LIGHTNING ANALYSIS & PROTECTION

By

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

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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.

Siti Hajar Binti Jaafar

ABSTRACT

Lightning is devastating and carry very high current of about 200,000 A! This natural phenomenon cannot be stopped and cannot be eliminated. It causes danger towards life and structure, and causes losses of millions ringgit. Various lightning codes and standards have been practiced worldwide. However, there is no standard lightning code that has been established in Malaysia to enforce lightning protection system. This project has been conducted to determine major causes of lightning damages and to develop a program to determine risk factors of structures towards lightning. The project will also propose the suitable lightning protection and design system which could reduce the risk factors. Several lightning cases will be discussed and analyzed to determine the root causes of the incidents. Australian, New Zealand, British and IEC codes and standards will be used to discuss risk factor analysis. The outcome of this project is to develop lightning protection program that can reduce the lightning risk factor of structures.

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CHAPTER 1

INTRODUCTION

This chapter discusses the background of the project, the problem statement, the objectives, and scope of the study. Problem statements are focused on the situation of the problem and research question which led to the objectives of the study. Students are required to clarify the boundary project work to ensure the feasibility within the given time frame.

1.1 Background of Study

Lightning is a natural phenomenon that brings huge losses and hazard to human being, animals, plants, and structures. This phenomenon cannot be stopped or eliminate. The most powerful strike is about 200 kA which could light up half a million of 100 W bulbs [1]. Lightning occurs in a few micro seconds, but leaves a very huge effect.

When lightning strikes a sky-scrapper building, usually it hits one of the corners of the building. Presumably electric fields induced on the building from a downward progressing leader from a thundercloud are largest at the corners and initiate upward leaders from these points [1]. Lightning protection system has been discussed by various scientist and intellectual such as Benjamin Franklin, Martin A. Uman, Harvoth, Cooray, Peter Hasses, and many more. However this topic needs more attention and research due to the protection from damages and safety purposes. Thus, various countries develop their standard and call upon meeting and discussion to set the standard of lightning protection system.

Malaysia has been highlighted due to the active lightning activities and high frequency of thunderstorm day annually. However this issue has not been taken seriously by Malaysians yet. Thus currently there is no particular standard for Malaysia. There is no firm regulation or enforcement body to see to the proper design and to ensure that installation of the lightning protection system is carried out. However, there are numerous private companies and consultants who offer to provide such services. Common lightning protection system that has been offered can cost up to RM15, 000 for 3-storey bungalow and RM800, 000 for high rise building [2]. Various types and methods will be discussed in this topic to clarify and determine reliable and dependable lightning protection.

1.2 Problem Statement

Lightning can cause injury and even death to people and animal. Lightning strikes on structures and buildings can cause damages to the properties and incur huge losses. For high voltage transmission, lightning causes spark, flashes, and even fire which is very dangerous and involve high cost of recovery. However not enough attention are being paid on this issue. There is no standard code that are being practiced or enforced to ensure safety or protection from lightning in this country.

1.3 Objective & Scope of Study

The objectives of this project are;

1. To discuss and explore the available lightning codes, standards and practices of certain selected countries.
2. To determine major causes of lightning and damages via case study.
3. To perform in depth mathematical analysis or modeling to determine the parameters that affects the risk.
4. To develop a program to determine risk factors of structures towards lightning damages.
5. To propose suitable lightning protection to reduce the risk factors of the structures.

1.4 Relevancy

The significance of this research is to make people aware how dangerous lightning is. As our country becomes more developed we experience a rapid increase in the number of structures and buildings. Thus, it is very important to know whether the structures or even the house that we lived in are safe as far as lightning strike is concern. It is appropriate and relevant to involve the various codes and standards so that the protection aspects towards lightning are well known and the public would not be cheated by company that provide non-standard protection. Since there is no enforcement body that checks on these protection systems and their effectiveness, the engineers must decide on the suitable protection for our safety.

1.5 Feasibility

It is feasible to complete the project within the scope and time frame, while maintaining substance to this project.

During the first semester (FYP I), the scope and task that will be covered are;

1. Review of lightning physics.
2. Determine and elaborate lightning code and practices from various countries.
3. Analyze several lightning incidents and their causes & effects.

For the following semester (FYP II), the scope and task that will be covered are;

1. Perform in depth mathematical analysis to determine the parameter that affects the risk.
2. Develop a program to determine risk factors of structures and propose suitable protections for the structures.

CHAPTER 2

LITERATURE REVIEW

This chapter will cover lightning theory and physics, codes & practices, lightning protection systems and incidences that occur due to lightning. How the lightning occurs, the effects and the physics behind the event will be discussed. Various codes and standards that have been practiced for the safety recommendation of lightning protection will also be elaborated.

2.1 Lightning Characteristic

Lightning can be defined as a bright flash of light that appear in the sky during storm. It gives out light in a crooked direction, moves swiftly, can be conducted through metals and gives out noise in exploding. It can melt metals, set fire to inflammable substances, and has sulphureous smell [3].

Lightning formation can be described as in Figure 1. Within a thundercloud, frozen raindrops bump into each other as they move around in the air. The positive charges or protons form at the top of the cloud and the negative charges or electrons form at the bottom of the cloud. Usually ground surface has a positive charge. Since opposite charges attract, the negative charges at the bottom of the thundercloud want to link up with the positive charges of the ground surface.

Once the negative charge at the bottom of the cloud gets large enough, a flow of negative charges rush toward the ground which is known as a stepped leader. When the stepped leader and the positive charges from the ground meet, a strong electric current carries positive charge up into the cloud. The steps are typically 50 m long and a few meters in diameter [4]. This electric current is known as the return stroke, also known as lightning.

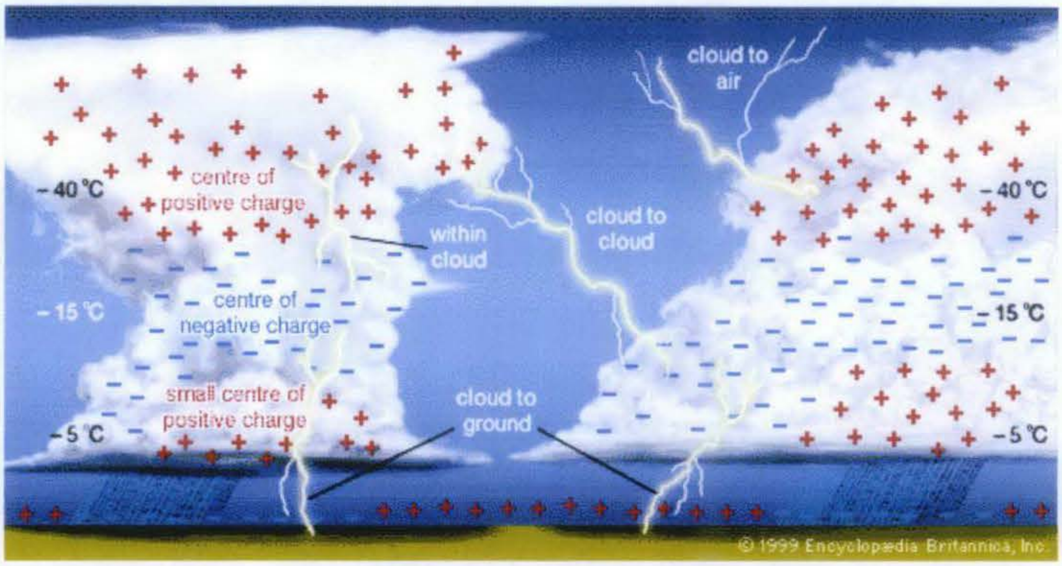


Figure 1 Formation of Lightning [5].

Lightning discharge can be classified into two groups – intercloud discharges and ground strikes. An intercloud spark is never a straight line, but rather has numerous bends and branching. Normally, the spark channel can be as long as several kilometers to dozens of kilometers [6].

Figure 2 shows the variation points of lightning discharges. Lightning discharge can occur in a few ways such as indirect lightning discharge on overhead distribution lines (A and B); Induced lightning discharge - electromagnetic coupling on incoming power or Telecom networks (C); Direct lightning discharge (D), Indirect lightning discharge - potential differences (E); Induced lightning discharge - electromagnetic coupling on internal and external conductors (F).

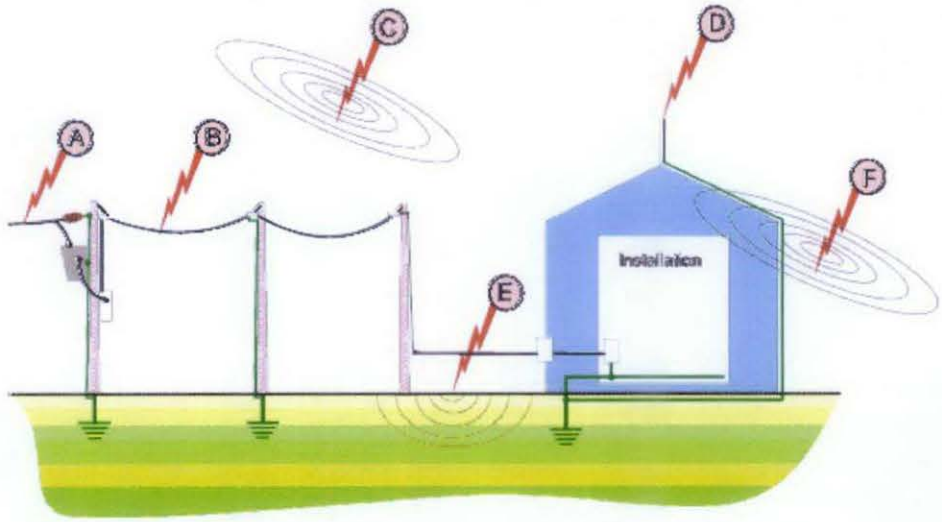


Figure 2 Typical Lightning Discharge

2.2 Lightning Frequency Distribution

Lightning frequency distribution can be measured by using the thunderstorm occurrence which is expressed in terms of the number of calendar days in year when thunder is heard at the location, averaged over several years. This study will focus on the lightning distribution in our country. However, for analysis and comparison purposes, data and information from other countries will also be stated.

The world map thunderstorm days is given in Appendix A. The map shows that most of the countries near the equator line have higher frequency of thunderstorm days [7]. High frequency of thunderstorm days per year means high frequency of lightning phenomena. The map also shows that Malaysia is among the countries with the highest frequency of thunderstorm days per year. In the Malaysia map thunderstorm days was given in Appendix B, the highest frequency thunderstorm is in Subang, Selangor (200 thunderstorm days per year) and Ipoh, Perak (197 thunderstorm days per year) [8]. This fact should make people aware that our country needs to pay attention of this phenomenon before more incidents and losses happen.

2.3 Lightning & Transient Overvoltage

Lightning activity can caused transient overvoltage on mains power supplies and data communication, signal or telephone line. A transient overvoltage is a **short duration increase in voltage** measured between two or more conductors. This transient overvoltage occurs in milliseconds (millionths of a second) to a few milliseconds (thousandths of a second) in duration. Transient overvoltages are by definition a very specific form of disturbance. Most of these disturbances can be represented as an aberration to the normal mains power supply.

Lightning discharges are claimed to have currents of up to 530,000 A, although 200,000 A is an accepted upper limit [9]. When lightning hit a building without a structural lightning protection scheme, this current would seek a path to earth through the building and its component's structure – in an erratic and unpredictable manner. The building is likely to be damaged and may even catch fire. Although transient overvoltage will occur, this may be just one aspect of extensive damage to the building and its content. Transient overvoltage may be caused through resistive, inductive, and capacitive coupling. Thus some protection measure has to be taken into account to avoid this natural hazard and disaster.

2.4 Common misconceptions

Most of people do not really understand the lightning phenomenon or have lack of knowledge about it. Some of the common misconceptions are;

1. Lightning strike high structures only.

   Actually, lightning can 'jump' to the nearby structures to create a short path to quickly dissipate the lightning discharge to the ground. Lightning can also strike at low structures, even at the open areas such as under the trees, bus stop, golf course, football field, and etc.

2. Lightning never strike twice at the same spot.

   The real fact is, lightning easily often strike the structures that has been struck before, because once struck it has created a 'good path' to go to the ground through the structure. For example, lightning strike the Statue of Liberty more than 150 times per year.

3. Lightning occurs during a heavy rain only.

   In reality, lightning can also occur during drizzles or light rain.

4. Lightning strikes only come from the top of structures.

   Lightning can strike from the top, from the side or even from the bottom of the building. However, the current from lightning flow to discharge, it create some potential and may induce the nearby object. Thus the object or structures nearby will be affected too.

2.5 Lightning Code, Standard, and Practice

In Malaysia, we do not have our own lightning code but usually practices other countries codes and standards. For whatever reason, the authority has not yet given an ACT to follow suitable standard for lightning protection. Most Engineers, Consultant and Construction Companies refer to British, International Engineering Council IEC, Australian, New Zealand and other country for lightning protection. These situations produce the qualities of tact and resistance to make money from supplier to produce their own product which are claimed to be the best solution for lightning protection.

2.5.1 British Standard, BS 6651

This code of standards BS6651:1992 has been prepared under the direction of the General Electrotechnical Standard Policy Committee and supersedes BS6651:1990, which is withdrawn. In this standard, there are 5 elements that have to be taken into account in calculating the weighting factor of lightning protection as given in the tables below. BS6651 stated that weighting factor that is more than 10^{-5} require the installation of lightning protection. Tables 1 to 5 show the risk factor for the various parameters of structure according to the British standard.

Table 1 Risk Factor A based on Use of Structures

A. Use of Structures	**Factor**
Houses and other building of comparable size	0.3
Houses and other building of comparable size with outside aerial	0.7
Factories, workshop, laboratories	1.0
Office block, hotels, flats, other residential buildings other than indicated below	1.2
Places of assembly, e.g. Churches, halls, theatres, museums, exhibitions, department stores, post offices, stations, airports, and stadium structures	1.3
Schools, hospitals	1.7

Table 2 Risk Factor B based on Type of Construction

B. Type of Construction	**Factor**
Steel framed encased with any roof other than metal	0.2
Reinforced concrete with any roof other than metal	0.4
Steel framed encased or reinforced concrete with metal roof	0.8
Brick, plain concrete or masonry with any roof other than metal or thatch	1.0
Timber framed or clad with any roof other than metal or thatch	1.4
Brick, plain concrete, masonry, timber framed but with metal roofing	1.7
Any building with thatched roof	2.0
* Structure of exposed metal which is continuous down to ground level is excluded from the table as it requires no lightning protection beyond adequate earthing arrangement.	

Table 3 Risk Factor C based on Content of Structures

C. Contents or consequential effects	**Factor**
Ordinary domestic or office buildings, factories and workshops not containing valuable or specially susceptible contents	0.3
Industrial and agricultural buildings with specially susceptible contents	0.8
Power station, gas installation, telephone exchanges, radio station	1.0
Key industrial plants, ancient monuments and historic buildings museums, art, galleries or other buildings with specially valuable contents	1.3
Schools, hospitals, place of assembly	1.7

Table 4 Risk Factor D based on Degree of Isolation

D. Degree of Isolation	**Factor**
Structure located in a large area of structures or tree of the same or greater height (e.g. In large town or forest)	0.4
Structures located in an area with few other structures or tree of similar height	1.0
Structures completely isolated or exceeding at least twice the height of surrounding structures or trees	2.0

Table 5 Risk Factor E based on Type of Terrain

E. Type of Terrain	**Factor**
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300m and 900m	1.3
Mountain country above 900m	1.7

The calculation of the risk factor for any particular building or structure can be calculated by multiplying the risk factors for each existing point reference. Some basic formula will be used on determining the necessity of lightning protection.

Collection area,

$$A_c = (L \times W) + 2(L \times H) + 2(W \times H) + \pi H^2$$

where;

A_c is Collection area
L is Length
W is Width
H is Height

Probability of being struck per year,

$$P = A_c \times N_g \times 10^{-6}$$

where;

P is Probability of being struck
A_c is Collection area
N_g is Ground Flash Density

Weighting factor,

$$WF = A \times B \times C \times D \times E$$

where;

WF is Weighting factor
A is Risk factor based on use of structures
B is Risk factor based on type of construction
C is Risk factor based on content of structures
D is Risk factor based on degree of isolation
E is Risk factor based on type of terrain

Overall risk factor,

$$ORF = WF^2 \times 10^{-3}$$

where;

ORF is Overall risk factor
WF is Weighting factor

If the $ORF \leq 10^{-5}$, lightning protection system is not necessary.

But if the $ORF > 10^{-5}$, the lightning protection system is required.

Sample calculation

A hospital in the Thames Valley is 10 m high and covers an area of 70 m x 12 m. The hospital is located in a flat country and isolated from other structures. The construction is of brick and concrete with non-metallic roof. Is lightning protection necessary? (Given no. of flashes per km^2, $N_g = 0.6$)

Collection area,

$$A_c = (L \times W) + 2(L \times H) + 2(W \times H) + \pi H^2$$

$$A_c = (70 \times 12) + 2(70 \times 10) + 2(12 \times 10) + \pi 10^2$$

$$= 2794$$

Probability of being struck per year

$$P = A_c \times N_g \times 10^{-6}$$

$$P = 27944 \times 0.6 \times 10^{-6}$$

$$= 1.7 \times 10^{-3}$$

Weighting Factor, (refer to the suitable factor in the risk factor table 1 – 5)

From the risk factor tables, A: 1.7, B: 1.0, C: 1.7, D: 2.0, E: 0.3

$$WF = A \times B \times C \times D \times E$$

$$WF = 1.7 \times 1.0 \times 1.7 \times 2.0 \times 0.3$$

$$= 1.734$$

And overall risk factors

$$ORF = WF^2 \times 10^{-3}$$

$$ORF = 1.734^2 \times 10^{-3}$$

$$= 3 \times 10^{-3}$$

From this sample calculation, $ORF > 10^{-5}$. Therefore suitable lightning protection is required to be installed for this building.

Although it does not mention about the height of the structure in the weighting factor, the protective angle seems to be important. For structures not exceeding 20 m height, the angle is within the protective range. However, for structures above 20 m, there is a possibility of such buildings being struck on the sideway; thus it is recommended to provide lightning protection [10].

2.5.2 British Standard, BSEN 62305

BSEN 62305 has replaced the previous version of BS 6651 due to several reason. This new standard handles lightning protection in a much more in-depth and detailed manner. The British Standard European Norm (BSEN) 62305 series consist of the following parts, under the general title "Protection against lightning"

Part 1: General principles
Part 2: Risk Management
Part 3: Physical damage to structure and life hazard
Part 4: Electrical and Electronic systems within structures

Part 1 introduces the other parts of the standard and essentially describes how to design a Lightning Protection System (LPS) in accordance with the accompanying parts of the standard. Part 2 does not concentrate so much on purely physical damage to a structure caused by lightning discharge, but more on the risk of loss of human life, loss of service to the public, loss of cultural heritage and economic loss. Part 3 relates directly to the major part of BS 6651, but differ as much that this new part has four classes of protection levels of LPS. Part 4 covers the protection of electrical and electronic systems housed within structures. This part essentially embodies what Annex/ Appendic C in BS 6651 carried out, but with a new zonal approach.

2.5.3 International Standard IEC 62305

The International Electrotechincal Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). IEC 62305 Lightning Protection is produced in accordance with the New Publications Plan approved by National Committees. IEC 62305 is quite similar to BSEN 62305 which covers four main parts. The minor difference between these two standard will be explained in the next chapter.

2.5.4 Australia & New Zealand Standard, NZS/AS 1768

In Australia, the standard were first published as ASMC1:1969 and revised and re-designated as AS1768:1975, second edition in 1983, and third edition in 1991. In New Zealand they were first published as NZS/AS1768:1991. Both of these were published jointly by Standards Australia (Homebush NSW) and Standards New Zealand (Wellington). This standard is intended to provide authoritative guidance on the principles and practice of lightning protection for a wide range of structures and systems, but excludes those owned or operated by public utilities and statutory authorities. It is not intended for mandatory application but, if called up in a contractual situation, compliance with this Standard requires compliance with all relevant clauses of the Standard. [11]

There are several sections that have not been discussed in British Standard but will be discussed in Australia-New Zealand Standard; Behavioral precautions for personal safety, Protection of buildings, Protection of persons and equipment within building, Protection of miscellaneous structures and property, Protection of structures with explosive or highly-flammable contents, Installation and maintenance practice. It seems that this standard has more section compared to the British's Standard section. The relevance of this difference is because there are major fatalities and incidences in Australia and New Zealand reported.

Tables 6 to 10 contains the risk factors for this standard which are based on Types of structures, Construction, Height, Situation, and Lightning Prevalence Comparing with British Code, Australian-New Zealand Code calculate risk index by using summation of the risk factors. The assessment of risk and the needs for protection are shown in Table 11, and the examples of calculation upon evaluation for the need for protection are shown in Table 12.

Table 6 Risk Factor A based on Type of Structure

A. Type of Structure	**Factor**
Protection not justified having regard to nature of building, occupancy and contents	-10
Structure and content inert, occupation infrequent, e.g. domestic outbuilding, farm shed, roadside hoarding, metal chimney or mast	0
Structure containing ordinary equipment or a small number of people, e.g. domestic dwelling, store, shop, small factory, railway station, tent or marquee	1.0
Structure or contents of fair importance e.g. water tower, store with valuable contents, office, factory or residential building, non-metallic chimney or mast	2.0
Cinema, Church, School, boat, historical monument of medium importance, densely populated marquee	3.0
Museum, art gallery, stadium, entertainment complex, telephone exchange, computer centre, aircraft hangar, airport terminal, airport control tower, lighthouse, industrial plant, power station, historical monument or tree of major importance	4.0
Petrol and gas installation, hospital	5.0
Explosive building	15.0

Table 7 Risk Factor B based on Construction

B. Construction	**Factor**
Fully metallic structure, electrically continuous	0
Reinforced concrete or steel frame with metallic roof	1.0
Reinforced concrete or steel frame with concrete or other non-metallic roof Cottage or small building of timber or masonry with metallic roof	2.0
Large area building of timber or masonry with metallic roof Small building of timber or masonry with non-metallic roof	3.0
Large area building of timber or masonry with non-metallic roof Large tent or marquee of flammable material Membrane structures with metallic frame	4.0

Table 8 Risk Factor C based on Height

C. Height of Structure, m	**Factor**
0 < Height < 6	0
6 < Height < 12	2.0
12 < Height < 17	3.0
17 < Height < 25	4.0
25 < Height < 35	5.0
35 < Height < 50	6.0
50 < Height < 70	7.0
70 < Height < 100	8.0
100 < Height < 140	9.0
140 < Height < 200	10.0
Height > 200	11.0

Table 9 Risk Factor D based on Situation

D. Situation	**Factor**
On the flat, at any elevation	0
Hillside up to three-quarters of the way up, or mountainous country up to 1000m	1.0
Mountain top above 1000m	2.0

Table 10 Risk Factor E based on Lightning Prevalence

E. Average Thunder day per year	**Factor**
0 < Thunder day < 2	0
2 < Thunder day < 4	1.0
4 < Thunder day < 8	2.0
8 < Thunder day < 16	3.0
16 < Thunder day < 32	4.0
32 < Thunder day < 64	5.0
Thunder day > 64	6.0

Table 11 Assessment of risk and need for protection

Risk Index, R **(R = A + B + C + D+ E)**	**Assessment of Risk**	**Need for Protection**
< 11	Negligible	Not needed
11	Small	Not needed
12	Fair	Might be advisable
13	Medium	Advisable
14	Great	Strongly advisable
>14	Very Great	Essential

Table 12 Evaluation of the need for protection

Example	**A**	**B**	**C**	**D**	**E**	**R**	**Assessment**	**Protection**
10m high domestic dwelling, bricks walls, non-metallic roof located on hillside – 15 thunder days	1	3	2	1	3	10	Negligible	Not Needed
10m high marquee located on flat - 40 thunder days	3	4	2	0	5	14	Great	Strongly advisable
24m high office building, reinforced concrete, located on flat - 15 thunder days	2	2	4	0	3	11	Small	Not needed
16m high wooden masted yacht on open sea - 10 thunder days	3	3	3	0	3	12	Fair	Might be advisable
20m high historic tree on flat - 60 thunder days	3	3	4	0	5	15	Very Great	Essential
15m high aircraft hangar, steel frame with metallic roof located in hilly country at 1000m - 15 thunder days	4	1	3	2	3	13	medium	Advisable

2.6 Lightning Protection System

Lightning protection is a system that should be able to withstand, protect from damages & losses, and could reduce the chances of damages to the building. The basic installations of lightning protections should cover the external, internal, and equipotential of the structures. For external part, there are air terminal systems, down conductors, and earthing system. In the other part, for internal structures the protection should prevent the magnetic and electric implications. Lightning Protection also convey the equipotential structures so that it could reduce the potential difference caused by lightning current.

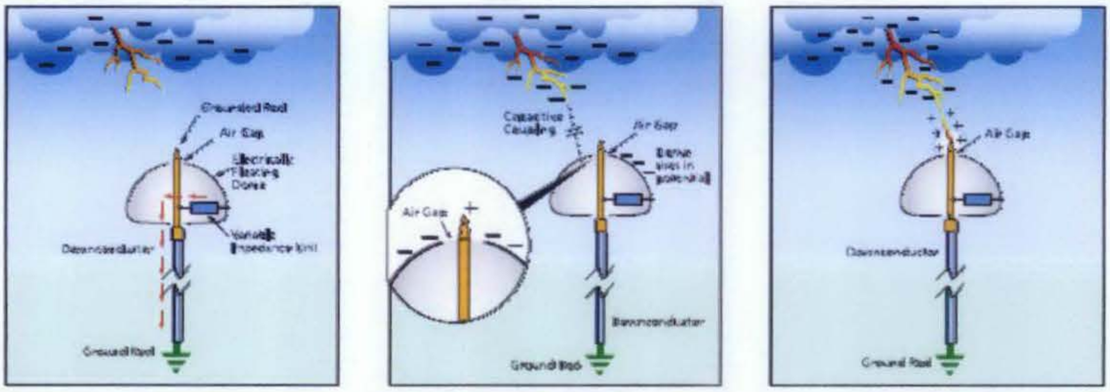
The primary task of lightning protection are to intercept lightning by air termination; discharge lightning current through down conductor or earthing systems to dissipated into the ground; and ohmically, capacitively, inductively 'incoupled' interferences must be reduced to a harmless value [12].

2.7 Lightning Protection Method

There are various types of lightning protection method that has been practiced in worldwide scenario. It covers houses, factories, hotel, high rise building, NASA, and many more. Different structures have different criteria and protection zone. Since the damages from lightning are very huge and the cost of the protection system is very expensive, thus the process of determining good and reliable system is very tedious. Various method either conventional or non-conventional lightning protection has been developed by scientist and researcher for example, Early Streamer Emission ESE, Mesh method, Protection angle (cone protection), Rolling spheres and etc. Conventional is standard which comply with the technical codes of practice while unconventional is non-standard that do not comply with the national and/or international standards.

2.7.1 Early Streamer Emission, ESE

The working principle of ESE system is shown in Figure 3. Early Streamer Emission, ESE principal states that one can increase the striking distance by the artificial generation of streamers or corona discharges from a lightning conductor as the leader propagates towards the ground [13]. When downward leader from the thunderstorm is approaching to ground surface, ESE Air Terminal has short initiation time in microseconds of creates an upward streamer compare to conventional lightning rod. There are different types of ESE Air Terminal on the market today. Each type of ESE Air Terminal has a different protective radius stated by its manufacture. This system works by collection and storing ground charge during the initial phase of thunderstorm development [14]. However, research has been done to distract lightning with non-conventional lightning protection which is Early Streamer Emission, ESE. However this type of protection has been proven unreliable. Representative of scientist from 15 countries including USA, Japan, Britain, and 12 countries from Continental Europe, and 14 of them are well known university professors oppose this ESE air terminals [15].



Static Thunderstorm Phase

Dynamic Thunderstorm Phase

Controlled Triggering Streamer Phase

Figure 3 Working principle of ESE system [16]

2.7.2 Mesh Method

This method is well known as Faraday cage which enclosure formed by conducting material or by a mesh of such material. It consists of series of horizontal air terminations (copper tape), which are bonded to vertically descending down conductors as shown in Figure 4. The structural steel if bonded may also be used to conduct the lightning impulse [17]. This method is suitable for plain surfaces with condition of air termination conductors must be positioned at roof edges, on roof overhangs and on the ridges of roofs with a pitch in excess of 1 in 10 (5.7°), and no metal installation protrudes above the air termination system [18].

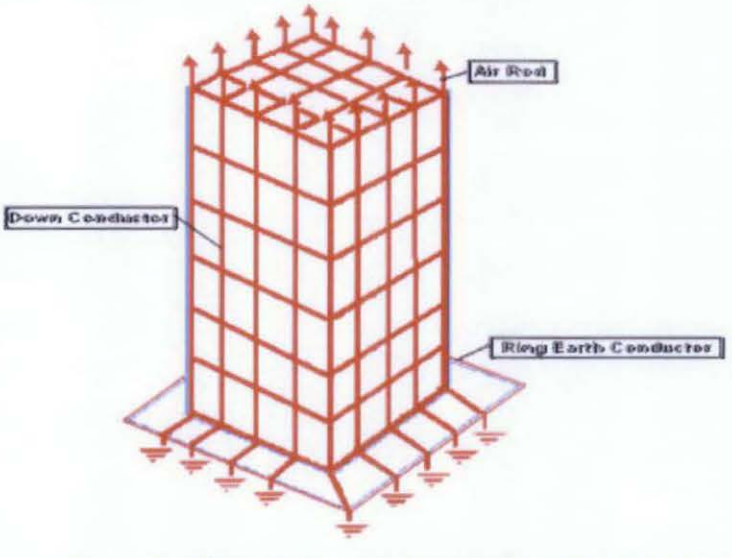


Figure 4 Illustration principal of Mesh Method [19].

2.7.3 Protection Angle

This method is adequate for the design protection of small structures. The zone of protection or protected volume provided by a lightning rod or other grounded vertical conductor considered imaginary cone called "cone of protection" [20]. Figure 5 illustrates the cone of protection.

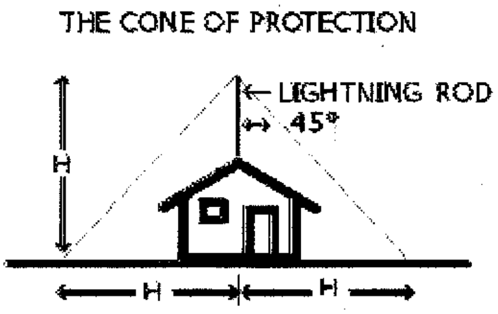


Figure 5 The Cone of Protection [21]

2.7.4 Rolling Sphere

This method was developed by Ralph H. Lee in 1977 for shielding buildings and industrial plants. The working principal of this method is using an imaginary sphere of radius *S* over the surface of a structure which the sphere rolls up and over the structure as shown in Figure 6 [22].

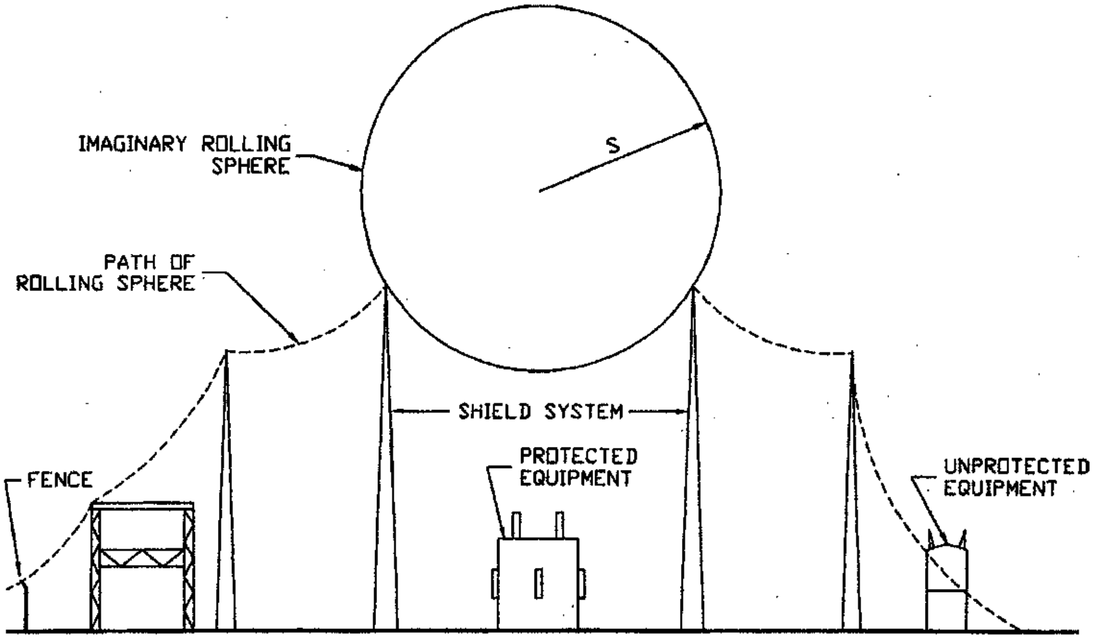


Figure 6 Rolling Sphere Methods [22]

2.8 Components of Lightning Protection Systems

According to national and international lightning protection engineering and standards, a lightning protection system for buildings requires the protection of the whole system against the effect of lightning which covers internal and external lightning protection [23]. Most common external lighting protection systems consist of air terminal, down conductors, and grounding system.

2.8.1 Air Terminal

Air terminal is used to capture the lightning discharge current and dissipate it harmlessly to earth via the down conductor and earth termination system. It highlights that the air termination components should be installed on corners, exposed points and edges of the structure [24].

2.8.2 Down conductor

A symmetrical arrangement down conductors minimize the inductive voltage drop, reducing voltage differences between objects or equipment, and minimizes the magnetic field inside the protected structure associated with the lightning current [20]. It provides a low impedance path from the air termination to the ground system so that the lightning current can be safely conducted to earth, without the development of excessively large voltage.

2.8.3 Grounding system

The earth termination system is vital for the dispersion of the lightning current safely and effectively into the ground. The standard advocates a low earthing resistance requirement of 10 ohms or less [24]. The best grounding system for ordinary structure is a metal mesh buried (in earth or concrete) beneath the structure. Grounding meshes are standard, for example in utility substation's where equalization of voltage difference is essential [20]. Table 13 gives indication of how many earth rods would be required to achieve 10 ohms or less for varying soil resistivity.

Table 13 Earth rods required to achieve 10 ohms or less [24].

Resistivity (ohm/m)	Number of earth rods	Length of earth rod (m)
500	50	2.4
400	38	2.4
300	28	2.4
200	18	2.4
100	8	2.4
50	3	2.4

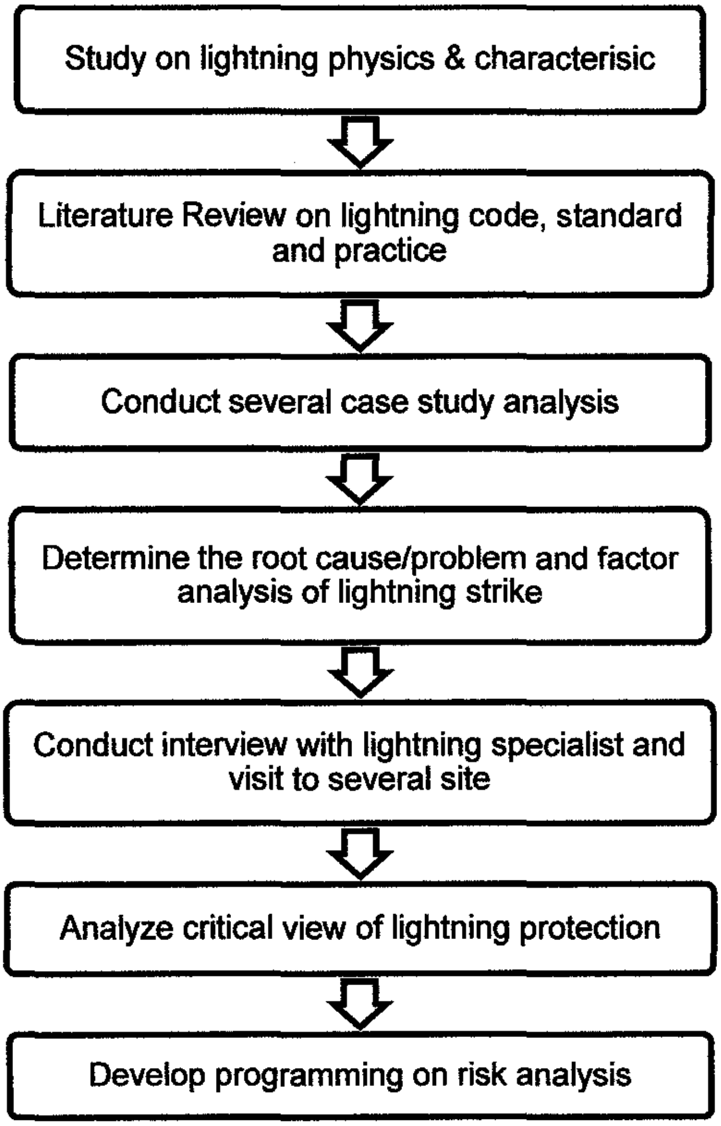
CHAPTER 3

METHODOLOGY

This chapter will cover the process and flow of this project. Besides project activities and Gantt chart, we will also brief the milestone and equipment used will also be stated.

3.1 Methodology

Method to be adopted;



3.2 Project Activities

The activities in this project are;

1. Reading and research material that could expand knowledge on lightning.
2. Compare different lightning code and practiced from various country to help find the best solution.
3. Study the lightning incident to find the factors, effect and solution in various countries.
4. Mathematical analysis of lightning risk parameter by using MATLAB.
5. Designing and recommend the best lightning protection.

3.3 Key milestone

The key milestones of this project are;

1. Reading and research material that could expand knowledge on lightning to be completed at week2 of FYP I.
2. Compare different lightning code and practiced from various country to help find the best solution to be completed at week 4 of FYP I.
3. Study the lightning incident to find the factors, effect and solution in various countries to be completed at week 6 of FYP I.
4. Mathematical analysis of lightning risk parameter by using MATLAB to be completed at week 3 of FYP II.
5. Designing and recommend the best lightning protection to be completed at week 7 of FYP II.

3.4 Software & Tools Used

The software that were used are Microsoft Excel, C++ programming, and Visual Basic Studio Programming. Microsoft Excel was used to plot a graph related to the analysis while C++ programming was applied to determine the necessity of lightning protection. The function that has been used in code is To-Do While loop [25]. Visual basic program was used for a convenient and user friendly interface.

CHAPTER 4

RESULTS AND DISCUSSIONS (PART I)

This chapter discusses several scenarios in Malaysia and other countries that has been studied and analyzed. The root cause and solution are discussed in this chapter. Various Codes and Standards was analyzed and compared.

4.1 Lightning Accident Analysis

Every year there are numerous cases of lightning incidents. Lightning has been reported to strike people and caused death, bring damages and create huge losses. This topic will discuss several major lightning accidents that happened in Malaysia and throughout the world. Lightning accidents will be analyzed with the cause and effect. Before this topic go to the detail, please remember that lightning occurs naturally, cannot be stopped or eliminated. In short, there are several cases that could have been prevented while others which could not have been avoided.

4.1.1 Columbia Airplane August 2010

This airplane got struck when it was about to land during a thunderstorm day. [26] The pilot cannot wait long enough in the air because of insufficient fuel. Thus, while the airplane was about to land; there are cloud-to-cloud lightning discharges which hit the airplane. The lightning strike was as strong as a knife that slices butter; it cut the airplane into 3 pieces! This incident caused 1 death and 114 injured. This incident cannot be stopped; the only solution is to check the weather forecast to avoid from flying during a thunderstorm.

Figure 7 Lightning strike Columbia Airplane [27]

4.1.2 *BASF Petronas Fuel and Natural Gas storage, Pasir Gudang April 2006*

Lightning struck the measuring cable of petronas fuel or gas storage which caused 2 storage tank of fuel and one storage tank of natural gas to explode. These incidents caused fire up to 30 m high from the storage and release poisonous chemical. More than 80 fire fighters came to get off the fire in more than 5 hours [28]. This incident happened because the measuring cable is a conductor that 'attracts' the lightning discharge. The measuring cable is supposed to be installed complete with lightning protection such like bonding it with another cable to the ground so that when lightning occurs, the current will be discharged and dissipated to the ground through that protection cable. A year after that, the same incidents happened in SHELL Malaysia refinery in Port Dickson which caused 2 oil storage tanks to explode.

Figure 8 Lightning strike BASF Petronas, Pasir Gudang [28]

4.1.3 Kerosene Tank, Netherlands 1975

This is a special incident that occurs where lightning struck indirectly. Lightning struck the willow trees, and current dissipate through the root of the trees [12]. However, this event leads to potential difference and induced to the nearby earth electrodes that belongs to the kerosene tank nearby which produces thermal effect and fire up the tank storage. The explosion from the tank was about 250 m high! From the study and analysis, this storage tank should be isolated, placed far from other structures. This storage tank also should have more earth electrode to distribute the lightning charge. More earth electrodes installed can dissipate the charges faster to the ground.

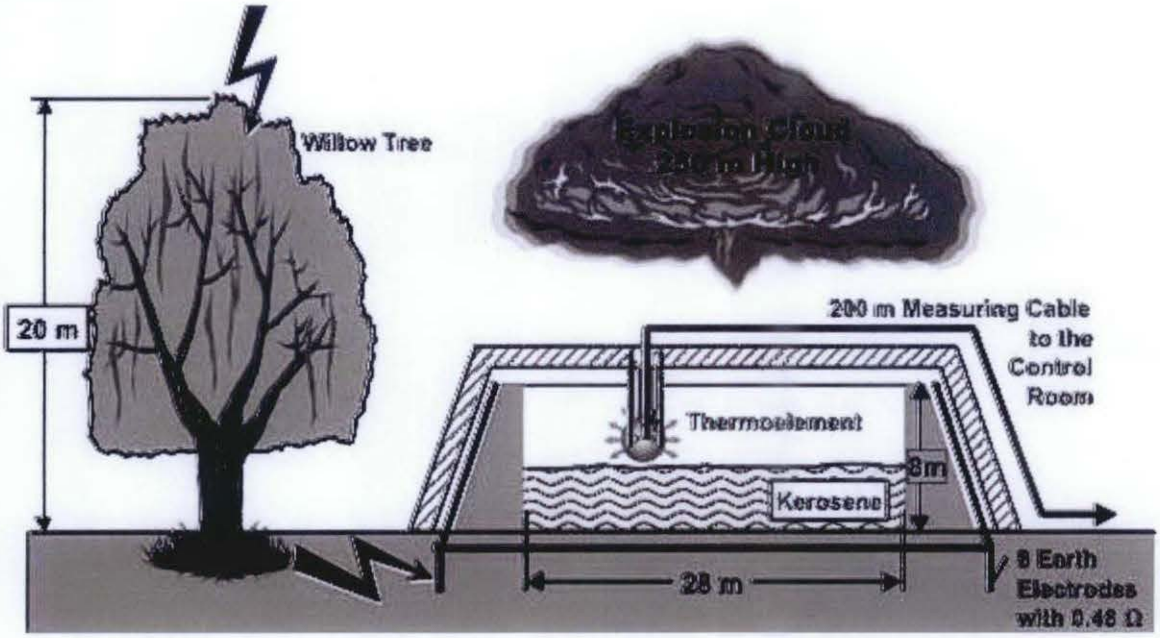


Figure 9 Lightning strike Kerosene Tank, Netherlands [12]

4.1.4 Lightning strike High rise building

This is a very common case, where lightning strike high structures. In Klang valley, 80% of high rise building has been struck annually. It affects the corner of the building and damage nearby structures. Lightning strike through the side way of the structure because not all electrical and mechanical conductors are bonded to the down conductor. All conductors should be tied and bonded to down conductor so that current could easily dissipate to the ground. If the conductor is not bonded, it will make incomplete circuit which could damage the structure.

Figure 10 High rise building in Klang area [29]

There a case in a condominium in Johor Bahru where lightning strike for every thunderstorm day. The insurance company is not willing to pay for more than 3 times the damages; instead they ask to find a solution to solve this matter. Based on an in depth analysis, it was found that the down conductor is not 'buried' to the earth electrode at the ground, but at the nearby soil at the balcony [30]. The piles and rebar were also not meshed accordingly during the construction time, so that it does not provide a good path to the ground systems. Figure 11 show that there was damaged on the missing globe while Figure 12 show that there was damaged on the roof top because no conductors bonded to the ground system. The roof also does not have or installed with copper link. At the roof top, a copper link is supposed to be installed all around the roof top, and bonded with air terminal and running conductors. Supposed the conductor is bonded at roof top as shown in Figure 13.

Figure 11 Damaged on the missing globe

Figure 12 Effect of lightning strike in Wadihana Condo, Johor Bahru

Figure 13 Proper bonding air terminal with copper tape at roof top [31]

4.1.5 Lightning strike inductively

When lightning strike directly, we could see it and fear it. But when it happen indirectly by induced or capacitive or resistive measure, it is more frightening. For this case, lightning induce from the root of trees to the underground metal pipe [32]. Thus, the energy from lightning traveled along this metal pipe. This underground metal pipe has been installed to supply water to the nearby houses, but no serious damage has been reported due to this scenario.

Figure 14 Lightning damage underground metal pipe [32]

4.1.6 Lightning strike caused electric short and fire

It has been reported that Sek Keb Perigi Acheh, Pasir Gudang caught fire due to lightning strike on April 29, 2010. The fire destroyed two classrooms, a storeroom and toilet. The fire is said to have been caused by a short circuit after a lightning strike at the electrical switch in the store room. [8]

Figure 15 Fire causes school to close for two days [8]

4.3 Factor Analysis

As a result of lightning analysis above, there are a set of risk parameter to determine the necessity of lightning protection systems. For this project, research has been conducted and found 10 parameters of risk which are;

1. Geographical area , location (refer to the lightning map in appendix).
2. Thunderstorm day per year (refer to the Table 14 and bar chart in Figure 15).
3. History / cases that has been reported nearby/ how many times has been struck.
4. Soil resistivity.
5. Amount of loss
    a. Risk of loss human life.
    b. Risk of loss service to public.
    c. Risk of loss cultural heritage.
    d. Risk of loss economic value.

4.3.1 Thunderstorm Day per Year

The lightning flash ground density, N_g in number of lightning flashes per km^2 and per year should be determined by measurement. Values of N_g may be estimated by different relationships as a function of the number of thunderstorm days per year, T_d. The International Standard suggests using the following approximation relation [33]:

$$N_g \approx 0.1 \times T_d$$

This formula has been used to calculate and analyze lightning flash ground density in several locations in Malaysia as shown in Table 14. The result of analysis is presented in Figure 15.

4.2 Summary of Accident Analysis

The table below is the summary of lightning analysis based on the cases discussed above. From the analysis that was conducted;

Case	Effect of lightning	Problem / Cause	Suggested preventive measure
Columbia Airplane	1) Airplane crashed into 3pieces. 2) 1death, 114 injured	Landing during thunderstorm weather	1) Should check weather before departure. 2) Should wait until the weather stable before landing to avoid lightning strike
BASF Petronas Fuel & Gas Storage	1) Two fuel storage and one natural storage are exploded 2) Contagious chemical spread and produce haze from the fire up to 30m high	Measuring cable is not protected from lightning	1) Should bond the measuring cable to the grounding system so that the lightning discharge could flow and dissipate to the ground
Kerosene Tank	1) Root of willow tree discharge and induce nearby earth electrode 2) Tank exploded and caused fire up to 250m high	Earth electrode is near to the root of the nearby tree (potential discharge)	1) Should calculate the effective distance with all potential discharge
High Rise Building	1) Damage the structure 2) Masonry corner effected	Improper or has not install lightning protection	1) Roof top should be surrounded with copper tape especially at the corner. 2) Air terminal will be necessary if height of structure is more than 45m
Underground Metal Pipe	1) Damage to the structure	Underground of metal pipe is close to the root of the tree	1) Do not install underground metal pipe underneath trees 2) Install non-conductor underground pipe.
School	1) Damage to the structure, electrical & electronics component	The electrical installation has not been provide with surge protector	1) For low voltage system installation should be provided with surge protector

Table 14 Lightning Ground Flash Density

Location	Thunderstorm Day average in a year, T_d	Lightning Flash Ground Density, N_g
Senai	169	16.9
Kluang	177	17.7
Mersing	162	16.2
Batu Pahat	160	16.0
Muazam Shah	131	13.1
Melaka	147	14.7
Temerloh	90	9.0
Kuantan	154	15.4
KLIA Sepang	180	18.0
Petaling Jaya	192	19.2
Subang	200	20.0
Cameron Highland	118	11.8
Setiawan	156	15.6
Ipoh	197	19.7
Bayan Lepas	184	18.4
Butterworth	158	15.8
Alor Setar	135	13.5
Langkawi	120	12.0
Kuala Krai	130	13.0
Kota Bharu	108	10.8
Kuala Terengganu	136	13.6
Kuching	182	18.2
Sibu	113	11.3
Sri Aman	99	9.9
Kapit	80	8.0
Bintulu	151	15.1
Long Lelang	110	11.0
Miri	93	9.3
Labuan	135	13.5
Kota Kinabalu	129	12.9
Tawau	143	14.3
Sandakan	140	14.0
Kudat	75	7.5

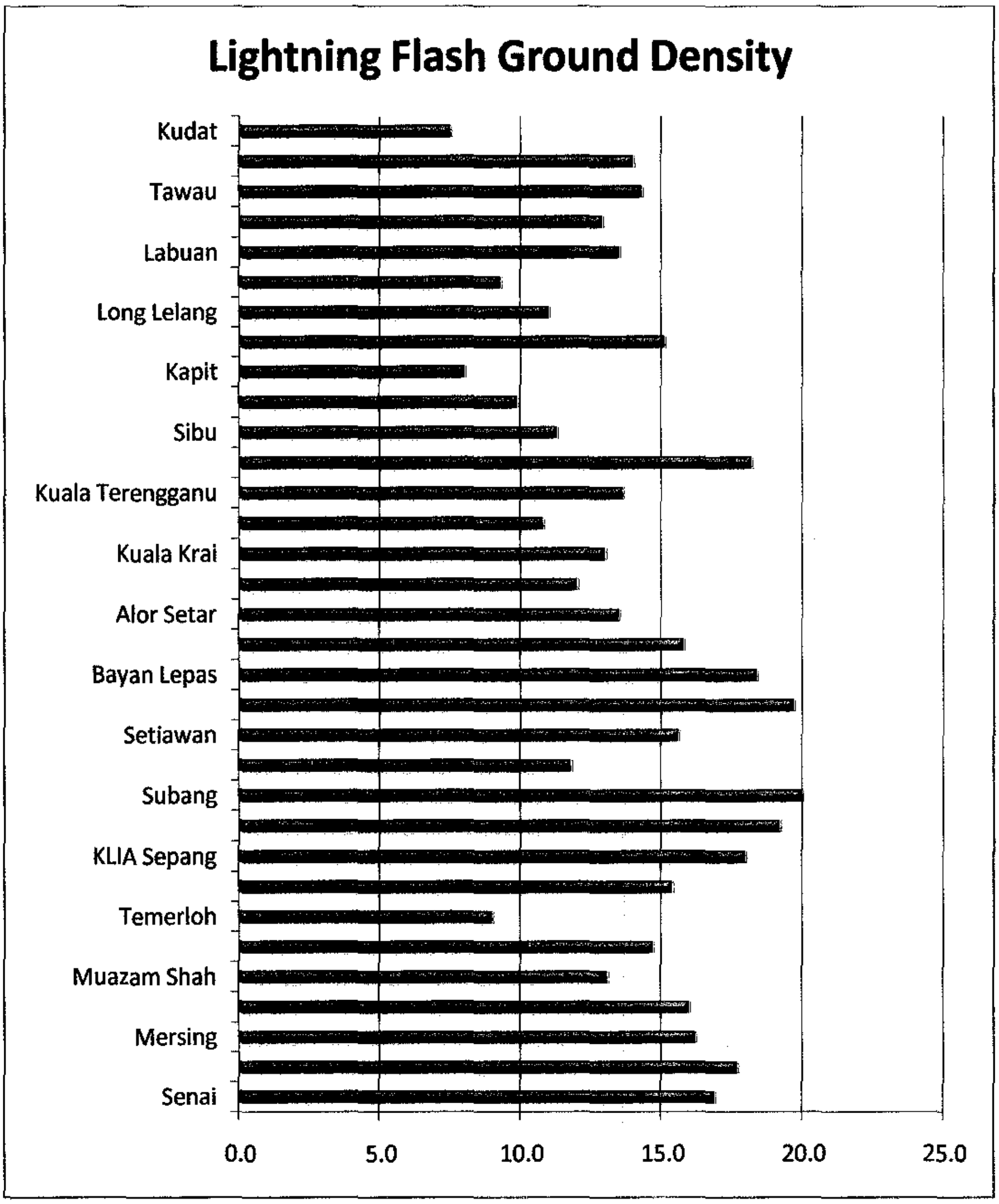


Figure 16 Bar Chart of Lightning Flash Density in Malaysia

4.3.2 Soil Resistivity

Soil resistivity is a function of soil moisture and the concentration of ionic soluble salts and is considered to be most comprehensive indicator of resistance of soil toward lightning discharge on grounding system. The resistance to remote earth of the grounding system needs to be at minimum in order to sustain its effectiveness [34].

Type of soil	Climate condition			
	Normal and high rainfall (i.e greater than 500mm a year)		Low rainfall & desert condition (less than 250 mm a year)	Underground waters (saline)
	Probable value Ω.m	Range Value Ω.m	Range of values Ω.m	Range of values Ω.m
Aluvium and lighter clays	5			
Clays (excluding alluvium)	10	5 to 20	10 to 100	1 to 5
Marls (e.g Keuper Marl)	20	10 to 30	50 to 300	1 to 5
Porous limestone (e.g chalk)	50	30 to 100	50 to 300	1 to 5
Porous sandstone	100	30 to 300	50 to 300	1 to 5
Quartzites	300	100 to 1000	50 to 300	1 to 5
Clay slates	1000	300 to 3000	1000 upward	30 to 100
Granite	1000	1000 upward	1000 upward	31 to 100
Fissile slate, schists, gneiss	2000	1000 upward	1000 upward	32 to 100

Table 15 Soil resistivity according to type of soil and climate conditions [35].

The lower the resistance is better. However during construction work the disturbance may alter the site condition. The resistance of vertical electrode is given approximately by the following equation:

$$R = \left[\frac{1}{2\pi L}\right]\left\{(\rho - \rho_c)\left(log_e\left[\frac{8L}{D}\right] - 1\right) + \rho_c\left(log_e\left[\frac{8L}{d}\right] - 1\right)\right\}$$

Where

ρ is the resistivity of soil in Ω.m

ρ_c is the resistivity of infill material in Ω.m

d is the diameter of the electrode in m

D is diameter of infill in m

L is the driven length of electrode in m

4.4 Site Visit to Pekat Teknologi Sdn. Bhd.

The objective of this visit is to check the relevant lightning standards, to analyze various methods for lightning protection systems, to undergo the real situation of lightning protection during construction work on site and to enhance skills and knowledge for lightning protection system design. During one week period, many activities and work was done. The outcome of the visit are an updated code of standards, installation of lightning protection in substructure and superstructure, the requirement of test point and soil resistivity test, and etc. These outcomes of the visit is very importance and beneficial for this project. The summary of the report for the site visit to Pekat Teknologi Sdn. Bhd is given in the Appendix D. From the literature, case study and site visit that was conducted, it was found that there are several differences of the code and standard as shown in Table 16.

Table 16 Comparison of Codes and Standards

Standard	**NZS/AS 1768**	**BSEN 6651**	**BSEN 62305**	**IEC 62305**
Risk Assessment	Summation of all risk factors.	Multiplication of all risk factors.	Detail assessment.	Detail assessment.
Protection System	Cannot reduce risk calculation	Cannot reduce risk calculation	Convey values which could reduce risk assessment	Convey values which could reduce risk assessment
L_f factor differ in Annex C	–	–	Convey typical mean values on several types of structures.	Convey a few values of general structures.

CHAPTER 5

RESULTS & DISCUSSIONS (PART II)

This chapter will briefly explain the programs that have been developed for this project. The overall finding and design on lightning protection system design will be discussed.

5.1 Programs Developed

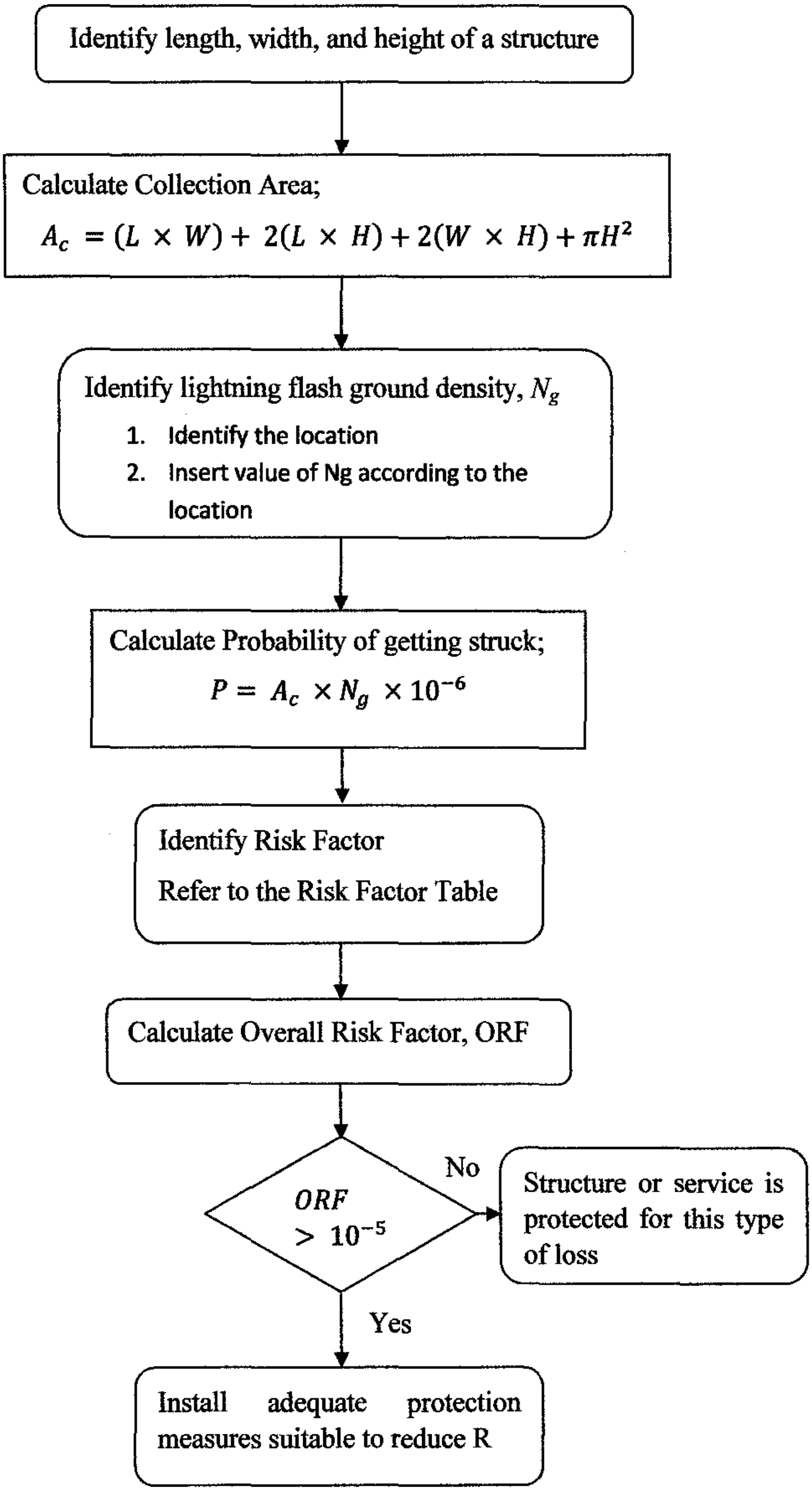
5.1.1 Lightning Calculator

This program was developed by using British Standard BS6651 which covers the probability of being struck, collection area, and risk calculation. It was developed using C++ program. The instruction, flow chart of the program, source code, interface and example will be discussed further.

Instructions for Lightning Calculator:

1. User need to identify the dimension of the structure for example the length, width, and height.
2. The program will calculate Collection Area based on dimension that has been entered by the user.
3. User need to insert number of thunderstorm day per year to calculate the probability of getting strike of lightning.
4. User would need to insert all the risk factor of the desired structure. The result will directly appear on the interface.

Flow Chart for Lightning Calculator:



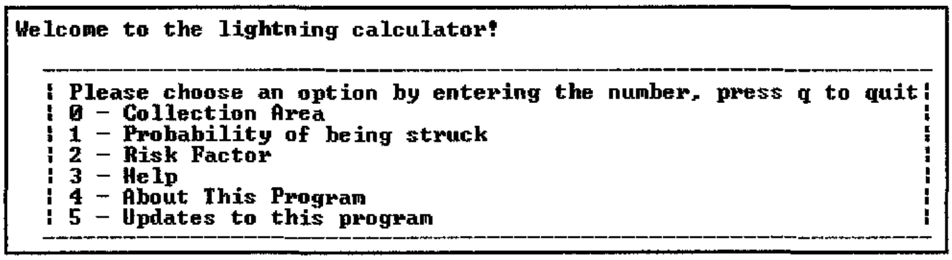
Source Code of Lightning Calculator:

```
#include <cstdlib>
#include <iostream>

using namespace std;

int main()
{
    double num;
    double num2;
    double num3;
    double num4;
    double num5;
    char choice;
    printf("Welcome to the lightning calculator\n");
    for (;;){
     do {
    cout<<"\n";
    cout<<"----------------------------------------------------------
--------\n";
    cout<<"| Please choose an option by entering the number, press q
to quit|\n";
    cout<<"| 0 - Collection Area
|\n";
    cout<<"| 1 - Probability of being struck
|\n";
    cout<<"| 2 - Risk Factor
|\n";
    cout<<"| 3 - Help
|\n";
    cout<<"| 4 - About This Program
|\n";
    cout<<"| 5 - Updates to this program
|\n";
    cout<<"----------------------------------------------------------
--------\n";
    cout<<"\n";
    cin>>choice;
    } while ( choice < '0' || choice > '5' && choice != 'q');
    if (choice == 'q') break;
    switch (choice) {
           case '0':
                cout<<"\n";
                cout<<"Please enter length\n";
                cin>>num;
                cout<<"Please enter width\n";
                cin>>num2;
                cout<<"Please enter height\n";
                cin>>num3;
                cout<<"Collection Area is\n";

cout<<(num*num2)+(2*num*num3)+(2*num2*num3)+(3.1416*num3*num3);
                cout<<"\n";
                cout<<"\n";
                cout<<"Next Operation\n";
                break;
           case '1':
                cout<<"\n";
                cout<<"Insert the Collection Area\n";
                cin>>num;
```

```
                cout<<"Insert the Lightning Flash Ground Density\n";
                cin>>num2;
                cout<<"Probability of being struck is\n";
                cout<<num * num2 * 0.000001;
                cout<<"\n";
                cout<<"\n";
                cout<<"Next Operation\n";
                break;
           case '2':
                cout<<"\n";
                cout<<"Please enter Factor A\n";
                cin>>num;
                cout<<"Please enter Factor B\n";
                cin>>num2;
                cout<<"Please enter Factor C\n";
                cin>>num3;
                cout<<"Please enter Factor D\n";
                cin>>num4;
                cout<<"Please enter Factor E\n";
                cin>>num5;
                cout<<"Your Risk Factor is\n";
                cout<<num*num * num2*num2 * num3*num3 * num4*num4 *
num5*num5 * 0.001;
                cout<<"\n";
                cout<<"If your risk factor > than 0.00001, protection
is necessary\n";
                cout<<"\n";
                cout<<"\n";
                cout<<"Next Operation\n";
                break;
           case '3':
                cout<<"\n";
                cout<<"This is a lightning calculator made by me -
Hajar.\n";
                cout<<"To select an option, type the number next to
the option and press enter\n";
                cout<<"E.G. for division, you would type 3 and press
enter.\n";
                cout<<"\n";
                cout<<"*************\n";
                cout<<"Next Operation\n";
                break;
           case '4':
                cout<<"\n";
                cout<<"The lightning calculator made by Siti Hajar
Binti Jaafar - Copyright 2011. :)\n";
                cout<<"for UTP Final Year Project purpose\n";
                cout<<"Feedback would be nice - hajar3588@gmail.com
also, \n";
                cout<<"Please consult me for any lightning problem.
Bye!!\n";
                cout<<"\n";
                cout<<"*************\n";
                cout<<"Next Operation\n";
                break;
           case '5':
                cout<<"\n";
                cout<<"Updates include;\n";
                cout<<"   1. Set some limitation of Overall Risk
Factor.\n";
                cout<<"   2. Different limitation for different
lightning protection design.\n";
```

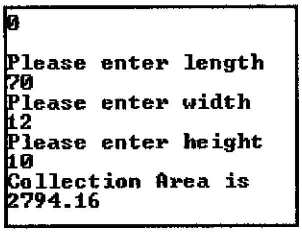
```
                cout<<"The new programme will be release in next
semester, Final Year Project II\n";
                cout<<"\n";
                cout<<"Next Operation\n";
                break;
           default:
                    cout<<"That is not an option";

                }

}
return 0;


}
```

Interface of Lightning Calculator



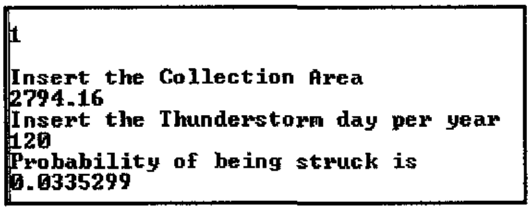
```
Welcome to the lightning calculator!

   ---------------------------------------------------------------------
   | Please choose an option by entering the number, press q to quit|
   | 0 - Collection Area                                              |
   | 1 - Probability of being struck                                  |
   | 2 - Risk Factor                                                  |
   | 3 - Help                                                         |
   | 4 - About This Program                                           |
   | 5 - Updates to this program                                      |
   ---------------------------------------------------------------------
```

When user select ‘0’,



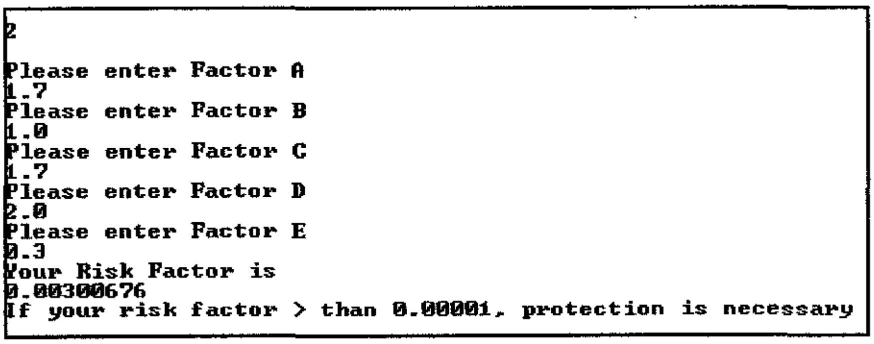
```
0

Please enter length
70
Please enter width
12
Please enter height
10
Collection Area is
2794.16
```

When user select ‘1’,



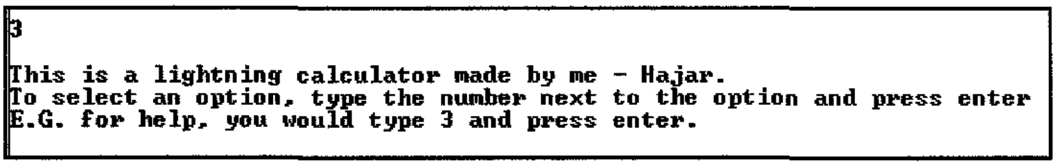
```
1

Insert the Collection Area
2794.16
Insert the Thunderstorm day per year
120
Probability of being struck is
0.0335299
```

When user select ‘2’,



```
2

Please enter Factor A
1.7
Please enter Factor B
1.0
Please enter Factor C
1.7
Please enter Factor D
2.0
Please enter Factor E
0.3
Your Risk Factor is
0.00300676
If your risk factor > than 0.00001, protection is necessary
```

When user select '3',

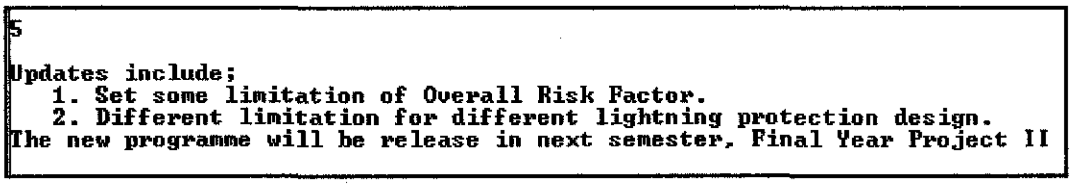


```
3

This is a lightning calculator made by me - Hajar.
To select an option, type the number next to the option and press enter
E.G. for help, you would type 3 and press enter.
```

When user select '4',

```
4

The lightning calculator made by Siti Hajar Binti Jaafar - Copyright 2011. :>
for UTP Final Year Project purpose
Feedback would be nice - hajar3588@gmail.com also,
Please consult me for any lightning problem. Bye!!
```

When user select '5',



```
5

Updates include;
   1. Set some limitation of Overall Risk Factor.
   2. Different limitation for different lightning protection design.
The new programme will be release in next semester, Final Year Project II
```

When user select 'q',

The program will stop and close the window (interface).

Discussion on Lightning Calculator Program:

Note that this data is taken from BS 6651 sample calculation and the value that has been calculated and value that this program evaluates are the same. From this example, the overall risk factor is 3×10^{-3} which is higher than tolerable risk value. Thus, lightning protection is necessary.

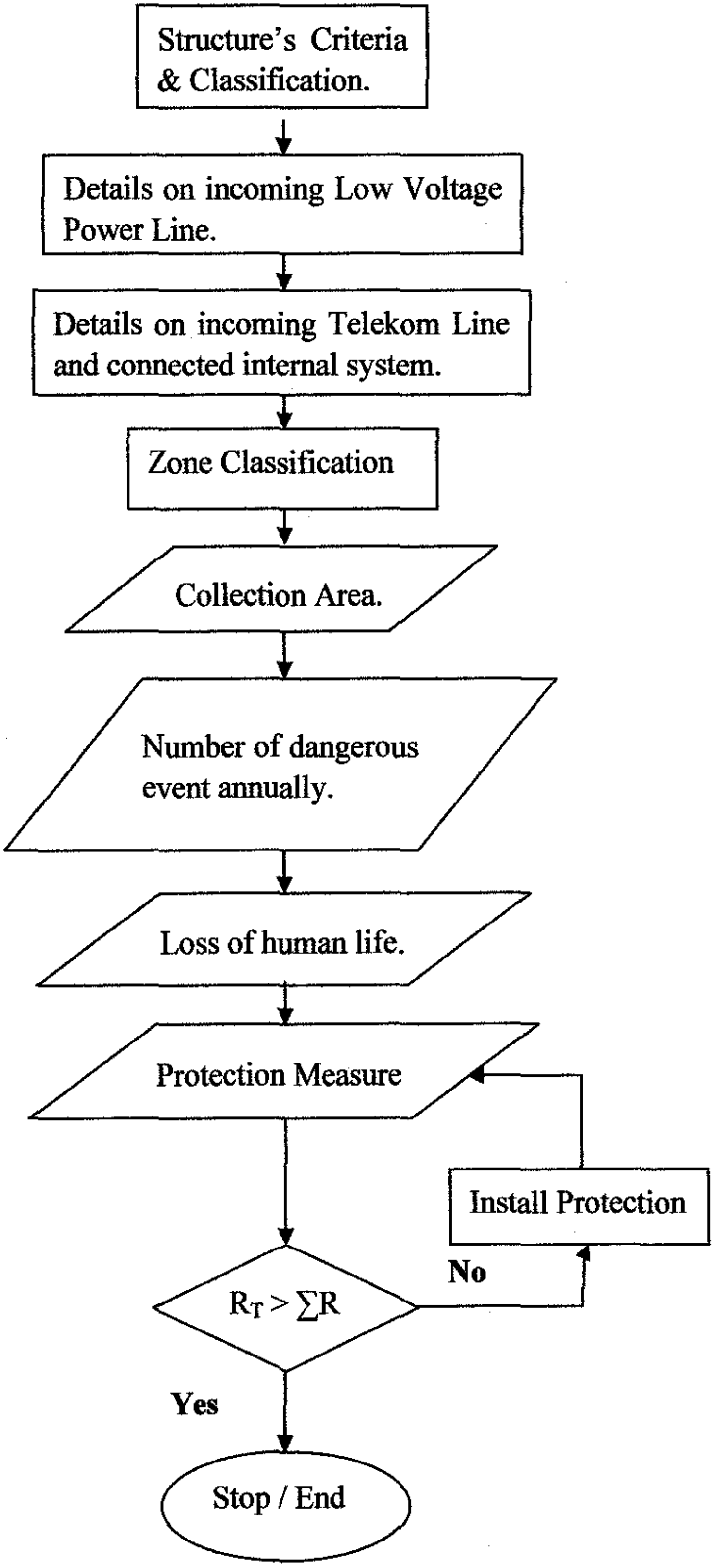
5.1.2 Lightning Risk Factors Analysis Program

This program was developed with considering the Codes and Standards of BSEN 62305 and IEC 62305. It was programmed using Microsoft Visual Basic 2010 Express. The calculation of this part is very complex and lengthy because it is combination of four difference books that covers four mains part of BSEN 62305 standard and IEC 62305 standard.

Instructions for Lightning Risk Factors Analysis:

1. User should key in the dimension and environmental elements of desired structure.
2. User should insert and choose the suitable criteria of Electrical Line of selected structure.
3. User should be able to determine and choose the most convenient criteria on the Zone Structure and Loss of Human Life.
4. For the first evaluation, user should choose on no protection measure installed to see the value of overall risk factors. After all the data has been filled, the user should press the 'Submit' button.
5. The result will appear as Calculated Risk, R_c at the top right side of the interface. If the value of R_c is bigger than Tolerable Risk, then the Lightning Protection System is required. Then user need to repeat step 1-3 and for step 4, choose the suitable lightning protection system that would reduce the risk.

Flow Chart of Lightning In-depth Risk Analysis:



R_T : Tolerable risk
$\sum R$: Summation of calculated risk

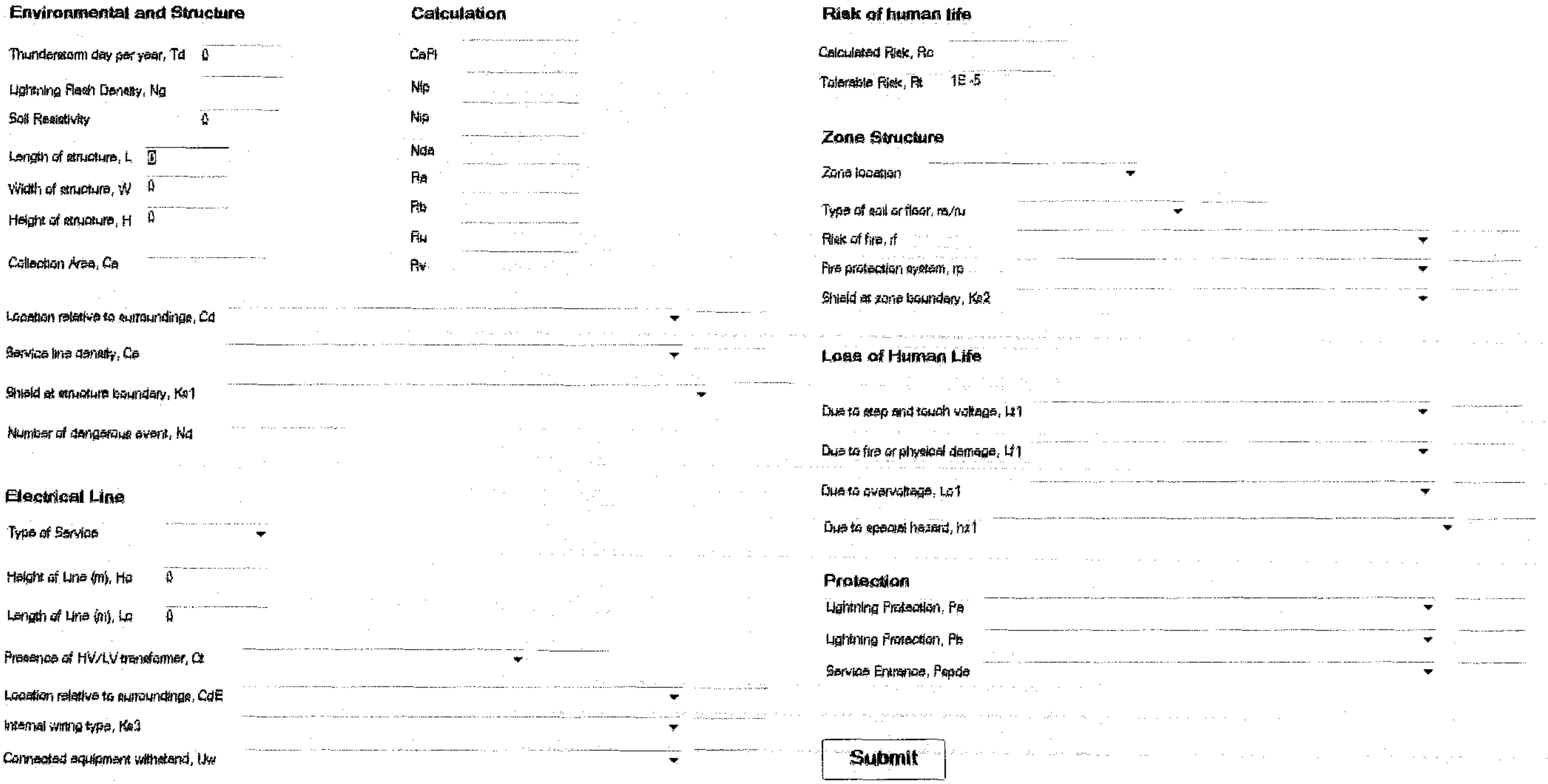
Interface of Lightning In-depth Risk Analysis:

The interface for this program is shown in Figure 16. User would need to fill in the required parameters or select from the drop-down options with respect to the instruction that mentioned earlier in Section 5.1.2. After that the user can press 'Submit' button and calculated risk will be given.

Discussion of Lightning In-depth Risk Analysis:

The program is tested on Wadihana Condominium in Johor Bahru to analyze the risk analysis using this program. Risk analysis was analyzed on the structure and returns the result that has a very high risk which is about 2.33×10^{-3} which is illustrated in Figure 17. However this value can be minimized with installing a proper lightning protection system. It was shown when the program is tested on the structure again with added lightning protection, the risk factor was reduced as shown in Figure 18 which is less than tolerable risk factor.

The relevancy of this example is that most hotels and commercial buildings in Malaysia is about 20-30 floor high. This Wadihana Condo has 28 floors which height is 95 m, length 20.35 m, and width of 8.46 m. Based on study that has been conducted, Wadihana condo has very high risk which got strike every year until the insurance company does not want to pay the damage that has been reported [30]. From the programming that has been run, the risk of the building is very high but it can be reduced by installing proper lightning protection.



Environmental and Structure

Thunderstorm day per year, Td 0
Lightning Flash Density, Ng
Soil Resistivity 0
Length of structure, L 0
Width of structure, W 0
Height of structure, H 0
Collection Area, Ca
Location relative to surroundings, Cd
Service line density, Ce
Shield at structure boundary, Ks1
Number of dangerous event, Nd

Electrical Line

Type of Service
Height of Line (m), Hc 0
Length of Line (m), Lc 0
Presence of HV/LV transformer, Ct
Location relative to surroundings, CdE
Internal wiring type, Ks3
Connected equipment withstand, Uw

Calculation

CaPl
Nlp
Nip
Nda
Ra
Rb
Ru
Rv

Risk of human life

Calculated Risk, Rc
Tolerable Risk, Rt 1E-5

Zone Structure

Zone location
Type of soil or floor, ra/ru
Risk of fire, rf
Fire protection system, rp
Shield at zone boundary, Ks2

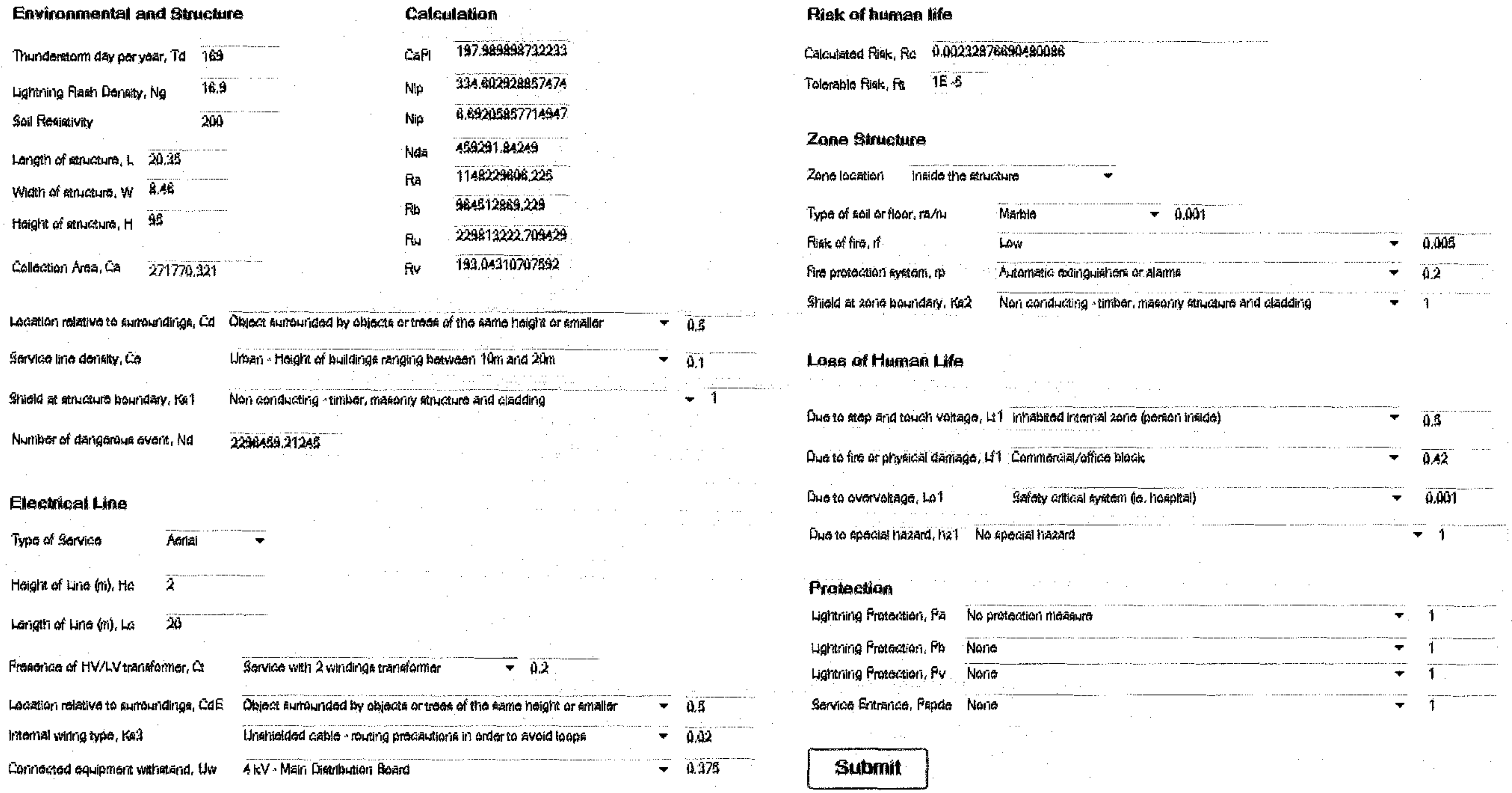
Loss of Human Life

Due to step and touch voltage, Lt1
Due to fire or physical damage, Lf1
Due to overvoltage, Lo1
Due to special hazard, hz1

Protection

Lightning Protection, Pa
Lightning Protection, Pb
Service Entrance, Pspde

Figure 17 Lightning Risk Factor Analysis Interface



Environmental and Structure

Thunderstorm day per year, Td	169
Lightning Flash Density, Ng	16.9
Soil Resistivity	200
Length of structure, L	20.35
Width of structure, W	8.46
Height of structure, H	95
Collection Area, Ca	271770.321

Calculation

CaPl	197.989898732233
Nlp	334.602928857474
Nip	6.69205857714947
Nda	459291.84249
Ra	1148229806.225
Rb	964512869.229
Ru	229813222.709429
Rv	193.04310707592

Location relative to surroundings, Cd	Object surrounded by objects or trees of the same height or smaller	0.5
Service line density, Ce	Urban - Height of buildings ranging between 10m and 20m	0.1
Shield at structure boundary, Ks1	Non conducting - timber, masonry structure and cladding	1
Number of dangerous event, Nd	2298459.21245	

Electrical Line

Type of Service	Aerial	
Height of Line (m), Hc	2	
Length of Line (m), Lc	20	
Presence of HV/LV transformer, Ct	Service with 2 windings transformer	0.2
Location relative to surroundings, CdE	Object surrounded by objects or trees of the same height or smaller	0.5
Internal wiring type, Ks3	Unshielded cable - routing precautions in order to avoid loops	0.02
Connected equipment withstand, Uw	4 kV - Main Distribution Board	0.375

Risk of human life

Calculated Risk, Rc	0.00232876690480086
Tolerable Risk, Rt	1E-5

Zone Structure

Zone location	Inside the structure	
Type of soil or floor, ra/ru	Marble	0.001
Risk of fire, rf	Low	0.005
Fire protection system, rp	Automatic extinguishers or alarms	0.2
Shield at zone boundary, Ks2	Non conducting - timber, masonry structure and cladding	1

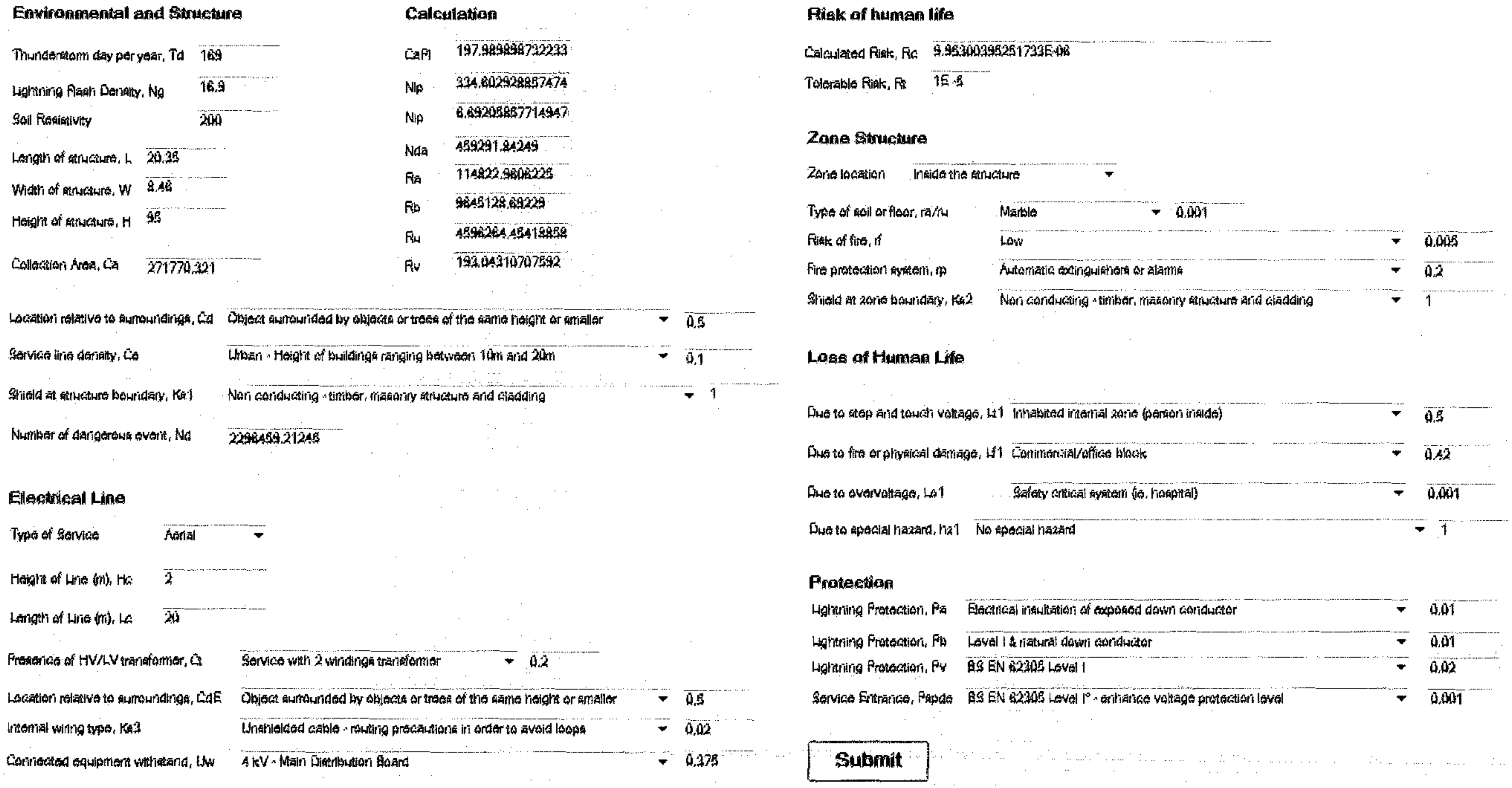
Loss of Human Life

Due to step and touch voltage, Lt1	Inhabited internal zone (person inside)	0.5
Due to fire or physical damage, Lf1	Commercial/office block	0.42
Due to overvoltage, Lo1	Safety critical system (ie. hospital)	0.001
Due to special hazard, hz1	No special hazard	1

Protection

Lightning Protection, Pa	No protection measure	1
Lightning Protection, Pb	None	1
Lightning Protection, Pv	None	1
Service Entrance, Pspd	None	1

Figure 18 Lightning Risk Factor Analysis on Condo Wadihana Johor Bahru – no lightning protection installed



Environmental and Structure

Thunderstorm day per year, Td	169
Lightning Flash Density, Ng	16.9
Soil Resistivity	200
Length of structure, L	20.35
Width of structure, W	8.46
Height of structure, H	95
Collection Area, Ca	271770.321

Calculation

CaPl	197.989898732233
Nlp	334.802928857474
Nip	6.69205857714947
Nda	459291.84249
Ra	114822.9606225
Rb	9645128.69229
Ru	4596264.45418858
Rv	193.04310707592

Location relative to surroundings, Cd	Object surrounded by objects or trees of the same height or smaller	0.5
Service line density, Ce	Urban - Height of buildings ranging between 10m and 20m	0.1
Shield at structure boundary, Ks1	Non conducting - timber, masonry structure and cladding	1
Number of dangerous event, Nd	2296459.21245	

Electrical Line

Type of Service	Aerial	
Height of Line (m), Hc	2	
Length of Line (m), Lc	20	
Presence of HV/LV transformer, Ct	Service with 2 windings transformer	0.2
Location relative to surroundings, CdE	Object surrounded by objects or trees of the same height or smaller	0.5
Internal wiring type, Ks3	Unshielded cable - routing precautions in order to avoid loops	0.02
Connected equipment withstand, Uw	4 kV - Main Distribution Board	0.375

Risk of human life

Calculated Risk, Rc	9.95300395251733E-08
Tolerable Risk, Rt	1E-5

Zone Structure

Zone location	Inside the structure	
Type of soil or floor, ra/ru	Marble	0.001
Risk of fire, rf	Low	0.005
Fire protection system, rp	Automatic extinguishers or alarms	0.2
Shield at zone boundary, Ks2	Non conducting - timber, masonry structure and cladding	1

Loss of Human Life

Due to step and touch voltage, Lt1	Inhabited internal zone (person inside)	0.5
Due to fire or physical damage, Lf1	Commercial/office block	0.42
Due to overvoltage, Lo1	Safety critical system (ie. hospital)	0.001
Due to special hazard, hz1	No special hazard	1

Protection

Lightning Protection, Pa	Electrical insulation of exposed down conductor	0.01
Lightning Protection, Pb	Level I & natural down conductor	0.01
Lightning Protection, Pv	BS EN 62305 Level I	0.02
Service Entrance, Pspd	BS EN 62305 Level I° - enhance voltage protection level	0.001

Figure 19 Lightning Risk Factor Analysis on Condo Wadihana Johor Bahru – lightning protection installed

CHAPTER 6

CONCLUSION & RECOMMENDATION

This chapter provides discussion and conclusion throughout this project which cover FYP I and FYP II.

6.1 Conclusion

6.1.1 Lightning Codes and Standards

Right from the research start, we could see that various type of lightning protection which covers a few countries standard, international standard, conventional and non-conventional type. However as an electrical engineer has authority to urge the government to have a specific or guideline for lightning protection standard in Malaysia. In conclusion, the guidelines of lightning protection standard in this project fall upon the suitable standard that has been discussed earlier.

6.1.2 Lightning Protection Program

6.1.2.1 Lightning Calculator

This program can calculate the collection area of desired structure and the probability of lightning strike using BS 6651 code of standard. The user has to acknowledge the parameters of the risk factor to calculate the overall risk factor. This program would be able to determine the necessity of lightning protection but unable to reduce the risk factor and cannot measure the suitable lightning protection measure.

6.1.2.2 Lightning Risk Factor Analysis

A program to determine the Risk Factor of any structure based on certain parameters has been developed which is more convenient and user friendly compare to the Lightning Calculator Program. This program is guided by BSEN 62305 and IEC 62305 code of standard. The program analysis was able to determine whether a particular building would need any lightning protection and how much is needed. It was also shown using the program that the risk factor can be reduced after the suggested lightning protection is installed. In conclusion, this program can help the user to determine risk of the building towards lightning strike, able to reduce the risk factors and initiate the suitable lightning protection system that follow the latest and dependable lightning protection code of standards.

6.2 Recommendation

This project is very wide in scope which covers lightning physic, incidents & cases, code & standards, protection and other related subtopics. Thus it is recommended that further study can be done by narrowing down the scope so that the outcome of the project will be more specific. Since this project has cover about code & standards, it is recommended that Malaysian government and authority are aware of this project and establish our own standard. The programming is useful and can be upgraded to higher level and will have market value. There is no lab in our country that provides utilities and equipment to do experiment on the 200 kA current of lightning. However, there is a lab that can experiment high voltage in UTM Skudai, Johor. Thus it is recommended to anybody that would like to further study on lightning characteristic to visit the lab and conduct experiments.

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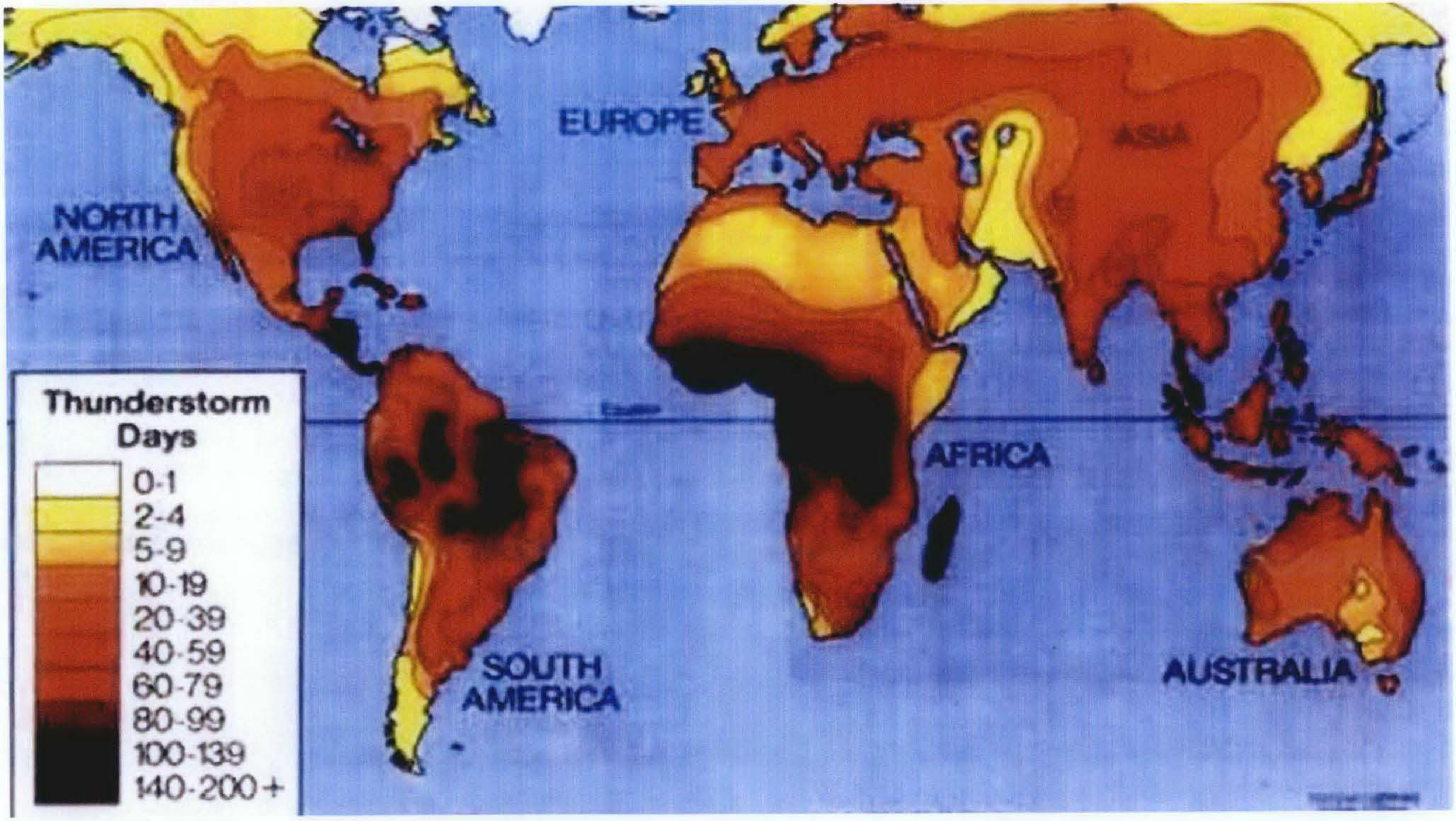
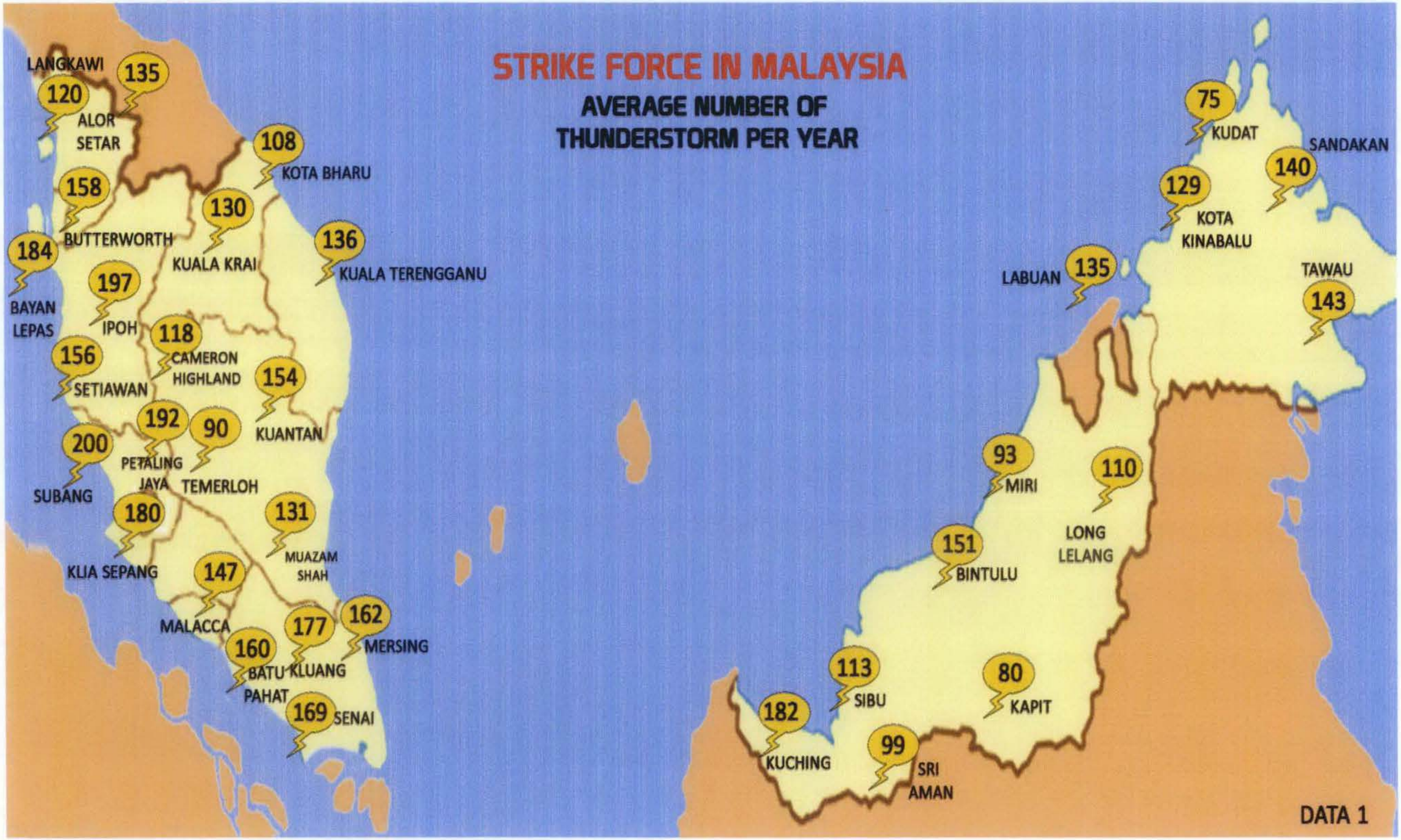
LIST OF APPENDICES

Appendix A World Thunderstorm Days Map



Appendix B Malaysia Thunderstorm Days Map



Appendix C Gantt Chart [FYP I]

	WEEK 1 24-30 JAN	WEEK 2 31-6 FEB	WEEK 3 7-13 FEB	WEEK 4 14-20 FEB	WEEK 5 21-27 FEB	WEEK 6 28-6 MAC	WEEK 7 7-13 MAC	WEEK 8 14-20 MAC	WEEK 9 21-27 MAC	WEEK 10 28-3 APR	WEEK 11 4-10 APR	WEEK 12 11-17 APR	WEEK 13 18-24 APR
Basic research	🟨												
Proposal		🟩											
Theory			🟨	🟨									
Code & Practice			🟨	🟨									
Case & Incident Causes				🟨	🟨	🟨							
Problem Statement						🟨							
Objective & Scope						🟨							
Extended Proposal						🟩							
Frequency							🟨						
World Map							🟨						
Parameter								🟨					
Proposal Viva								🟩	🟩				
Analysis								🟨	🟨				
Indeep Research										🟨	🟨		
Presentation & Report											🟨	🟨	
Interim Report													🟩

Appendix D Gantt Chart [FYP II]

	WEEK 1 23-29 MAY	WEEK 2 30-5 JUN	WEEK 3 6-12 JUN	WEEK 4 13-19 JUN	WEEK 5 20-26 JUN	WEEK 6 27-3 JULY	WEEK 7 4-10 JULY	WEEK 8 11-17 JULY	WEEK 9 18-24 JULY	WEEK 10 25-31 JULY	WEEK 11 1-7 AUG	WEEK 12 8-14 AUG	WEEK 13 15-21 AUG
Site visit.	🟨												
In-depth research & clarification.		🟨	🟨										
Design Consideration.			🟨	🟨									
lightning design technique: a) Mesh Method. b) Protective angle.					🟨	🟨							
c) Rolling Sphere methods.						🟨	🟨						
Submission of Progress Report.								🟩					
Flow Chart of Programming.									🟨				
Programming of LPS Design.										🟨	🟨		
Submission of Interim Report.												🟩	
Final Oral Presentation.													🟩

Appendix D: Report on visit to PEKAT Teknologi Sdn. Bhd

Final Year Project's Title: **Lightning Analysis & Protection**

Objectives of the visit:

- To check the relevant lightning standards.
- To analyze various methods for lightning protection systems.
- To undergo the real situation of lightning protection during construction work on site.
- To enhance skills and knowledge for lightning protection system design.

Activities:

1. Meeting with lightning specialist, Mr. Vincent:
   a. Brief on lightning theory.
   b. Brief on lightning standards, IEC, BSEN.
2. Review and discuss lightning protection system with sales & marketing department and project department.
3. Site visit at Bandar Enstek, Seremban [3storey Tabung Haji Data Centre's Project].
4. Site visit at KLIA Sepang [Mega Project KLIA – New Terminal].
5. Meeting with the site supervisor, Mr. Low;
   a. Discuss on lightning protection system design plan and schematic single line diagram.
   b. Make sure lightning protection installation is same in design plan and schematic single line diagram.
   c. Identify missing of components or material in lightning protection system, for example copper tape.
6. Meeting with the lightning specialist and manager of company, Mr. Vincent and Mr. Wee;
   a. Discuss on new project lightning protection system installation in Penang's Airport, Bayan Lepas.
   b. Analysis and brainstorm the suitable design for lightning protection systems.
7. Client & Customer services;
   a. Consultation between Mr. Teng (customer) and me regarding the theory and necessity of lightning protection systems.

Outcomes:

1. Standard that has been used for analysis in FYP1 which is BSEN 6651:1992 has the latest version which is BSEN 62305: 2006 which has update the ANNEX C.
2. Board of Lightning Specialists (ASEAN) has agreed and highly recommend the BSEN: 1999 and IEC 62305 for lightning protection standard.
3. PEKAT Teknologi Sdn. Bhd has met those standards and gets the ISO approval.
4. The major difference with both standards are the Appendix C, BSEN has accomplish and

evaluate various value of L_f factors due to different geographical area, economic view, society and the environment of the UK nation itself.

5. Three different methods can be used to design lightning protection;
    a. Mesh Methods.
    b. Rolling Sphere Methods.
    c. Protective Angle Methods.
6. Estimated budget for lightning protections system complete with installation are;
    a. 3storey bungalow: RM 15,000.
    b. High rise building (up to 36storey): RM 800,000.
7. Exothermic welding can be done for both lightning test point and interlinking earth.
8. Interlinking earth should be install in both horizontal and vertical structure in such a way that connect the column and slab.
9. Lightning protection system cover substructure, superstructure, and the roof top installation;
    a. Substructure: structural elements that should be constructed below the ground floor level.
    b. Superstructure: structural element that is above ground floor slab.
10. Lightning test point should be install similar to running electrical riser or cable that should avoid water pump or pipe riser.
11. Electrical grounding system should be separate from lightning protection grounding systems.
12. Lightning down conductor installation should be tight to the rebar right from the bottom up to the top of the building and to be connecting to the air terminal networks.
13. As in FYP1, I found that risk factor for lightning activity can be calculated, but cannot be reduced. However, from this visit I figure out that loss factor can be calculated and reduce by installing suitable lightning protection system.

*L_f factor : Loss due to physical damage