245C	936C	33
B	372	744	1.20	1.00	1.2t	t	893C	744C	20
C	210	420	1.00	1.00	T	t	420C	420C	-
D	5040	5040	1.00	1.00	T	t	5040C	5040C	-
E	3360	3360	0.85	1.00	0.85t	t	2856C	3360C	15
							10454C	*10500C*	

= under design

= over design

where:

- 't' represents the thickness for 1 kN/m^2 of wind pressure
- 'C' represents cost per unit thickness by unit area

CHAPTER 5
DISCUSSION

5.1 Analysis of Wind Loads Design

ASCE 7-05 defines a fully enclosed building as "a building that does not comply with requirements for open or partially enclosed building". The Twin-Bistari Condominium is assumed to be a fully enclosed building as it is located in non-hurricane zone and hence, the glazing of the building is not subjected to flying missile debris. For the benefit of the analysis, the design of wind pressure for partially enclosed building had also been taken into account in order to observe the differences of wind behavior acting on both types of building (fully enclosed building versus partially enclosed building).

The distinction in the design of wind pressure between for fully enclosed building and for partially enclosed building is in terms of the internal pressure coefficient,GC_{pi}. The internal pressure coefficient for partially enclosed building is ±0.55, where as for fully enclosed building is ±0.18.

From the obtained computation of wind pressures acting on critical face (windward face), the partially enclosed building had shown greater values of wind pressure compared to the fully enclosed building. The reason being is because, when a building is partially enclosed, the volume of air in the building would be increased. This will eventually create a higher internal pressure or "suction" which resulting in a higher negative value of wind pressure. Nevertheless, as the height of the building increases, the difference in values of wind pressure for fully enclosed building and partially enclosed building had tend to converge, as indicated in Table 11 and Table 12 in Appendix A. This convergence of wind pressure variation is due to the reduction of turbulence when the wind pressure approached the atmospheric boundary layer at greater height of the building.

Aside from that, it was found that the values of wind pressure acted on critical face for MWFRS were not in much difference as for C & C (which now referred for fully enclosed building) in Zone 4. In contrary, the design of wind pressure in Zone 5 for C & C was significantly higher than for MWFRS and had reached approximately by 36% at the height of 175 m. The reason of such difference is because, when wind strikes a building, the streamlines are forced to diverge and pass around the building's edges. Consequently, the wind pressure is much higher at the edges of the building (Zone 5) compared to the near center of the building's face (Zone 4).

The design of wind pressure for C & C is somehow more critical compared to MWFRS. By recalling Section 1.2, many building failures are associated with failure of the curtain wall due to high pressure of wind. A classic example is the shattering of glass which can cause enormous damage to the surrounding of a particular building and in a worst case could cause death of inhabitants. This type of damage is related to the failure of wind pressure design for C & C. Hence, we can say that the significance of wind pressure design for C & C has always been neglected and not well-predicted.

5.1.1 Design of Wind Pressure Based on Current Consultancy Practices versus Detailed Analysis Using ASCE 7-05

By referring to the Table 4 in Section 4.2.2, it was indicated that the design of wind pressure for current consultancy practices was not well-predicted. Typically, engineering consultants would simply adopt a conservative design of curtain wall based on a uniform wind pressure of 1.0 kN/m^2. Even though the design is generally being conservative, nonetheless, this prediction of uniform wind pressure was inadequate at certain area, especially at the edges in Zone 5. By referring to the Figure 22(b), it was denoted that approximately above 35 m upwards of the building's height, the actual wind pressures in Zone 5 were greater than 1.0 kN/m^2. Hence, this insufficient assessment of wind pressure could promote the failure of the curtain wall.

5.1.2 Imperative Provisions of ASCE 7-05

The following discussion emphasizes on important provisions highlighted in ASCE 7-05. The contents of this section is mainly adopted from ASCE 7-05 and "The Wind Provisions" prepared by Quimby (2007).

- **Wind Directionality Factor, K_d**

  As discussed in Section 2.5, wind direction is associated with the direction of where the wind originates. Wind directionality factor accounts for two (2) effects:

  1) The reduced probability of maximum winds coming from any given direction.
  2) The reduced probability of maximum pressure coefficient occurring for any given wind direction.

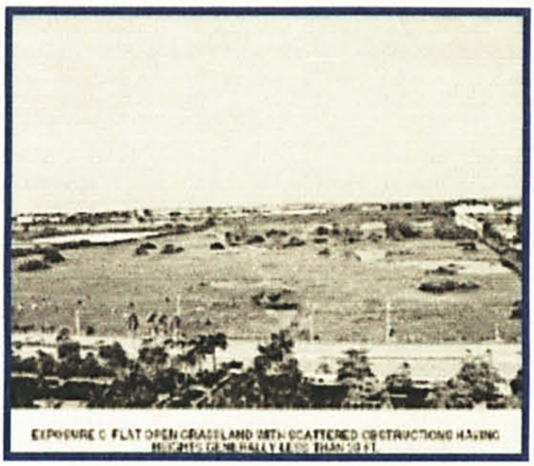
  The value of this factor differs from one structure to another which was established from references in literature and collective committee judgment.

- **Exposure Categories**

  1) *Exposure A*: It was deleted in ASCE 7-02. Formerly, it was intended for large city centers with tall buildings, as illustrated in Figure 23(a). Due to the great number of tall buildings in that area, the wind variability becomes very significant which then require special category A to be defined.
  2) *Exposure B*: It is referred to urban and suburban areas, wooden areas and areas with closely spaced obstruction, as illustrated in Figure 23(b).
  3) *Exposure C*: It is referred to open terrain with scatter obstructions such as airports and area that normally flat and open, as illustrated in Figure 23(c).
  4) *Exposure D*: It is intended for flat, unobstructed areas which include mud flats, salt flats and unbroken ice that extend 5000 ft or 20 times the building height in the upwind direction. Figure 23(d) shows the illustration of exposure D.

(a) Exposure A

(b) Exposure B



(c) Exposure C

(d) Exposure D

Figure 23: Illustration of Exposure categories, adopted from "Enclosure Category" by Blueprint for Safely (2010)

- **Topographic Effect and Factor, K_{zt}**

  Building sited on isolated hill or escarpment may experience significantly higher wind speeds than buildings situated on ground. This is where the topographic factor comes into play, whereby it takes into account some parameters such as the shape of topographic feature, the height of the hill, the maximum speed-up near the crest and so forth. For a building situated in a flat terrain, the topographic factor, $K_{zt} = 1.0$.

- **Gust Effect Factor, *G***

  National Oceanic and Atmospheric Administration (NOAA) defines wind gust as "the maximum 3-second wind speed forecast to occur within a 2-minute interval at a height of 10 meters". In the computation, this wind gust is referred as basic wind speed, *V*. The gust effect factor accounts for:

  - Gustiness and turbulence
  - Gust frequency and size
  - Gust correlation
  - Structural damping, and so forth.

  For stiff buildings and structures, gust factor, *G* is taken to be 0.85 where as for flexible buildings and other structures, it shall be computed by rational analysis that incorporated the dynamic properties.

- **Importance Factor, *I***

  This factor is used to adjust the level of structural reliability of a building or other structures to be consistent with the building classification indicated in Table 1-1 in ASCE 7-05 (Appendix B). It adjusts the velocity pressure to different annual probabilities of being exceeded.

- **Velocity pressure exposure coefficient, K_z**

  It reflects the change in wind speed with height and terrain roughness (Liew, 2008).

- **Velocity Pressure, q_z**

  The basic wind speed is basically converted to velocity pressure, q_z. The constant 0.613 in the equation reflects the mass density of air for standard atmosphere, that is:

  - Temperature of 15°C
  - Sea level pressure of 101.325 kPa
  - Dimensions are associated with wind speed (m/s)

- **Enclosure Classification**

  Enclosure can be classified into three (3) categories, namely: enclosed, partially enclosed and open. The assessment is based on the amount of openings in the envelope. ASCE 7-05 defines the term 'openings' as "apertures or holes in the building envelope which allow air to flow through the building envelope and which are designed as *open* during design winds". Some of the examples include doors, operable windows, gaps in cladding, and ventilation system.

- **Internal Pressure Coefficient, GC_{pi}**

  The magnitude and sense of internal pressure is relying on the magnitude and location of openings around the building envelope. Once the enclosure classification is determined, the appropriate internal pressure coefficient shall be selected. As the gust effect is not significant internally, the gust factor and the pressure coefficient are combined (GC_{pi}). In a nutshell, the magnitude of internal pressure coefficient is dependent on the enclosure classification. Figure 24 illustrates the different cases of internal pressure.

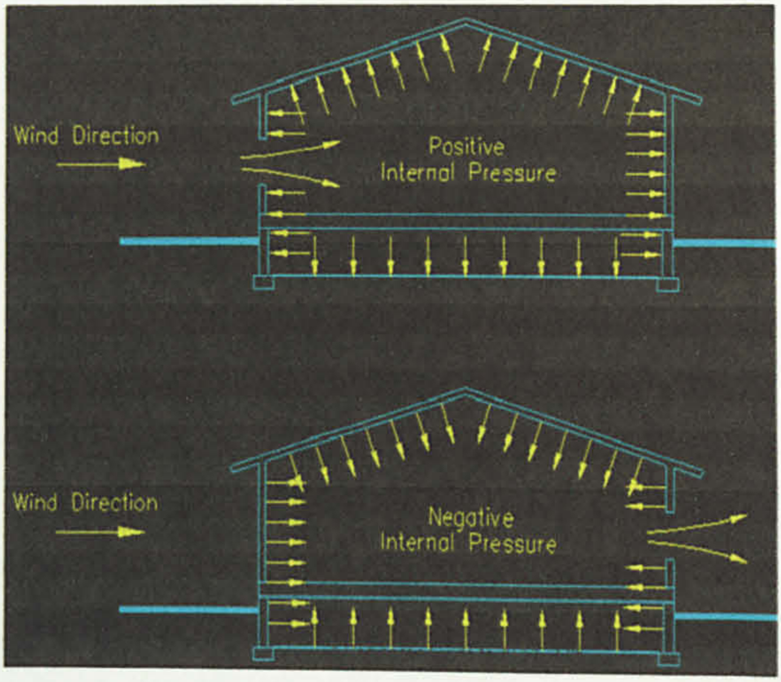


Figure 24: Illustration of positive and negative internal pressure coefficient, adopted from "Wind Loads: The ASCE 7 Provisions" by Quimby (2007)

- **External Pressure Coefficient, C_p**

  The external pressure coefficient, C_p differs for MWFRS and C & C. For MWFRS, the coefficient for building walls is depends on the ratio of the length and width of the building (L/B). In contrast, the coefficient for C & C generally depends on the effective area in different zones of the building's wall.

5.2 Analysis of Curtain Wall Design

Parametric Cost Estimate Method is one of many other tools in estimating cost prior to activities or production being taken. Evans et al (2006) define parametric method as a "method using Cost Estimating Relationships (CER) and associated mathematical algorithm (or logic) to establish cost estimate". This method generally correlates cost as the dependent variable with one or more independent variables. It sets cost as a function with one or more technical parameters (John, 2000). In this project, the independent variables and the technical parameters are the thickness as well as the area of the glazing. The main advantage of this method is that it allows a large portion of estimation within limited time and production definition. In an actually project implementation, this method shall be used during feasibility studies, design concept phase, and project definition phase.

By referring to Table 5, it was denoted that the cost for the design of curtain wall glazing in Zone A, based on the "traditional" method was significantly lower by 33% than for the exact design based on ASCE 7-05. This lower percentage indicates that the curtain wall within this zone had been insufficiently assessed by current consultancy practices and hence, it is considered as under-designed. This case also applied in Zone B, where by the percentage difference is 20%.

On the contrary, the "traditional" method had over-estimated the cost of curtain wall glazing by 15% higher at the near center of the building face in Zone E. Therefore, we can say that the design of curtain wall glazing within this zone is over-designed.

Even though the total cost applied for both approaches was not much difference, but we can observe the difference became significant if the analysis is performed in we can observe the difference became significant if the analysis is performed in zones. From the overall perception, the "traditional" method based on current consultancy practices is considered conservative to be applied for low rise building, as the design of the curtain wall is within the actual design standard. On the other hand, detailed analysis of wind pressure for designing a curtain wall shall be emphasized for high rise building. As denoted in Table 5, in higher zones especially at edges (Zone A and Zone B), the design of curtain wall was inadequate, and this eventually could lead to progressive curtain wall failures.

5.2.1 Important Considerations in Curtain Wall Design

The design of the thickness of curtain wall glazing is not the only major design that should be emphasized. There are other considerations that should be taken into account. For instance, the frames to hold the glass also play a major role in the design of curtain wall. Variation of thickness applied to building face would result in a more complex curtain wall system. Hence, the design of the framing system for entire face of the building would rather not be easy. It requires in-depth deliberation and expertise as poor knowledge of the system would in return produce inefficient and uneconomical design.

The breakage characteristics of glass play a role in determining the appropriate type of glass to be used in a particular structure. Ordinary float glass usually shatters into big pieces when a breaking force is applied and consequently would be dangerous to the vicinity of the glass, as shown in Figure 25(a). In comparison, tempered or toughened safety glass shatters into a small and relatively harmless compared to ordinary float glass, illustrated in Figure 25(b). It shall be used in any situation that requires high safety, strength and resistance to great impact (G. James, 2000). In the event of breakage, laminated glass has the tendency to remain intact with the frame when an impact is being applied, as shown in Figure 25(c). Hence, the severity of physical injury is significantly reduced. It is suitable to be used in locations where there is a risk of human impact.

Apart from that, the color of glass would affect the aesthetic features of a building. When a particular building applies various thicknesses of glass throughout its face, clear glass would significantly be chosen comparative to colored glass (Lai, 2010). The intensity of colored glass is rather in proportion to the variation of thickness of the glass. Hence, when the thickness of glass varies, the intensity of the glass' color shall vary as well which in return causing unappealing effects.

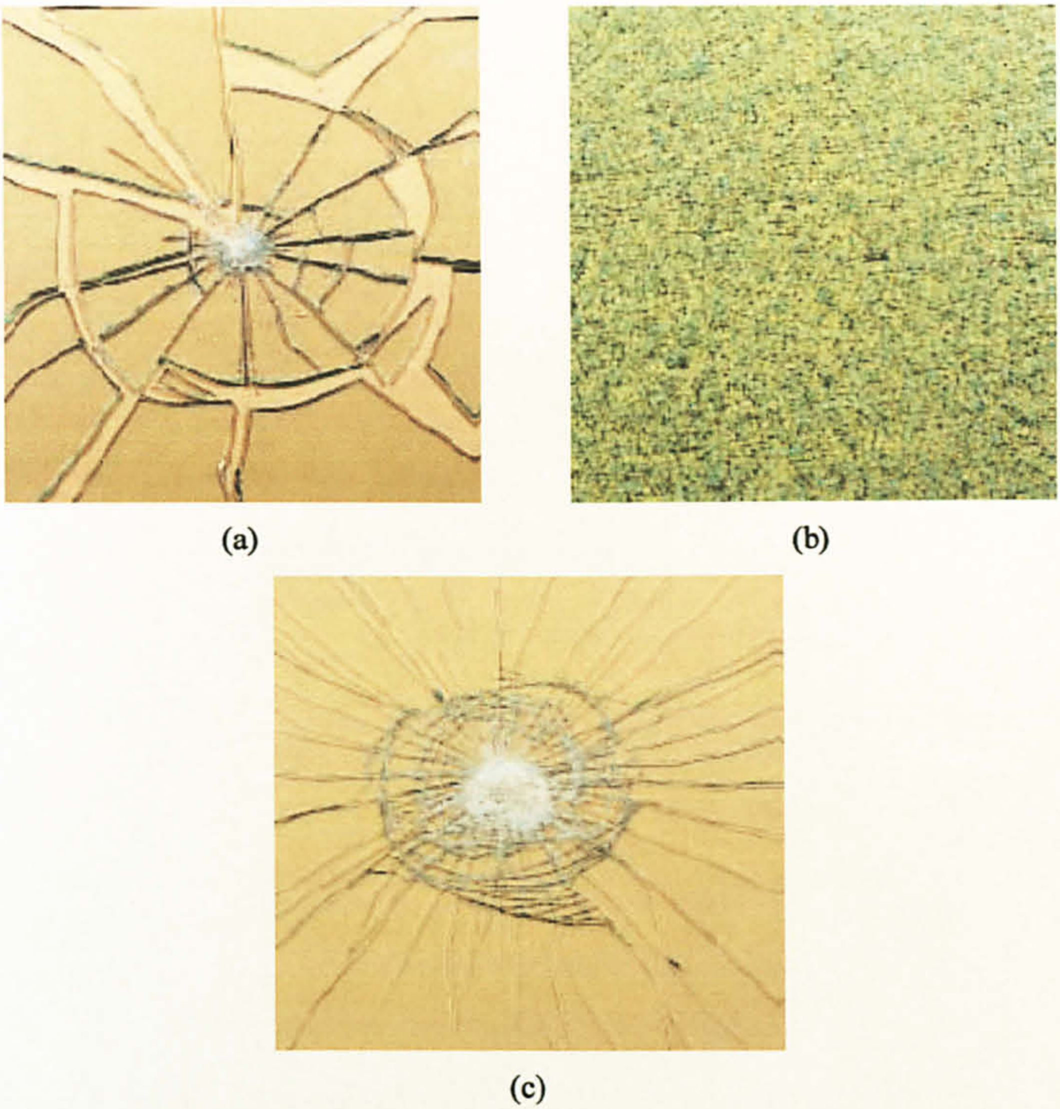


Figure 25: (a) Ordinary float glass; (b) Tempered safety glass; (c) Laminated glass

Even though the impact of wind pressure is very much essential in designing a curtain wall, there are numerous other considerations that shall be emphasized. Therefore, great understanding and assessment in many aspects related to the design of curtain wall must be taken into account as to produce more efficient and economical design of curtain wall.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

Comprehensive analysis of wind pressure acting upon a curtain wall is seldom practiced in Malaysia. Generally in Malaysia, curtain wall design is under the concern of architects. Architects do not have the expertise in analyzing the wind loads and pressure acting upon the curtain wall and the analysis is often being predicted poorly. Although Malaysia is not subjected to extreme weather conditions, nevertheless, it is currently experiencing abrupt development of high rise building which require in-depth understanding of the wind behavior. The assessment of curtain wall design also shall be zoned based on the actual design of known wind codes and standards. The proposed design of curtain wall introduced in this project emphasized the importance of great understand of wind pressure in designing a curtain wall, which in return resulting in an effective and feasible design.

One of the important aspects in designing curtain wall is the determination of the glazing thickness with respect to the wind pressure distribution. As the wind pressure varies with height in accordance to the power law or logs law, the thickness of the glazing shall vary as well. In Malaysia practices, architects are more likely to design the thickness based on 1 kN/m^2 uniform wind pressure. Even though the design is generally being conservative, nonetheless, this prediction of uniform wind pressure was inadequate at certain area, especially at the edges of building face. Consequently, the design of the curtain wall that has been practiced in Malaysia is said to be both overdesigned and inadequate at certain zone.

From the economic impact studies, it was indicated that the total cost applied for both approaches was not much difference. However, the difference became significant if the analysis is performed in zones. The "traditional" method based on current consultancy practices is considered conservative to be applied for low rise building, as the design of the curtain wall is within the actual design standard. On the other hand, detailed analysis of wind pressure for designing a curtain wall shall be emphasized more on high rise building, as the wind pressure is under-predicted by the current consultancy practices.

While the impact of wind pressure is very much important in designing a curtain wall, there are numerous other considerations that shall be taken into account as to ensure the reliability of the proposed design of curtain wall, which has been introduced in this project. These include the understanding of the behavior of the various types of glass, specifically the breakage characteristics as well as the entire curtain wall system particularly the framing system.

Therefore, great understanding and assessment in many aspects related to the design of curtain wall must be taken into account as to produce more efficient and economical design of curtain wall.

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APPENDICES

APPENDIX A

DETAILED DESIGN OF WIND PRESSURE

Dimension: 60 m (B) x 40 m (W) x 175 m (H)

Terrain: open terrain

Location: Kuala Lumpur

Basic Wind Speed (based on 3-second gust): 32.1 m/s – acted at 60 m face

1) Determine exposure category *(ASCE 7-05: Section 6.5.6.3)*

   Exposure C

2) Classification of Building *(ASCE 7-05: Table 1-1)*

   Occupancy category III

3) Compute velocity pressure *(ASCE 7-05: Equation 6 – 23)*

   $q_z = 0.613 K_z K_{zt} K_d V^2 I$

   - Importance factor, I: 1.15 (Non-hurricane prone region) *(Table 6-1)*
   - Wind directionality factor, K_d: 0.85 *(Table 6-4)*
   - Topographic factor, K_{zt}: 1.0 (homogeneous topography) *(Figure 6-4)*
   - Velocity pressure coefficient, K_z: *(Table 6-3)*

The values of computed velocity pressure coefficient, K_z shown in Table 6, as follows:

Table 6: Values of velocity pressure coefficient, Kz

z (m)	Kz
0	0.85
10	1.00
15	1.09
30	1.26
45	1.37
60	1.46
75	1.53
90	1.59
105	1.64
120	1.69
135	1.73
150	1.77
165	1.81
175	1.83

Thus, variation of velocity pressures is tabulated in Table 7, as follows:

Table 7: Values of velocity pressure, q_z

z (m)	Kz	Kzt	Kd	V^2	I	q_z (N/m^2)	q_z (kN/m^2)
0	0.85	1	0.85	1030.41	1.15	524.12	0.52
10	1.00	1	0.85	1030.41	1.15	618.00	0.62
15	1.09	1	0.85	1030.41	1.15	673.07	0.67
30	1.26	1	0.85	1030.41	1.15	778.82	0.78
45	1.37	1	0.85	1030.41	1.15	848.22	0.85
60	1.46	1	0.85	1030.41	1.15	901.18	0.90
75	1.53	1	0.85	1030.41	1.15	944.53	0.94
90	1.59	1	0.85	1030.41	1.15	981.49	0.98
105	1.64	1	0.85	1030.41	1.15	1013.86	1.01
120	1.69	1	0.85	1030.41	1.15	1042.77	1.04
135	1.73	1	0.85	1030.41	1.15	1068.95	1.07
150	1.77	1	0.85	1030.41	1.15	1092.92	1.09
165	1.81	1	0.85	1030.41	1.15	1115.07	1.12
175	1.83	1	0.85	1030.41	1.15	1128.97	1.13

Part 1: Design for MWFRS

1) Natural period of vibration checking

   T = 0.1N

   (Note: Each floor was taken as 4 m height excluding the ground floor)

   $$N = \frac{175-10}{4} + 1 = 42 \text{ floors}$$

   T = 0.1 x 42 = 4.2 s

   $$f = \frac{1}{T} = \frac{1}{4.2} = 0.24\ Hz$$

   Since f < 1.0 Hz, the building is taken as a slender and flexible building. Thus,

   $p = qG_fC_p - q_i(GC_{pi})$ *(ASCE 7-05: Equation 6 – 19)*

2) Computing Gust Factor, G_f:

   $$G_f = 0.925\left(\frac{1+1.7\,I_{\bar{z}}\sqrt{g_Q{}^2\,Q^2+g_R{}^2\,R^2}}{1+1.7\,g_vI_{\bar{z}}}\right)$$ *(ASCE 7-05: Equation 6- 8)*

   $g_Q = g_v = 3.4$

$$g_R = \sqrt{2\ln(3600n_1)} + \frac{0.577}{\sqrt{2\ln(3600n_1)}} = 3.6774 + \frac{0.577}{3.6774} = 3.8343$$

*Note: n_1= f = 0.24 Hz

$$Q = \sqrt{\frac{1}{1+0.63(\frac{B+h}{L_{\check{z}}})^{0.63}}} \text{ (ASCE 7-05: Equation 6 -6)}$$

where $L_{\check{z}} = (\frac{\check{z}}{10})^{\varepsilon}$ *(ASCE 7-05: Equation 6 – 7)*

For $h \geq z_{min}$, $\check{z} = 0.6h$

Since h = 175 > 4.57 → ž = 0.6 x 175 = 105 m

$$L_{\check{z}} = 152.4\left(\frac{105}{10}\right)^{\frac{1}{5}} = 243.91 \text{ m}$$

$$Q = \sqrt{\frac{1}{1+0.63(\frac{60+175}{243.91})^{0.63}}} = 0.7868$$

$$R = \sqrt{\frac{1}{\beta}R_n R_h R_B(0.53 + 0.47R_L)} \text{ (ASCE 7-05: Equation 6 – 10)}$$

Adopt 5% damping ratio, β

$$R_n = \frac{7.47N_1}{(1+10.3N_1)^{5/3}} \text{ where } N_1 = \frac{n_1 L_z}{v_z} \text{ and } v_z = b(\frac{\check{z}}{10})^{\alpha}V = 29.96$$

$$N_1 = \frac{0.24 \times 243.92}{29.96} = 1.9540$$

$$R_n = \frac{7.47(1.9540)}{(1+10.3(1.9540))^{5/3}} = 0.09041$$

$$\eta = \frac{4.6n_1 h}{v_z} = \frac{4.6(0.24)(175)}{29.96} = 6.4486$$

$$R_h = \frac{1}{6.4486} - \frac{1}{2(6.4486)^2}[1 - e^{-(2x6.4486)}] = 0.1430$$

$$\eta = \frac{4.6n_1 B}{v_z} = \frac{4.6(0.24)(60)}{29.96} = 2.2109$$

$$R_B = \frac{1}{2.2109} - \frac{1}{2(2.2109)^2}[1 - e^{-(2x2.2109}] = 0.3512$$

$$\eta = \frac{15.4n_1 L}{v_z} = \frac{15.4(0.24)(40)}{29.96} = 4.9346$$

$$R_L = \frac{1}{4.9346} - \frac{1}{2(4.9346)^2}[1 - e^{-(2x4.9346}] = 0.1821$$

$$R = \sqrt{\frac{1}{(0.05)}(0.09041)(0.1430)(0.3512)[0.53 + 0.47(0.1821)]} = 0.2364$$

$$I_{\check{z}} = c(\frac{10}{\check{z}})^{1/6} = I_z = 0.2(\frac{10}{105})^{1/6} = 0.1352$$

Thus, $G_f = 0.925(\frac{1+1.7\,(0.1352)\sqrt{(3.4)^2\,(0.7868)^2+(3.8343)^2(0.2364)^2}}{1+1.7\,(3.4)(0.1352)} = 0.8563$

3) Determine pressure coefficient

i) External pressure coefficient *(Figure 6-6)*:

- Windward face: C_p = 0.8 → G_fC_p= 0.8563 (0.8) = 0.685
- Leeward face: C_p = -0.5 → G_fC_p= 0.8563 (-0.5) = -0.4282
- Sidewall face: C_p = -0.7 → G_fC_p= 0.8563 (0.7) = -0.5994

ii) Internal pressure coefficient *(Figure 6-5)*:

GC_{pi} for enclosed buildings: ± 0.18

4) Compute design wind pressure, p

Refer to Table 8, Table 9 and Table 10

Windward face (q = q_z, q_i = q_h)

Table 8: Wind pressure distribution acting on windward face for MWFRS

z (m)	q	qGfCp	qi(GCpi)	p (kN/m²)
0	0.52	0.36	-0.20	0.56
10	0.62	0.42	-0.20	0.62
15	0.67	0.46	-0.20	0.66
30	0.78	0.53	-0.20	0.73
45	0.85	0.58	-0.20	0.78
60	0.90	0.62	-0.20	0.82
75	0.94	0.65	-0.20	0.85
90	0.98	0.67	-0.20	0.87
105	1.01	0.69	-0.20	0.89
120	1.04	0.71	-0.20	0.91
135	1.07	0.73	-0.20	0.93
150	1.09	0.75	-0.20	0.95
165	1.12	0.76	-0.20	0.96
175	1.13	0.77	-0.20	0.97

Leeward face ($q = q_i = q_h$)

Table 9: Wind pressure distribution acting on leeward face for MWFRS

z (m)	q	qGfCp	qi(GCpi)	p (kN/m²)
0 -175	1.13	-0.48	0.20	-0.68

Sidewall face ($q = q_i = q_h$)

Table 10: Wind pressure distribution acting on sidewall face for MWFRS

z (m)	q	qGfCp	qi(GCpi)	p (kN/m²)
0 -175	1.13	-0.68	0.20	-0.88

Part 2: Design for C & C

1) Compute a

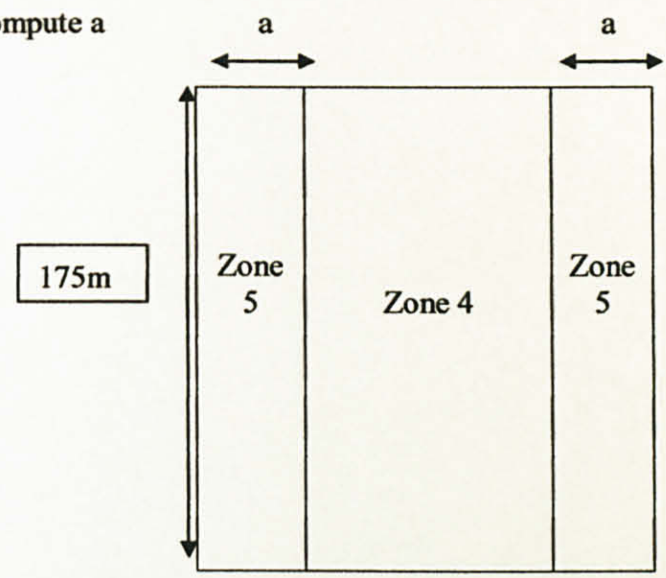


Figure 26: Illustration of Illustration of Zone 4 and Zone 5 on a building face

Windward face & leeward face: a = 0.1 x B = 0.1 x 60 = 6 m

Sidewall face: a = 0.1 x 40 = 4 m

2) Determine pressure coefficient

i) External pressure coefficient *(ASCE 7-05: Figure 6-17)*

- Windward face = Leeward face
  - Zone 4: Effective area = 48 x 175 = 8400 m²
    - $GC_p: +0.6, -0.7$
  - Zone 5: Effective area = 6 x 175 = 1050 m²
    - $GC_p: +0.6, -1.0$

- Sidewall face
  - Zone 4: Effective area = 32 x 175 = 5600 m²
    - $GC_p: +0.6, -0.7$
  - Zone 5: Effective area = 4 x 175 = 700 m²
    - $GC_p: +0.6, -1.0$

ii) Internal pressure coefficient*(Figure 6-5)*:

GC_{pi} for enclosed buildings : ± 0.18

GC_{pi} for partially enclosed buildings : ± 0.55

2) Compute design wind pressure from the following equation:

$p = q(GC_p) - q_i(GC_{pi})$ *(ASCE 7-05: Equation 6-23)*

**Refer to Table 11 until Table 16*

Windward face ($q = q_z$, $q_i = q_h$)

Zone 4, Effective Area = 8400 m²

Table 11: Wind pressure distribution acting on windward face (Zone 4) for C & C

		Fully Enclosed		Partially Enclosed		Percentage difference (%)
		GCpi= 0.18		GCpi = 0.55		
z (m)	qGCp	qi(GCpi)	p (kN/m²)	qi(GCpi)	p (kN/m²)	
0	-0.37	0.20	-0.57	0.62	-0.99	74
10	-0.43	0.20	-0.63	0.62	-1.05	67
15	-0.47	0.20	-0.67	0.62	-1.09	63
30	-0.55	0.20	-0.75	0.62	-1.17	56
45	-0.59	0.20	-0.79	0.62	-1.21	53
60	-0.63	0.20	-0.83	0.62	-1.25	51
75	-0.66	0.20	-0.86	0.62	-1.28	49
90	-0.69	0.20	-0.89	0.62	-1.31	47
105	-0.71	0.20	-0.91	0.62	-1.33	46
120	-0.73	0.20	-0.93	0.62	-1.35	45
135	-0.75	0.20	-0.95	0.62	-1.37	44
150	-0.77	0.20	-0.97	0.62	-1.39	43
165	-0.78	0.20	-0.98	0.62	-1.40	43
175	-0.79	0.20	-0.99	0.62	-1.41	42

Zone 5, Effective Area = 1050 m²

Table 12: Wind pressure distribution acting on windward face (Zone 5) for C & C

		Fully Enclosed		**Partially Enclosed**		**Percentage difference (%)**
		GCpi= 0.18		GCpi = 0.55		
z (m)	qGCp	qi(GCpi)	p (kN/m²)	qi(GCpi)	p (kN/m²)	
0	-0.52	0.20	-0.72	0.62	-1.14	58
10	-0.62	0.20	-0.82	0.62	-1.24	51
15	-0.67	0.20	-0.87	0.62	-1.29	48
30	-0.78	0.20	-0.98	0.62	-1.40	43
45	-0.85	0.20	-1.05	0.62	-1.47	40
60	-0.90	0.20	-1.10	0.62	-1.52	38
75	-0.94	0.20	-1.14	0.62	-1.56	38
90	-0.98	0.20	-1.18	0.62	-1.60	36
105	-1.01	0.20	-1.21	0.62	-1.63	35
120	-1.04	0.20	-1.24	0.62	-1.66	34
135	-1.07	0.20	-1.27	0.62	-1.69	33
150	-1.09	0.20	-1.29	0.62	-1.71	33
165	-1.12	0.20	-1.32	0.62	-1.74	32
175	-1.13	0.20	-1.33	0.62	-1.75	32

Leeward face (q = q_i = q_h)

Zone 4, Effective Area = 8400 m²

Table 13: Wind pressure distribution acting on leeward face (Zone 4) for C & C

		Fully Enclosed		**Partially Enclosed**		**Percentage difference (%)**
		GCpi= 0.18		GCpi = 0.55		
z (m)	qGCp	qi(GCpi)	p(kN/m²)	qi(GCpi)	p(kN/m²)	
0-175	-0.79	0.20	-0.99	0.62	-1.41	42

Zone 5, Effective Area = 1050 m²

Table 14: Wind pressure distribution acting on leeward face (Zone 5) for C & C

		Fully Enclosed		Partially Enclosed		Percentage difference (%)
		GCpi= 0.18		GCpi = 0.55		
z (m)	qGCp	qi(GCpi)	p(kN/m²)	qi(GCpi)	p(kN/m²)	
0-175	-1.13	0.20	-1.33	0.62	-1.75	32

Sidewall face (q = q_i = q_h)

Zone 4, Effective Area = 5600 m²

Table 15: Wind pressure distribution acting on sidewall face (Zone 4) for C & C

		Fully Enclosed		Partially Enclosed		Percentage difference (%)
		GCpi=0.18		GCpi = 0.55		
z (m)	qGCp	qi(GCpi)	p (kN/m²)	qi(GCpi)	p(kN/m²)	
0 - 175	-0.79	0.20	-0.99	0.62	-1.41	42

Zone 5, Effective Area = 1050 m²

Table 16: Wind pressure distribution acting on sidewall face (Zone 5) for C & C

		Fully Enclosed		Partially Enclosed		Percentage difference (%)
		GCpi=0.18		GCpi = 0.55		
z (m)	qGCp	qi(GCpi)	p (kN/m²)	qi(GCpi)	p(kN/m²)	
0 - 175	-1.13	0.20	-1.33	0.62	-1.75	32

APPENDIX B

OCCUPANCY CATEGORY OF BUILDING AND OTHER STRUCTURES – ASCE 7-05

TABLE 1-1 OCCUPANCY CATEGORY OF BUILDINGS AND OTHER STRUCTURES FOR FLOOD, WIND, SNOW, EARTHQUAKE, AND ICE LOADS

Nature of Occupancy	Occupancy Category
Buildings and other structures that represent a low hazard to human life in the event of failure, including, but not limited to: • Agricultural facilities • Certain temporary facilities • Minor storage facilities	I
All buildings and other structures except those listed in Occupancy Categories I, III, and IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with daycare facilities with a capacity greater than 150 • Buildings and other structures with elementary school or secondary school facilities with a capacity greater than 250 • Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients, but not having surgery or emergency treatment facilities • Jails and detention facilities Buildings and other structures, not included in Occupancy Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure, including, but not limited to: • Power generating stations[a] • Water treatment facilities • Sewage treatment facilities • Telecommunication centers Buildings and other structures not included in Occupancy Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released. Buildings and other structures containing toxic or explosive substances shall be eligible for classification as Occupancy Category II structures if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the toxic or explosive substances does not pose a threat to the public.	III

APPENDIX C

INTERNAL PRESSURE COEFFICIENT, GC_{PI} – ASCE 7-05

Main Wind Force Res. Sys. / Comp and Clad. – Method 2		All Heights
Figure 6-5	Internal Pressure Coefficient, GC_{pi}	Walls & Roofs
Enclosed, Partially Enclosed, and Open Buildings		

Enclosure Classification	GC_{pi}
Open Buildings	0.00
Partially Enclosed Buildings	+0.55 -0.55
Enclosed Buildings	+0.18 -0.18

Notes:

1. Plus and minus signs signify pressures acting toward and away from the internal surfaces, respectively.
2. Values of GC_{pi} shall be used with q_z or q_h as specified in 6.5.12.
3. Two cases shall be considered to determine the critical load requirements for the appropriate condition:

   (i) a positive value of GC_{pi} applied to all internal surfaces
   (ii) a negative value of GC_{pi} applied to all internal surfaces

APPENDIX D

EXTERNAL PRESSURE COEFFICIENT, C_P (MWFRS) - ASCE 7-05

Main Wind Force Resisting System – Method 2		All Heights
Figure 6-6 (con't)	External Pressure Coefficients, C_p	Walls & Roofs
Enclosed, Partially Enclosed Buildings		

Wall Pressure Coefficients, C_p

Surface	L/B	C_p	Use With
Windward Wall	All values	0.8	q_z
Leeward Wall	0-1	-0.5	q_h
	2	-0.3	
	≥4	-0.2	
Side Wall	All values	-0.7	q_h

Roof Pressure Coefficients, C_p, for use with q_h

Wind Direction	Windward									Leeward		
	Angle, θ (degrees)									Angle, θ (degrees)		
	h/L	10	15	20	25	30	35	45	≥60#	10	15	≥20
Normal to ridge for θ ≥ 10°	≤0.25	-0.7 -0.18	-0.5 0.0*	-0.3 0.2	-0.2 0.3	-0.2 0.3	0.0* 0.4	0.4	0.01 θ	-0.3	-0.5	-0.6
	0.5	-0.9 -0.18	-0.7 -0.18	-0.4 0.0*	-0.3 0.2	-0.2 0.2	-0.2 0.3	0.0* 0.4	0.01 θ	-0.5	-0.5	-0.6
	≥1.0	-1.3** -0.18	-1.0 -0.18	-0.7 -0.18	-0.5 0.0*	-0.3 0.2	-0.2 0.2	0.0* 0.3	0.01 θ	-0.7	-0.6	-0.6

Wind Direction	h/L	Horiz distance from windward edge	C_p
Normal to ridge for θ < 10 and Parallel to ridge for all θ	≤ 0.5	0 to h/2	-0.9, -0.18
		h/2 to h	-0.9, -0.18
		h to 2 h	-0.5, -0.18
		> 2h	-0.3, -0.18
	≥ 1.0	0 to h/2	-1.3**, -0.18
		> h/2	-0.7, -0.18

*Value is provided for interpolation purposes.

**Value can be reduced linearly with area over which it is applicable as follows

Area (sq ft)	Reduction Factor
≤ 100 (9.3 sq m)	1.0
200 (23.2 sq m)	0.9
≥ 1000 (92.9 sq m)	0.8

Notes:

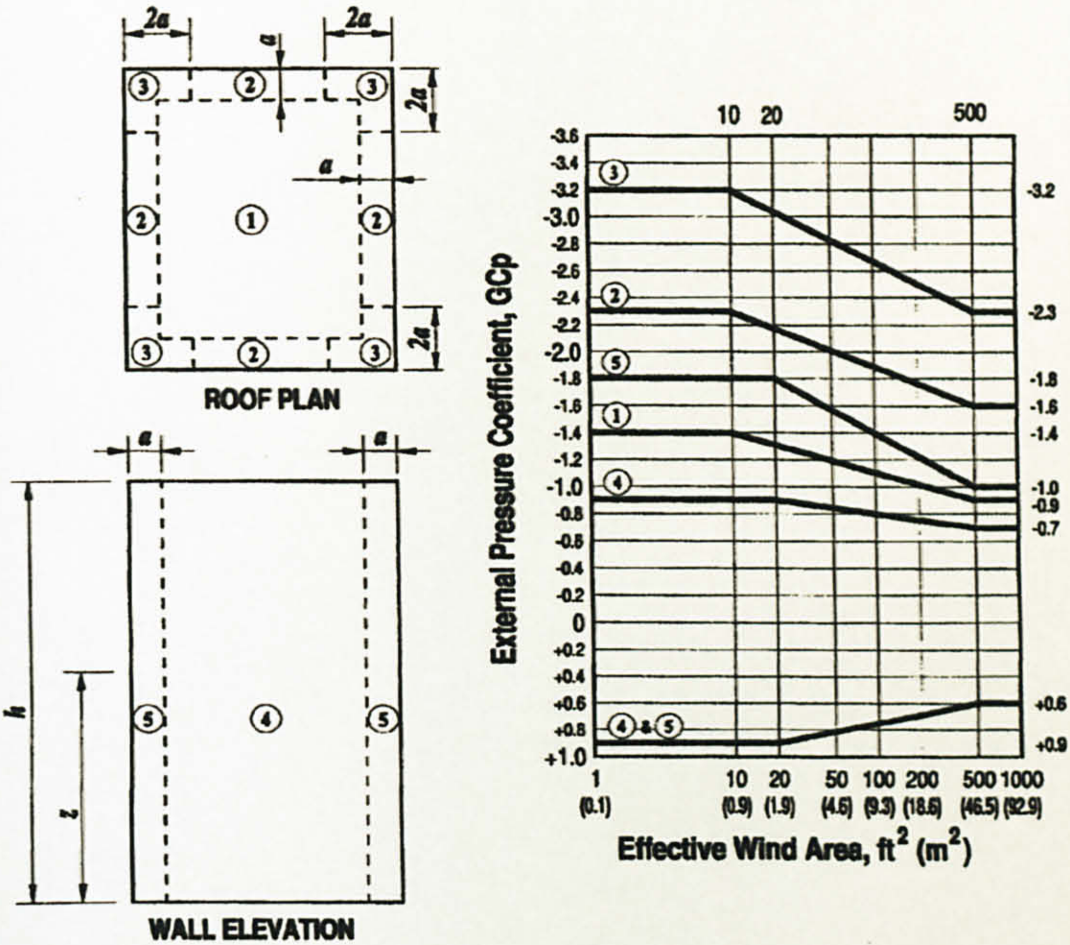
1. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
2. Linear interpolation is permitted for values of *L/B*, *h/L* and θ other than shown. Interpolation shall only be carried out between values of the same sign. Where no value of the same sign is given, assume 0.0 for interpolation purposes.
3. Where two values of C_p are listed, this indicates that the windward roof slope is subjected to either positive or negative pressures and the roof structure shall be designed for both conditions. Interpolation for intermediate ratios of h/L in this case shall only be carried out between C_p values of like sign.
4. For monoslope roofs, entire roof surface is either a windward or leeward surface.
5. For flexible buildings use appropriate G_f as determined by Section 6.5.8.
6. Refer to Figure 6-7 for domes and Figure 6-8 for arched roofs.
7. Notation:
   B: Horizontal dimension of building, in feet (meter), measured normal to wind direction.
   L: Horizontal dimension of building, in feet (meter), measured parallel to wind direction.
   h: Mean roof height in feet (meters), except that eave height shall be used for θ ≤ 10 degrees.
   z: Height above ground, in feet (meters).
   G: Gust effect factor.
   q_z, q_h: Velocity pressure, in pounds per square foot (N/m^2), evaluated at respective height.
   θ: Angle of plane of roof from horizontal, in degrees.
8. For mansard roofs, the top horizontal surface and leeward inclined surface shall be treated as leeward surfaces from the table.
9. Except for MWFRS's at the roof consisting of moment resisting frames, the total horizontal shear shall not be less than that determined by neglecting wind forces on roof surfaces.

#For roof slopes greater than 80°, use C_p = 0.8

APPENDIX E

EXTERNAL PRESSURE COEFFICIENT, GC_P (C & C) – ASCE 7-05

Components and Cladding Method 2		h > 60 ft.
Figure 6-17	External Pressure Coefficients, GCp	Walls & Roofs
Enclosed, Partially Enclosed Buildings		



Notes:

1. Vertical scale denotes GC_p to be used with appropriate q_z or q_h.
2. Horizontal scale denotes effective wind area A, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Use q_z with positive values of GC_p and q_h with negative values of GC_p.
5. Each component shall be designed for maximum positive and negative pressures.
6. Coefficients are for roofs with angle $\theta \leq 10°$. For other roof angles and geometry, use GC_p values from Fig. 6-11 and attendant q_h based on exposure defined in 6.5.6.
7. If a parapet equal to or higher than 3 ft (0.9m) is provided around the perimeter of the roof with $\theta \leq 10°$, Zone 3 shall be treated as Zone 2.
8. Notation:
   - a: 10 percent of least horizontal dimension, but not less than 3 ft (0.9 m).
   - h: Mean roof height, in feet (meters), except that eave height shall be used for $\theta \leq 10°$.
   - z: height above ground, in feet (meters).
   - θ: Angle of plane of roof from horizontal, in degrees.

APPENDIX F

IMPORTANCE FACTOR, *I* – ASCE 7-05

Importance Factor, I (Wind Loads)

Table 6-1

Category	Non-Hurricane Prone Regions and Hurricane Prone Regions with V = 85-100 mph and Alaska	Hurricane Prone Regions with V > 100 mph
I	0.87	0.77
II	1.00	1.00
III	1.15	1.15
IV	1.15	1.15

Note:

1. The building and structure classification categories are listed in Table 1-1.

APPENDIX G

WIND DIRECTIONALITY FACTOR, K_D

Wind Directionality Factor, K_d

Table 6-4

Structure Type	Directionality Factor K_d*
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Round	0.95
Solid Signs	0.85
Open Signs and Lattice Framework	0.85
Trussed Towers	
Triangular, square, rectangular	0.85
All other cross sections	0.95

*Directionality Factor K_d has been calibrated with combinations of loads specified in Section 2. This factor shall only be applied when used in conjunction with load combinations specified in 2.3 and 2.4.

APPENDIX H

BASIC WIND SPEED, *V*

Station	V_{20}	$V_s = V_{50}$	V_{100}
Temerloh	25.1	27.4	29.1
Tawau	24.6	26.6	28.1
Subang	29.2	32.1	34.3
Sri Aman	27.6	30.3	32.4
Sitiawan	23.3	25.3	26.7
Sibu	27.0	29.3	31.0
Senai	26.9	29.0	30.7
Sandakan	23.4	25.8	27.7
Petaling Jaya	28.8	31.4	33.4
Muadzam Shah	22.6	24.4	25.8
Miri	26.9	29.0	30.5
Mersing	29.3	32.0	33.8
Melaka	26.7	29.4	31.3
Labuan	26.0	27.7	29.0
Kudat	27.1	29.1	30.6
Kuala Terengganu	25.5	27.2	28.5
Kuantan	27.3	29.8	31.6
Kluang	29.6	32.6	34.9
Kuala Krai	27.2	29.5	31.3
Kuching	29.3	32.6	34.9
Kota Bahru	30.0	32.4	34.2
Kota Kinabalu	28.3	30.5	32.2
Ipoh	30.6	33.5	35.7
Chuping	23.8	25.6	27.0
Cameron Highlands	25.2	26.8	28.0
Butterworth	24.6	26.4	27.7
Batu Embun	25.3	27.3	29.2
Bayan Lepas	25.6	27.3	28.9
Bintulu	23.9	25.6	26.9
Alor Setar	27.2	29.9	31.8

Note: This tabulation of basic wind speed was adopted from the Malaysian Meteorological Services (Jabatan Kajicuaca Malaysia).