

**BEng Project:**  
**Lightning Protection System (Palace  
of Festivals of Cantabria, Spain)**



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# **1. REPORT**

## ***1.1 Lightning, the phenomenon***

Lightning is an atmospheric electric discharge in the form of a spark or flash, accompanied by thunder. It is originating in a charged cloud, usually associated and produced by cumulonimbus clouds (a towering vertical cloud that is very tall, dense, and involved in thunderstorms and other inclement weather), but also occurring during volcanic eruptions or in or can be caused by violent forest fires which generate sufficient dust to create a static charge.

There are some 16 million lightning storms in the world every year. Lightning causes ionization in the air through which it travels, leading to the formation of nitric and ultimately, nitric acid, of benefit to plant life below.

From this discharge of atmospheric electricity, a leader of a bolt of lightning can travel at speeds of 220 000 km/h and can reach temperatures approaching 30 000 °C (54 000 °F).



Figure 1. Lighting examples.

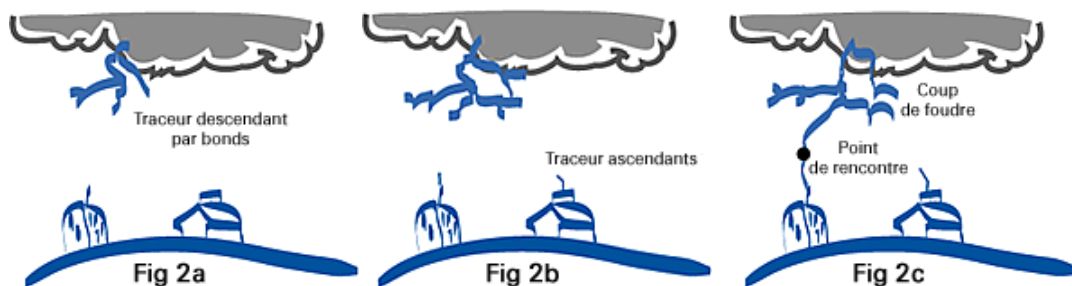
How lightning initially forms is still a matter of debate. Scientists have studied root causes ranging from atmospheric perturbations (wind, humidity, friction and atmospheric pressure) to the impact of solar wind and accumulation of charged solar particles. Ice inside a cloud is thought to be a key element in lightning development,

and may cause a forcible separation of positive and negative charges within the cloud, thus assisting in the formation of lightning.

Due to various mechanisms in storm cloud formation, such as the rising and falling of air currents carrying moisture and ice particles, the storm cloud generates an electrical charge at its base. Charged regions in a thundercloud create conductive ionization channels through the atmosphere called “stepped leaders,” while an opposite electrical charge or “shadow” accumulates on the ground below.

It has now been known for a long time that thunder clouds are charged, and that the negative charge centre is located in the lower part of the cloud where the temperature is about  $-5^{\circ}\text{C}$ , and that the main positive charge centre is located several kilometers higher up, where the temperature is usually below  $-20^{\circ}\text{C}$ . In the majority of storm clouds, there is also a localized positively charged region near the base of the cloud where the temperature is  $0^{\circ}\text{C}$ .

The first stage of a lightning strike involves an initial discharge of low luminosity known as a downward leader. It forms at the cloud centre and moves down toward the ground in steps of several dozen meters at a time. (Fig. 2a) At the same time, the electric charge in the atmosphere at ground level increases as the downward leader gets closer. Any high point in the vicinity such as an electricity pylon or a lightning rod immediately gives rise to natural ionization in the form of a series of electrical discharges which are in blue color. This is the point effect or corona effect. As soon as the downward leader is close enough to the ground, the ionization due to the corona effect intensifies, especially near any high point, and eventually turns into an upward discharge: this discharge is the upward leader that develops toward the cloud. (Fig. 2b) When one of these upward leaders comes into contact with the downward leader, a conductive path is created allowing a powerful current to flow. This is lightning and is characterized by its bright flash and the deafening sound of thunder. (Fig. 2c) The lightning strike may in fact be made up of a number of successive return strokes, only a few hundredths of a second apart, all following the same highly ionized path.



Fields of about 1000 V/m exist near the centre of a single bipolar cloud in which charges of about 20 C are separated by distances of about 3 km, and indicate the total potential difference between the main charge centers to be between 100 and 1000 MV. The energy dissipated in a lightning flash is therefore of the order of 1000 to 10,000 MJ, much of which is spent in heating up a narrow air column surrounding the discharge, the temperature rising to about 15,000 C in a few tens of microseconds. Vertical separation of the positive and negative charge centres is about 2 - 5 km, and the charges involved are 10 - 30 C. The average current dissipated by lightning is of the order of kilo-amperes. During an average lightning storm, a total of the order of kilo-coulombs of charge would be generated, between the 0 C and the -40 C levels, in a volume of about 50 km<sup>3</sup>.

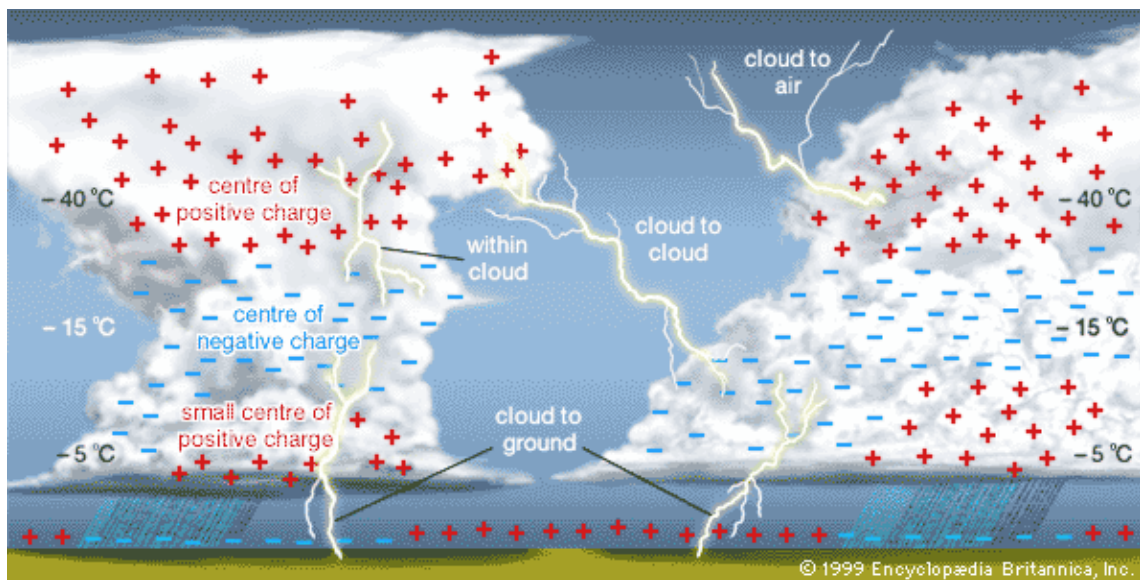


Figure 3. Physical aspects.

There are different types of lightning. In temperate climates, the vast majority (about 90%) of lightning is of the negative downward variety where the discharge is from the negatively charged cloud base down to the ground.

Occasionally - usually during the winter - a downward leader may build up within a positively charged pocket in the base of the cloud and discharge down to the ground. This type of lightning is known as positive downward.



When electrical conditions in the atmosphere permit, an upward leader variety of lightning may shoot up spontaneously from a point of high altitude (e.g. a mountain peak, telecommunications tower or high building). The resulting lightning is known as positive upward, or, less frequently, negative upward, lightning depending upon the cloud's electrical charge.



An average bolt of negative lightning carries an electric current of 30,000 amperes (30 kA), and transfers 15 coulombs of electric charge and 500 mega joules of energy. Large bolts of lightning can carry up to 120 kA and 350 coulombs. An average bolt of positive lightning carries an electric current of about 300 kA — about 10 times that of negative lightning.

The voltage involved for both is proportional to the length of the bolt. However, lightning leader development is not just a matter of the electrical breakdown of air, which occurs at a voltage gradient of about 1MV/m. The ambient electric fields

required for lightning leader propagation can be one or two orders of magnitude ( $10^{-2}$ ) less than the electrical breakdown strength.

The potential (voltage) gradient inside a well-developed return-stroke channel is on the order of hundreds of volts per meter (V/m) due to intense channel ionization, resulting in a true power output on the order of one megawatt per meter (MW/m) for a vigorous return stroke current of 100 kA. The average peak power output of a single lightning stroke is about one trillion watts — one terawatt ( $10^{12}$  W), and the stroke lasts for about 30 millionths of a second — 30microseconds.

Lightning rapidly heats the air in its immediate vicinity to about 20,000 °C — about three times the temperature of the surface of the Sun. The sudden heating effect and the expansion of heated air give rise to a supersonic shock wave in the surrounding clear air. It is this shock wave, once it decays to an acoustic wave, which is heard as thunder.

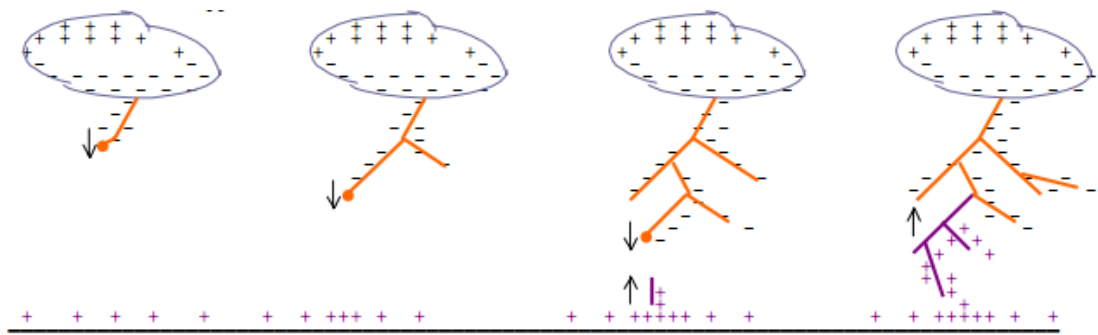
Different locations have different potentials and currents for an average lightning strike.

NASA scientists have found that electromagnetic radiation created by lightning in clouds only a few miles high can create a safe zone in the Van Allen radiation belts that surround the earth. This zone, known as the "Van Allen Belt slot", may be a safe haven for satellites in middle Earth orbits (MEOs), protecting them from the Sun's intense radiation.

### ***1.1.1 Breakdown Process***

Under the influence of sufficiently strong fields, large water drops become elongated in the direction of the field and become unstable, and streamers develop at their ends with the onset of corona discharges. Drops of radius 2 mm develop streamers in fields exceeding a 9 kV/cm - much less than the 30 kV/cm required to initiate the breakdown of dry air. The high field need only be very localized, because a streamer starting from one drop may propagate itself from drop to drop under a much weaker field. When the electric field in the vicinity of one of the negative charge centers builds up to the critical value (about 10 kV/cm), an ionized channel (or streamer) is formed, which propagates from the cloud to earth with a velocity that might be as high as one-tenth the speed of light. Usually this streamer is extinguished when only a short distance from the cloud.





Forty micro-seconds or so after the first streamer, a second streamer occurs, closely following the path of the first, and propagating the ionized channel a little further before it is also spent. This process continues a number of times, each step increasing the channel length by 10 to 200 m. Because of the step like sequence in which this streamer travels to earth, this process is termed the stepped leader stroke.

When eventually the stepped leader has approached to within 15 to 50 m of the earth, the field intensity at earth is sufficient for an upward streamer to develop and bridge the remaining gap. A large neutralizing current flows along the ionized path, produced by the stepped leader, to neutralize the charge. This current flow is termed the return stroke and may carry currents as high as 200 kA, although the average current is about 20 kA.

The luminescence of the stepped leader decreases towards the cloud and in one instances it appears to vanish some distance below the cloud. This would suggest that the current is confined to the stepped leader itself. Following the first or main stroke and after about 40 ms, a second leader stroke propagates to earth in a continuous and rapid manner and again a return stroke follows. This second and subsequent leader strokes which travel along the already energized channel are termed dart leaders.

What appears as a single flash of lightning usually consist of a number of successive strokes, following the same track in space, at intervals of a few hundredths of a second. The average number of strokes in a multiple stroke is four, but as many as 40 have been reported. The time interval between strokes ranges from 20 to 700 ms, but is most frequently 40-50ms. The average duration of a complete flash being about 250ms.

The approximate time durations of the various components of a lightning stroke are summarized as follows.

Stepped leader = 10 ms

Return stroke = 40  $\mu$ s

Period between strokes = 40 ms

Duration of dart leader = 1 ms

For the purpose of surge calculations, it is only the heavy current flow during the return stroke that is of importance. During this period it has been found that the waveform can be represented by a double exponential of the form

$$i = I(e^{-\alpha t} - e^{-\beta t})$$

with wave front times of 0.5 – 10  $\mu$ s, and wave tail times of 30 – 200  $\mu$ s.

The standard voltage waveform used in high voltage testing has a 1.2/50  $\mu$ s waveform to take into account the most severe conditions. For the standard waveform, the coefficients  $\alpha$  and  $\beta$  in the double exponential have values of  $\alpha = 1.426 \times 10^4 \text{ s}^{-1}$ , and  $\beta = 4.877 \times 10^6 \text{ s}^{-1}$

### **1.1.2 Lightning parameters**

Nowadays the electrical activity measured in tall objects has been widely characterized, but the collected data of lightning rods installed in buildings do not amount to enough to obtain reliable statistics. The measures stored at relatively few points are not representative of the different types of installations. Furthermore, the protection model applied for lightning air terminal installations is based on theoretical models.

The technical committee TC 81 “Lightning Protection” of the International Electrotechnical Commission IEC was established in Stockholm in June 1980 the scope to prepare international standards and guides for lightning protection for structures and buildings, as well for persons, installations, services and contents. Meanwhile, the results of TC 81 are published in the international standard series IEC 62305.

TC 81 decided as one of the first steps to define the lightning threat as a common basis to any protection measures. The lightning threat is mainly derived from the measurements of Berger performed at two 70m towers on the Mountain San Salvatore in Switzerland. Up to now, the results published in CIGRE Electra in 1975 and

1980 represent the most complete data base of lightning currents and their relevant parameters.

#### *Relevant current parameters for the lightning protection*

The current is the primary source for all thermal and mechanical damages caused by lightning. Besides that, the rate-of-rise of the lightning currents may induce overvoltages in electric and electronic systems or devices. The lightning threat is associated with the following current parameters:

- Current peak:  $i_{\max}$
- Charge:  $Q = \int i \cdot dt$
- Specific energy:  $\frac{W}{R} = \int i^2 \cdot dt$
- Maximum current derivative:  $\left(\frac{di}{dt}\right)_{\max}$

The peak current is important for the design of the earth termination system. When the lightning current enters the earth, the current flowing through the earthing resistance produces a voltage drop. The peak current determines the maximum value of this voltage drop. This voltage drop may lead to side flashes when conductive services lines enter a building unbounded.

The charge  $Q$  is responsible for the melting effects at the attachment points of the lightning channel. The energy input at the arc root is given by the anode/cathode voltage drop multiplied by the charge  $Q$ .

The specific energy  $W/R$  is responsible for mechanical forces and for the heating effects, when the lightning current flows through metallic conductors.

Electronic devices are normally connected to different electrical services as the mains supply and the data link. Depending on the line routing inside a structure, large loops may be formed by these lines. The maximum current steepness determines the maximum of the magnetically induced voltages into open loops.

### **1.1.3 Current components**

Lightning is a natural phenomenon where, for the purpose of analysis and design, a statistical approach is taken. Data from International Council of Large Electrical Systems (CIGRE) indicates that:

- 5% of first, negative lightning strokes exceed 90 kA (average is 33 kA)
- 5% of positive lightning strokes exceed 250 kA (average is 34 kA)

- 5% of negative subsequent strokes exceed a rate of current rise of 161 kA/ $\mu$ s

The measurements revealed that the current parameters of the upward lightning do not exceed the current parameters of the downward lightning. Because no additional threat has to be taken into account for the upward lightning, the current components codified in the IEC 62305-1 are exclusively based on the currents of the downward lightning. In order to represent the threat of the lightning currents, the following basic current components are fixed in the standard IEC 62305-1:

- First short stroke current
- Subsequent short stroke current
- Long stroke current

The first short stroke current takes into account the threat of the first return strokes of downward lightning. The threat of the first return strokes mainly originates from the positive lightning higher current peaks  $i_{\max}$  higher impulse charge  $Q_i$  and higher specific energy  $W/R$  compared to the negative lightning. According to the measurements of *Berger*, a relatively strong correlation exists between these three parameters.

In the IEC 62305 series, four lightning protection levels LPL are introduced to take into account the different safety requirements of various buildings. For instance, a dwelling house requires a lower safety level than a plant handling explosive materials.

For a reliable protection against the thermal and mechanical effects of lightning as well as induced over-voltage the current parameters at the upper end of the statistical lightning current distributions have to be taken into account. It was the intention of TC 81 that the parameters fixed for LPL I shall not be exceeded in naturally occurring lightning with a probability of about 99%. For the LPL II the parameters of LPL I are reduced to 75% and for LPL III and LPL IV to 50% of LPL I. The reduction follows a linear relationship for a peak current, impulse charge and current steepness, but a quadratic one for the specific energy.

The following table indicates for these lightning protection levels the maximum current expected and the probability that this may be exceeded. The standard ensures that air-termination, conductor and earth termination size are sufficient to withstand the expected maximum current.

	LPL I	LPL II	LPL III	LPL IV
Maximum peak current (kA 10/350 $\mu$ s)	200	150	100	100
Probability current is greater (%)	1	2	3	3

The following table shows the relations between lightning protection level, interception criterion, final striking distance and minimum peak value of current:

Lightning protection level LPL	Probabilities for the limit values of the lightning current parameters		Radius of the rolling sphere (final striking distance $h_p$ ) r in m	Min. peak value of current I in kA
	< Max. values acc. to Table 5 IEC 62305-1 (EN 62305-1)	> Min. values acc. to Table 6 IEC 62305-1 (EN 62305-1)		
IV	0.84	0.97	60	16
III	0.91	0.97	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

## **1.2 History**

### **1.2.1 Mythology aspects (*The electric magic*)**

There was another earlier time when lightning was the magic fire from the sky which man captured and used to keep warm at night. It kept the savage animals away. As primitive man sought answers about the natural world, lightning became a part of his superstitions, his myths and his early religions.

- Early Greeks believed that lightning was a weapon of Zeus. Thunderbolts were invented by Athena, the goddess of wisdom. Since lightning was a manifestation of the gods, any spot struck by lightning was regarded as sacred. Greek and Roman temples often were erected at these sites, where the gods were worshipped in an attempt to appease them.
- The Moslems also attributed lightning and thunder to their god. The Koran says, "He is who showed you lightning and launches the thunderbolts."
- Scandinavian mythology alludes to Thor, the thunderer, who was the foe of all demons. Thor tossed lightning bolts at his enemies. Thor also gave us Thursday.
- In the pantheistic Hindu religion, Indra was the god of heaven, lightning, rain, storms and thunder. The Maruts used the thunderbolts as weapons.
- Umpundulo is the lightning bird-god of the Bantu tribesmen in Africa. Even today their medicine men go out in storms and bid the lightning to strike far away.
- The Navajo Indians hold that lightning has great power in their healing rituals. Sand paintings show the lightning bolt as a wink in the Thunderbird's eye. Lightning is associated with wind, rain and crop growth.
- As late as the early 1800s in Russia, when rain was wanted, three men climbed a tree. One would knock two firebrands together; the sparks imitating lightning. Another one would pour water over twigs, imitating rain. A third would bang on a kettle to attract the thunder. And throughout early Europe, church bell ringers would make as much noise as possible, hoping to scare away the storms from these holy dwellings which were struck frequently by lightning.
- Even Santa Klaus gets into the act with his reindeer Donner (thunder) and Blitzen (lightning).



### **1.2.2 Evolution**

Early superstitions were observed as “Cause and Effect”, which now has been fancified as science. The first attempt at a scientific explanation of lightning was undertake by Socrates, who claimed “it was not Zeus up there, but a vortex of air”.

Ghengis Kahn forbade his subjects from washing garments or bathing in running water during a storm. Thales, the Greek philosopher, in 600 BC, rubbed a piece of amber with a dry cloth and noted that it would then attract feathers and straw. But he didn't link the phenomenon to lightning.

In ancient Rome, members of the College of Augurs divined the will of the gods by observing the southern sky for lightning, birds, and shooting stars. A lightning bolt passing from left to right was a favorable omen; a lightning bolt passing from right to left was a sign that Jove did not approve of current political events. Furthermore, whenever the augurs reported any sign of lightning, the magistrates of Rome were required to cancel all public assemblies on the following day. The augurs' reports became politically useful to postpone unwanted meetings, delay the passage of laws, or prevent the election of certain magistrates by popular assemblies.

Meanwhile Ghengis Kahn took a much more practical approach to lightning, forbidding his subjects from washing garments or bathing in running water during a storm.

By the late 1500s, European scientists were undertaking the first experiments to duplicate it on a laboratory scale. William Gilbert, court healer to Queen Elizabeth used amber to duplicate the earlier experiments. He named this "via electrica", after electra which is Greek for amber. He didn't know it, but he was demonstrating static electricity.

During the sixteenth century various machines for generating static electricity were invented...the Leyden jar was like a thermos bottle which stored volts. Friction machines could charge the jars and electricity could be carried around and demonstrated. "Electric magic" was in great demand at the royal courts of Europe as entertainment. The parlor tricks amused and fascinated people.

In medieval Europe and England it was general practice to ring church bells violently during thunderstorms in an effort to keep the lightning from striking the tall church spire. Some felt the clamor of the bells dispersed evil spirits that sought to destroy the church with fire; others claimed that the noise of the bells disrupted the lightning strokes. (The second reason explains the common inscription on medieval bells: "Fulgura Frango" which means "I break up the lightning flashes"). This didn't stop lightning from striking 386 French church towers during the years from 1753 to 1786. Even worse, during the same period lightning running down the bell ropes killed 103 French bell ringers.

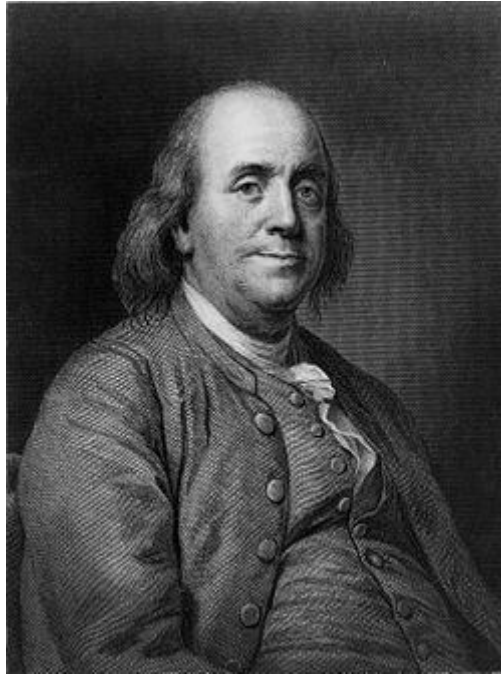
The 17th Century saw rapid advances in many areas of science and mathematics, usually involving Sir Isaac Newton. He proposed that basic mathematical laws were the foundation for understanding the forces of nature, but with "electric magic" there was insufficient experimental investigation to explain its behavior.

In 1746, however, a Scot called Dr. Spence came to Philadelphia. He there demonstrated some "electric magic" to an audience which included the local postmaster. That man was **Benjamin Franklin**. Franklin was curiosity personified. At age eight he left the Boston Grammar School, ending his formal studies. He was endowed with a strong sense of investigation and self-discipline. He learned and studied things all his life. He invented the bifocal glasses and the Franklin stove. An expert swimmer, a vegetarian, multi-lingual, and a word-smith publisher, his Poor Richard's Almanac was selling 10,000 copies a year in the colonies...

### ***1.2.3 Benjamin Franklin***

Benjamin Franklin (January 17, 1706 – April 17, 1790) was one of the Founding Fathers of the United States. A noted polymath, Franklin was a leading author, printer, political theorist, politician, postmaster, scientist, musician, inventor, satirist, civic activist, statesman, and diplomat. As a scientist, he was a major figure in the American Enlightenment and the history of physics for his discoveries and theories regarding electricity. He invented the lightning rod, bifocals, the Franklin stove, a carriage odometer, and the glass 'armonica'.





Benjamin Franklin was fascinated by storms; he loved to study them.

It was in Boston, Massachusetts, in 1746 that Franklin first stumbled upon other scientists' electrical experiments. He quickly turned his home into a little laboratory, using machines made out of items he found around the house. During one experiment, Ben accidentally shocked himself. Franklin spent the summer of 1747 conducting a series of groundbreaking experiments with electricity. He wrote down all of his results and ideas for future experiments in letters to Peter Collinson, a fellow scientist and friend in London who was interested in publishing his work. By July, Ben used the terms positive and negative (plus and minus) to describe electricity, instead of the previously used words "vitreous" and "resinous." Franklin described the concept of an electrical battery in a letter to Collinson in the spring of 1749, but he wasn't sure how it could be useful.

Later the same year, he explained what he believed were similarities between electricity and lightning, such as the color of the light, its crooked direction, crackling noise, and other things. There were other scientists who believed that lightning was electricity, but Franklin was determined to find a method of proving it.

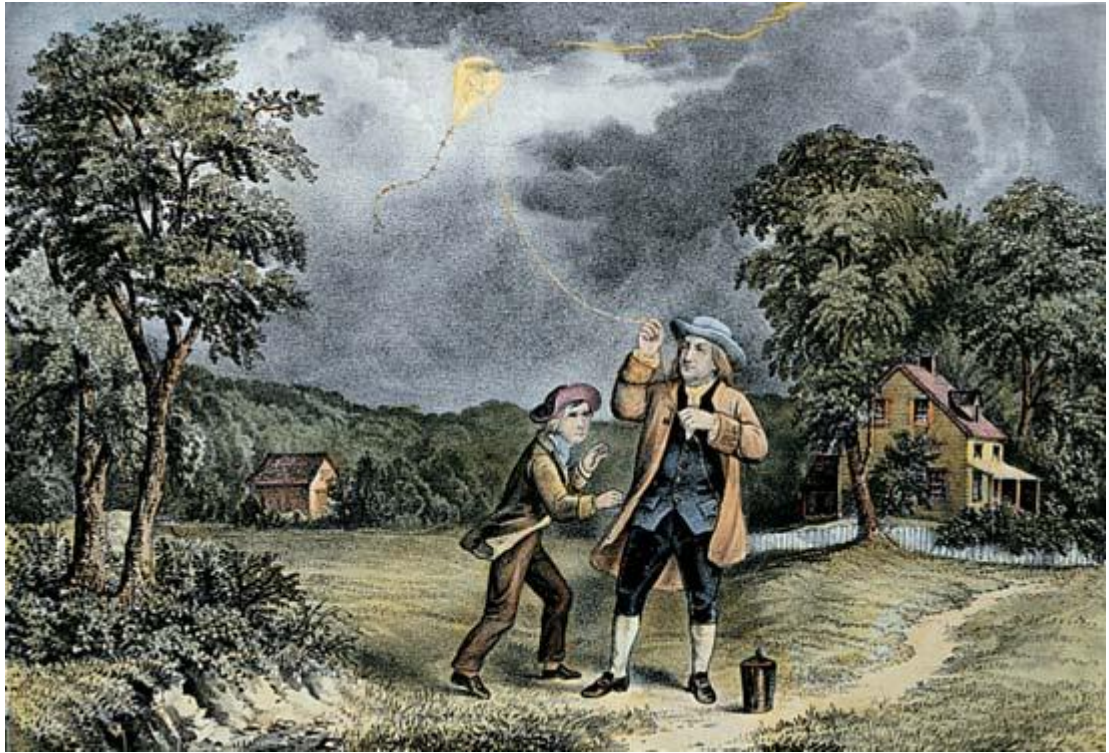
By 1750, in addition to wanting to prove that lightning was electricity, Franklin began to think about protecting people, buildings, and other structures from lightning. This grew into his idea for the lightning rod. Franklin described an iron rod about 8 or 10 feet long that was sharpened to a point at the end. He wrote, "the electrical fire would, I think, be drawn out of a cloud silently, before it could come near enough to strike..." Two years later, Franklin decided to try his own lightning experiment. Surprisingly, he never wrote letters about the legendary kite experiment; someone else wrote the only account

15 years after it took place.

In June of 1752, Franklin was in Philadelphia, waiting for the steeple on top of Christ Church to be completed for his experiment (the steeple would act as the "lightning rod"). He grew impatient, and decided that a kite would be able to get close to the storm clouds just as well. Ben needed to figure out what he would use to attract an electrical charge; he decided on a metal key, and attached it to the kite. Then he tied the kite string to an insulating silk ribbon for the knuckles of his hand. Even though this was a very dangerous experiment, some people believe that Ben wasn't injured because he didn't conduct his test during the worst part of the storm. At the first sign of the key receiving an electrical charge from the air, Franklin knew that lightning was a form of electricity. His 21-year-old son William was the only witness to the event.

Two years before the kite and key experiment, Ben had observed that a sharp iron needle would conduct electricity away from a charged metal sphere. He first theorized that lightning might be preventable by using an elevated iron rod connected to earth to empty static from a cloud.

Franklin began to advocate lightning rods that had sharp points. His English colleagues favored blunt-tipped lightning rods, reasoning that sharp ones attracted lightning and increased the risk of strikes; they thought blunt rods were less likely to be struck. King George III had his palace equipped with a blunt lightning rod. When it came time to equip the colonies' buildings with lightning rods, the decision became a political statement. The favored pointed lightning rod expressed support for Franklin's theories of protecting public buildings and the rejection of theories supported by the King. The English thought this was just another way for the flourishing colonies to be disobedient to them.



Franklin's lightning rods could soon be found protecting many buildings and homes. The lightning rod constructed on the dome of the State House in Maryland was the largest "Franklin" lightning rod ever attached to a public or private building in Ben's lifetime. It was built in accord with his recommendations and has had only one recorded instance of lightning damage. The pointed lightning rod placed on the State House and other buildings became a symbol of the ingenuity and independence of a young, thriving nation, as well as the intellect and inventiveness of Benjamin Franklin.

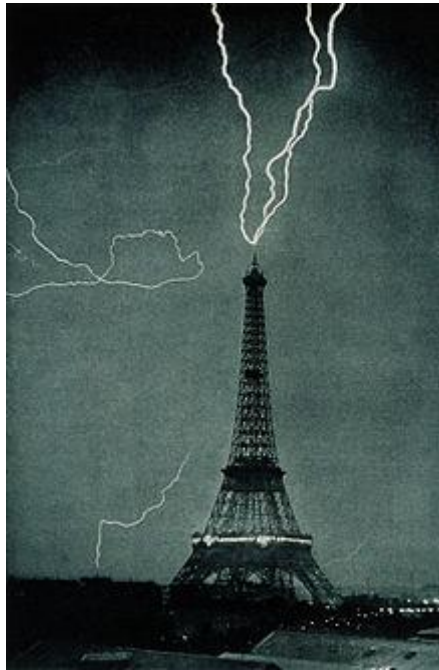
In addition to electricity, Franklin studied a number of other topics, including ocean currents, meteorology, causes of the common cold and refrigeration. He developed the Franklin stove, which provided more heat while using less fuel than other stoves, and bifocal eyeglasses, which allow for distance and reading use.

### ***1.2.4 XX Century***

This was the largest step made in the understanding of lightning until the late 1800s. About this time, photography and spectroscopic tools became available for lightning research.

Using more advanced equipment, the researcher Pockels, was able to analyze the magnetic field induced by lightning. This allowed him to accurately estimate the magnitude of the current in a lightning bolt. Similar methods were used by many experimenters throughout the late 19th century.

Although experiments from the time of Benjamin Franklin showed that lightning was a discharge of static electricity, there was little improvement in theoretical understanding of lightning (in particular how it was generated) for more than 150 years. The impetus for new research came from the field of power engineering: as power transmission lines came into service, engineers needed to know much more about lightning in order to adequately protect lines and equipment. In 1900, Nikola Tesla generated artificial lightning by using a large Tesla coil, enabling the generation of enormously high voltages sufficient to create lightning.



Lightning research was heavily increased in the 1960s. This increase was caused by several things. First of all, lightning posed a great threat to aerospace vehicles and solid state electronic used in computers and other devices (which came into play in the 1960s). Secondly, the research was made easier and better by improved measurement and observational capabilities created by technology.

Recently some scientists have concluded that lightning may have played a part in the evolution of living organisms. Nobel Prize winning chemist Harold Urey proposed that the earth's early atmosphere consisted of ammonia, hydrogen, methane, and water vapor. One of his students, Stanley Miller, used an electric spark to duplicate lightning and introduced it into the chemical brew. He was careful to exclude any living organisms from the experiment. At the end of a week, he examined the mixture and found it contained newly-formed amino acids, the very building blocks of protein. Did lightning play a role in creating life itself? Science now is pushing the envelope of lightning's secrets. More has been learned about this transient phenomenon in the

past 3-4 years than in the preceding two hundred forty four years since Franklin's "kites and keys" experiments.

## 1.3 Introduction to protection methods

The design of a lightning protection system needs to:

- Intercept lightning flash (i.e. create a preferred point of strike)
- Conduct the lightning current to earth
- Dissipate current into the earth
- Create an equipotential bond to prevent hazardous potential differences between LPS, structure and internal elements/circuits.

In achieving this the lightning protection system must:

- Not cause thermal or mechanical damage to the structure
- Not cause sparking which may cause fire or explosion
- Limit step and touch voltages to control the risk of injury to occupants
- Limit damage to internal electrical and electronic systems

The lightning protection system is generally considered in two parts. The external lightning protection system intercepts, conducts and dissipates the lightning flash to earth. The internal lightning protection system prevents dangerous sparking within the structure (using equipotential bonding or separation distance).

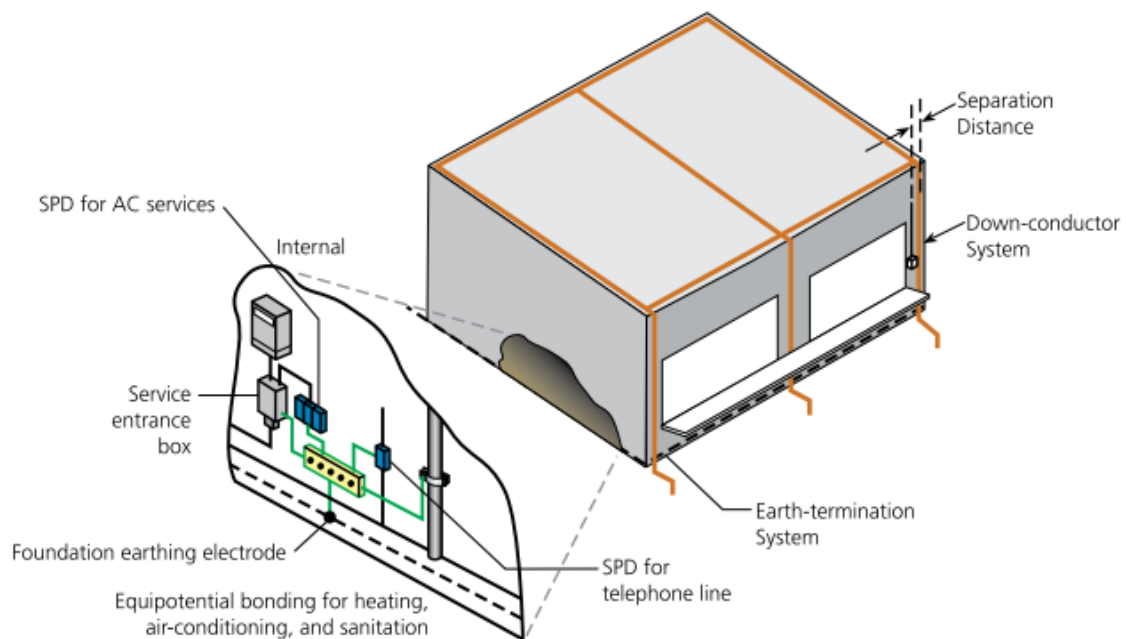
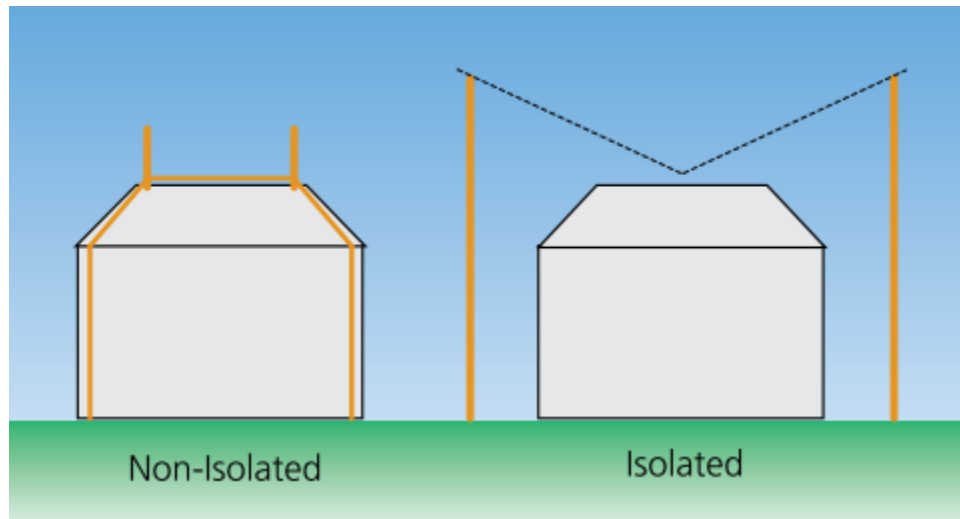


Figure 4. External and internal lightning protection system.

Lightning protection systems typically follow two approaches:

- Non-isolated system: where potentially damaging voltage differentials are limited by bonding the lightning protection system to the structure.

- Isolated system: where the lightning protection system is isolated from the structure by a specified separation distance. This distance should be sufficient that energy is contained on the LPS and does not spark to the structure. Isolated systems are well suited to structures with combustible materials such as thatched roofs, or telecommunication sites that want to avoid lightning currents being conducted on masts and antenna bodies.



The standard provides simple geometric forms of design which are comprised of cost, effectiveness and simplicity in design. The design methods are:

- Mesh method
- Rolling sphere method (RSM)
- Protection angle method (PAM)

These methods are used to determine the optimum location of the air-terminations and the resulting down-conductor and earthing requirements.

A risk assessment is generally undertaken to determine the level of risk for a specific structure, in order to make a comparison with a pre-determined value of “acceptable risk”. Protection measures, at an appropriate lightning protection level (LPL), are then implemented to reduce the risk to or below the acceptable risk. The lightning protection level determines the spacing of the mesh, radius of rolling sphere, protective angle, etc.

It should be noted that while lightning protection is typically implemented as a bonded network of air-terminals and downconductors, other methods are permitted:

- To limit touch and step potential risks:
  - Insulation of exposed conductive parts

- Physical restriction and warning signs
- To limit physical damage:
  - Fire proofing, fire extinguishing systems, protected escape routes.



## **1.4. Risk management**

IEC 62305-2 provides a lightning risk management procedure that provides a tolerable limit of risk, methods to calculate the actual risk, and then evaluates the protection methods required to reduce the actual risk to be equal or lower than the tolerable risk. The main outcome from this risk assessment is to determine if lightning protection is required and if so, to select the appropriate lightning class. The lightning class determines the minimum lightning protection level (LPL) that is used within the lightning protection design.

Lightning protection can be installed even when the risk management process may indicate that it is not required. A greater level of protection than that required may also be selected.

A full manual analysis of all risks can take tens of hours to complete. Therefore for most situations a reduced analysis is conducted, preferably with an electronic tool. For this purpose, the IEC standard comes with software, and additional third-party software is also available.

For complex or high risk structures/situations, a more detailed analysis should be considered using the full standard. This would include, but is not limited to:

- Locations with hazardous or explosive materials
- Hospitals or other structures where failure of internal systems may cause a life hazard

### **1.4.1. Overview of risk analysis**

Conceptually the risk analysis follows the general process of:

- 1) Identifying the structure to be protected and its environment
- 2) Evaluating each loss type and associated risk (R1 to R3)
- 3) Comparing R1 to R3 to the appropriate tolerable risk RT to determine if protection is needed
- 4) Evaluating protection options so  $R1 \text{ to } R3 \leq RT$

Note that separate RT figures exist for risk of losses R1 to R3. Lightning protection is required such that R1, R2 & R3 are all equal or lower than the respective tolerable risk (RT).

Lightning protection may also be justified upon the economic risk R4 and the respective economic benefit. A separate procedure in IEC 62305-2 is followed for this analysis.

Each of the following risks are broken down into individual risk components (sub categories), which are then evaluated with regard to direct and indirect lightning effects upon the structure and on the services. This requires the computation of the number of dangerous events, which is related to the structure size and lightning flash density.

***Sources of damage, type of damage, type of loss and risk of loss***

It is important to understand the sources of damage, types of damage and types of losses as the procedure to assess the risk evaluates various combinations considering structure, contents, services and environment with the source and type of damage.

The sources of damage are (figure 5):

- S1: Lightning flash to the structure
- S2: Lightning flash near the structure
- S3: Lightning flash to the services
- S4: Lightning flash near to the services

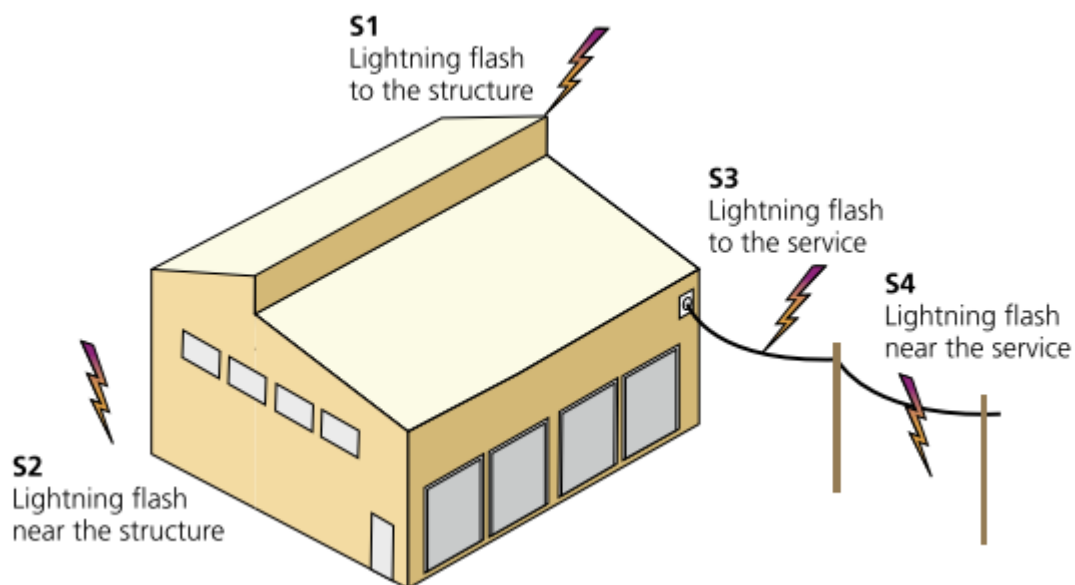


Figure 5. Sources of damage

With the possible sources of damage due to lightning flash defined, three possible types of damage are identified:

- D1 – Injury of living beings (humans and animals) due to touch and step potential

- D2 – Physical damage (fire, explosion, mechanical destruction, chemical release)
- D3 – Failure of internal electrical/electronic systems due to lightning electromagnetic impulse

With each type of damage, four types of losses are identified:

- L1 – Loss of human life
- L2 – Loss of essential service to the public
- L3 – Loss of cultural heritage
- L4 – Economic loss (structure and its contents, service and loss of activity)

Care is required with the term “services”, as it is dependant upon its context within the standard. This may refer to the physical services connected to the building (water, power, gas, fuel or data/telecommunications), or services provided to the public (e.g. information services). The scope of services to the public includes any type of supplier who, due to lightning damage, can not provide their goods or “service” to the public.

Table 1 summarizes the types of damage and types of loss for each of the four sources of damage [from IEC 62305-1 Table 3]. For each of the first three types of losses (L1, L2 & L3), the procedure of IEC 62305-2 evaluates the risk of these respective losses (R1, R2 & R3) and compares them to tolerable levels. For Loss L4, the economic cost of the loss, with and without lightning protection, is compared to the cost of the protection measures.

Source of damage (Point of strike)	Type of damage	Type of loss
<b>S1</b> Lightning flash to the structure	D1 - Injury	L1 – Loss of human life L4 – Economic loss <sup>(1)</sup>
	D2 – Physical damage	L1 – Loss of human life <sup>(2)</sup> L2 – Loss of service L3 – Loss of heritage L4 – Economic loss
	D3 – Failure of systems	L1 – Loss of human life <sup>(2)</sup> L2 – Loss of service L4 – Economic loss
<b>S2</b> Lightning flash near the structure	D3 – Failure of systems	L1 – Loss of human life L2 – Loss of service L4 – Economic loss
<b>S3</b> Lightning flash to the services	D1 - Injury	L1 – Loss of human life L4 – Economic loss <sup>(1)</sup>
	D2 – Physical damage	L1 – Loss of human life L2 – Loss of service L3 – Loss of heritage L4 – Economic loss
	D3 – Failure of systems	L1 – Loss of human life <sup>(2)</sup> L2 – Loss of service L4 – Economic loss
<b>S4</b> Lightning flash near to the services	D3 – Failure of systems	L1 – Loss of human life <sup>(2)</sup> L2 – Loss of service L4 – Economic loss

**Notes:**

<sup>(1)</sup> Only for properties where animals may be lost

<sup>(2)</sup> Only for structures with risk of explosion and for hospitals or other structures where failure of services or internal systems endangers human life

Table 1. Damages and losses in a structure for different sources

***Risk management procedure & tolerable risk***

For each of the losses L1 to L3, the risk of each loss is determined (R1 to 3). The risk of each loss is then compared to a tolerable risk:

- If the calculated risk is equal or less than the respective tolerable risk (RT), then lightning protection is not required
- If the calculated risk is higher than the tolerable risk then protection is required. Protective measures should be evaluated to reduce the calculated risk to be equal or less than the tolerable risk

Table 2 provides the tolerable risks as provided by IEC standard. The tolerable risk is expressed in the form of number of events per year and is given in engineering units (e.g. 10-x). Table 2 also expresses these in the format of x in y events (per year).

Types of loss	$R_T(y^{-1})$
	IEC 62305-2
Loss of human life	$10^{-5}$ (risk of 1 in 100,000)
Loss of service to the public	$10^{-3}$ (risk of 1 in 1,000)
Loss of cultural heritage	$10^{-3}$ (risk of 1 in 1,000)

Table 2. Tolerable risk RT

## 1.5 Design methods:

The rolling sphere method, mesh method and protection angle method are used to determine the required positioning of the lightning protection air-terminations. While there are limits on the application of the protection angle and mesh methods, generally the standard considers the three methods as equivalent.

The rolling sphere method is recommended as the most universal method, while the mesh method is more suitable for the protection of flat surfaces. The protection angle method can only be used with limited vertical distances. Different design methods can be applied to different regions of a single lightning protection system, provided the zones afforded by each method overlap to protect the entire structure.

Any of these methods can be used to determine placement of the air-terminations. Permitted air-terminations are:

- Rods (including masts and free standing masts)
- Meshed conductors (on building surface or elevated)
- Catenary wires
- Natural components

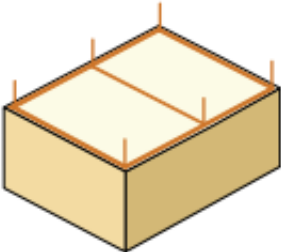
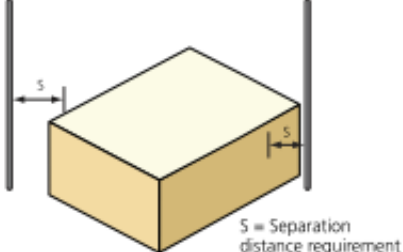
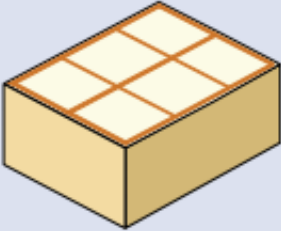
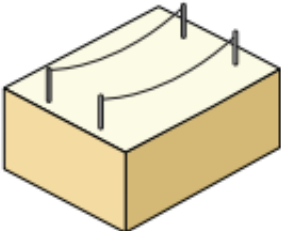
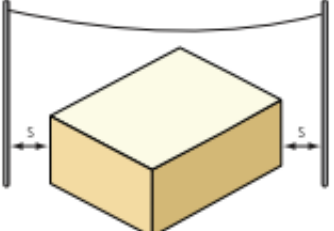
	Non isolated	Isolated
Air-terminations		
Meshed conductors		Only practical for specific circumstances
Catenary wires		

Figure 6. Air-Terminations.

Meshed conductors used as air-terminations should not be confused with the mesh method. While the mesh method requires the use of surface mounted meshed conductors (a grid) to protect flat surfaces, the rolling sphere and protection angle method can also be used to determine protection provided by elevated meshed conductors to protect a variety of compound surfaces.

While the standard considers the three methods to be equivalent, recent research has questioned the true effectiveness of the mesh method. The rolling sphere method generally provides the most optimized design and the vertical air-terminal is far more effective at capturing lightning flashes than mesh conductors installed upon, or just above structure surface.

The radius of the rolling sphere, the mesh size and the angles used in the protection angle method are related to the class of the lightning protection system. Lightning protection class

I, II, III & IV relate to protection level I, II, III, & IV respectively. For example if the risk assessment determines that a lightning protection system with lightning protection class II is required to reduce the risk to below the tolerable level, then the design of the lightning protection system will need to be in accordance with the requirements of lightning protection level II (or higher). The greater the level of lightning protection (LPL I being the greatest), the larger the resulting material requirement for the lightning protection system.

The Class of LPS/LPL influences the:

- Rolling sphere radius, mesh size and protection angle
- Typical distances between down-conductors and between ring conductors
- Separation distances
- Minimum length of earth electrodes

Air-termination	Protection method		
	Rolling sphere	Mesh method	Protection angle
Rod	✓✓✓		✓✓
Meshed conductors – (on structure surface)		✓ <sup>(1)</sup>	
Meshed conductors – (elevated from structure)	✓✓		✓✓
Catenary wires	✓✓		✓✓

**Note:** <sup>(1)</sup> Mesh method is appropriate for the evaluation of the protection of the bound flat surface. Rolling sphere and protection angle methods can be used to determine protection of adjacent areas.

Table 3. Suitability of air-termination methods and design methods.

Class of LPS (lightning protection level)	Rolling sphere radius (m)	Mesh size (m)	Protection angle
I	20	5 x 5	<b>Refer Figure</b>
II	30	10 x 10	
III	45	15 x 15	
IV	60	20 x 20	

Table 4. Maximum values for design method

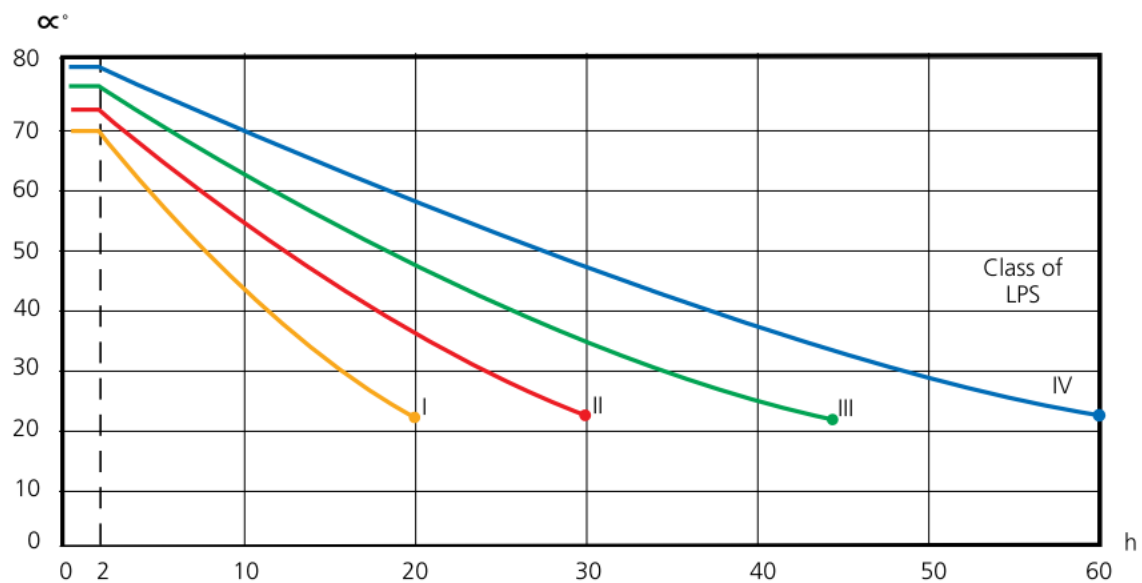


Figure 7. Protection angle graph.

### 1.5.1 Mesh method

For protection of a plane (flat) surface, the mesh method is considered to protect the whole bound surface if meshed conductors are:

- Positioned on the edges (perimeter) of the surface
- The mesh size is in accordance with Table 5

LPL	Mesh Size
I	5 m x 5 m
II	10 m x 10 m
III	15 m x 15 m
IV	20 m x 20 m

Table 5. Mesh size for mesh method.

- No metallic structures protrude outside the volume
- From each point, at least two separate paths exist to ground (i.e. no dead ends), and these paths follow the most direct routes

Natural components may be used for part of the mesh grid, or even the entire grid. The mesh method is recommended for flat roof surfaces. It is also recommended for the protection of the sides of tall buildings against flashes to the side.

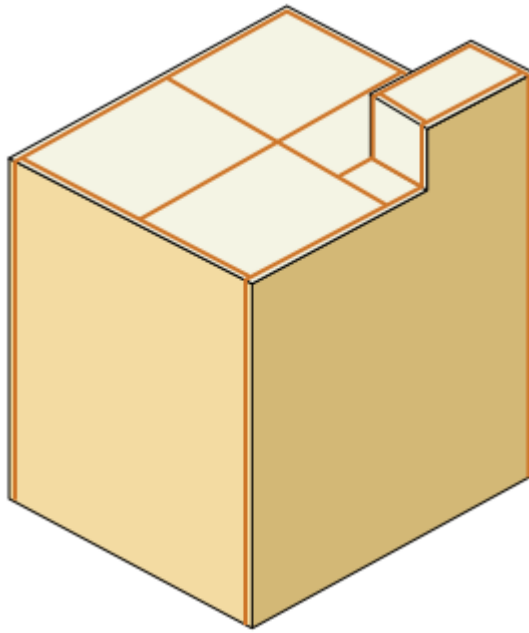


Figure 8. Protection via mesh method

The mesh method should not be used on curved surfaces, but can be used on non-horizontal plane surfaces and compound surfaces. For example on the vertical sides of tall buildings for protection against flashes to the side, or on compound surfaces such as industrial roofs. For compound surfaces, conductors should be placed on the roof

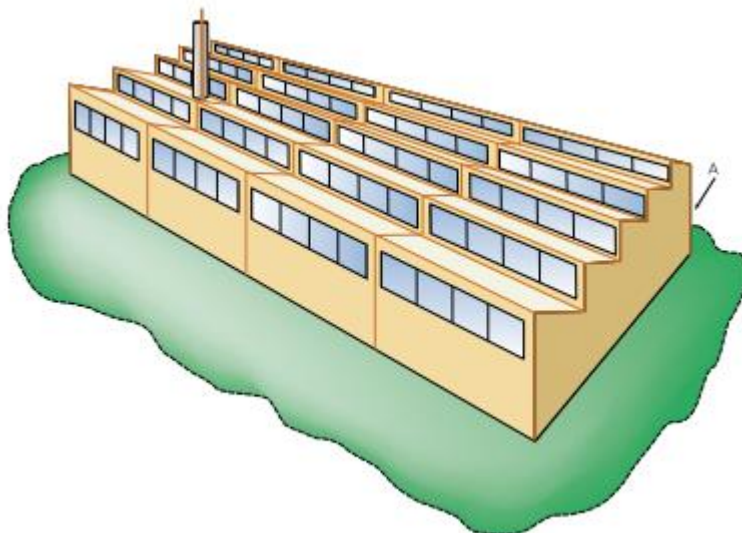




Figure 9. Mesh method for compound shapes.

The protective area provided by the mesh method is the area bounded by the mesh. The protection to areas adjacent to the mesh (e.g. building sides and lower structural points) is determined by the protection angle method (PAM) or rolling sphere method (RSM) (refer to Figure 10).

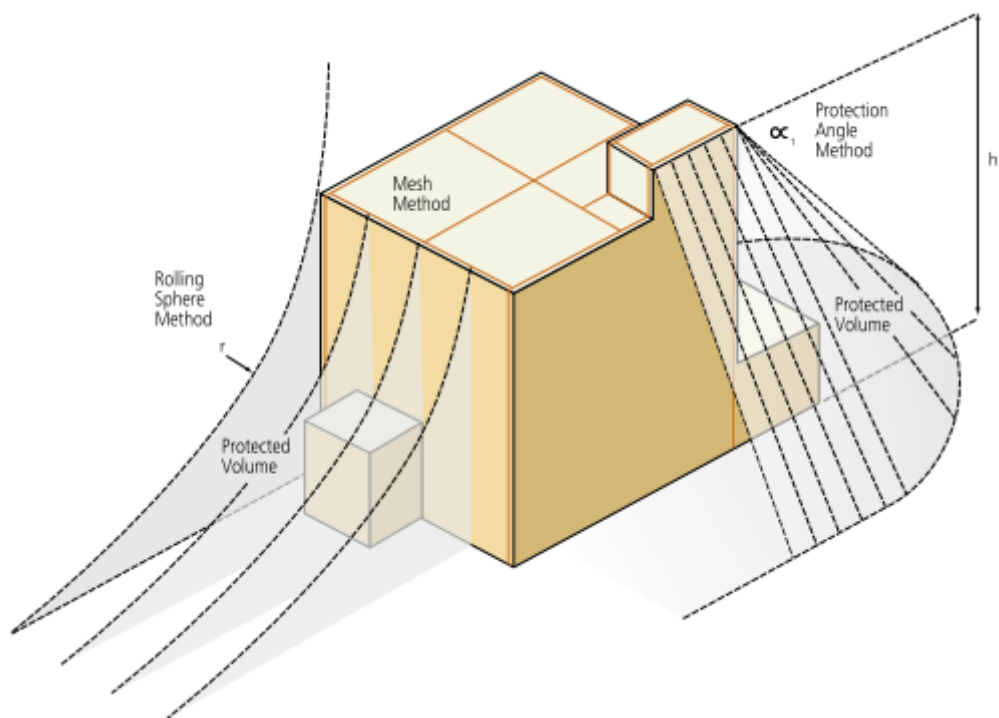


Figure 10. Volume protected by meshed conductors according to PAM and RSM method.

The protection provided by meshed conductors not placed in full accordance with the mesh method, e.g., those raised above the building surface, should be determined with an alternative design method, i.e., PAM or RSM, applied to the individual conductors.

### ***1.5.2 Protection angle method***

Air-terminations (rods/masts and catenary wires) are located so the volume defined by the protection angle (refer to Figure 11) covers the structure to be protected. The height of the air-termination is measured from the top of the air-termination to the surface to be protected. The protection angle method is limited in application to heights that are equal to or less than the corresponding rolling sphere radius.

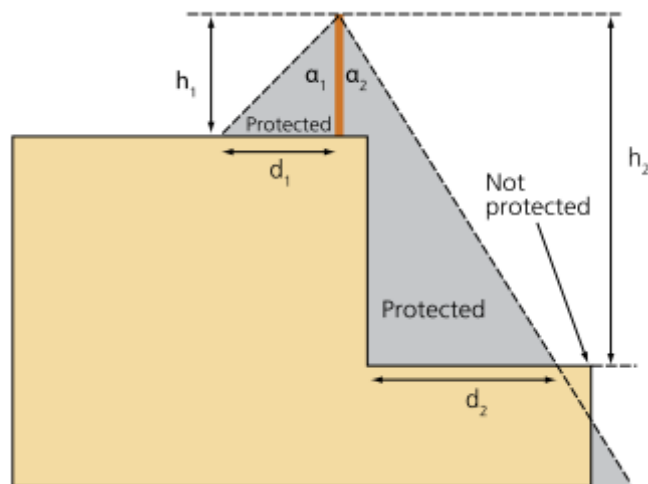


Figure 11. Protection angle method.

Where the protection angle method alone is employed, multiple rods are generally required for most structures. However the protection angle method is most commonly used to supplement the mesh method, providing protection to items protruding from the plane surface.

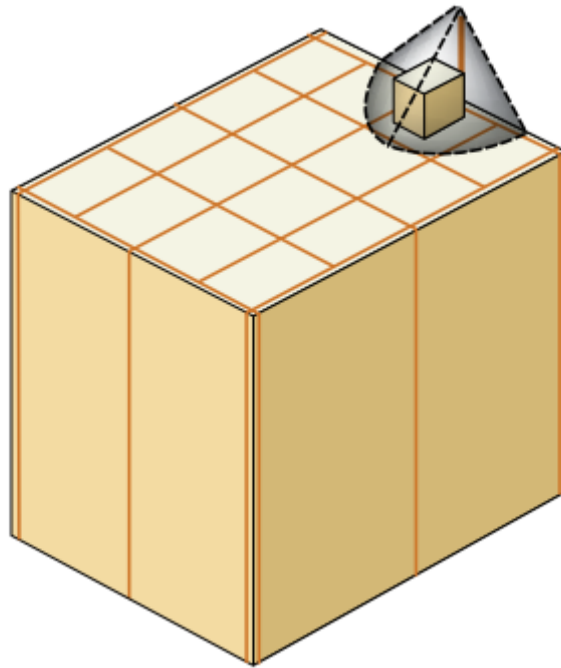


Figure 12. Combination protection.

The protection angle method can be used on inclined surfaces, where the height of the rod is the vertical height, but the protection angle is referenced from a perpendicular

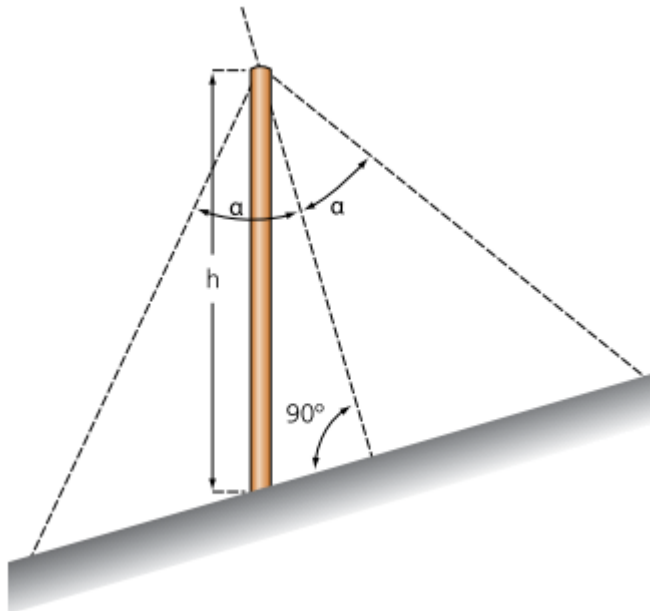


Figure 13. Protection angle method applied to inclined surface.

Height h of air- termination (m)	Distance d (m) and protection angle (rounded down to nearest degree)							
	LPL I		LPL II		LPL III		LPL IV	
	Distance	Angle	Distance	Angle	Distance	Angle	Distance	Angle
1	2.75	70	3.27	73	4.01	76	4.70	78
2	5.49	70	6.54	73	8.02	76	9.41	78
3	7.07	67	8.71	71	10.46	74	12.99	77
4	7.52	62	9.42	67	12.31	72	13.95	74
5	8.32	59	10.25	64	14.52	71	16.35	73
6	8.57	55	10.82	61	14.14	67	17.43	71
7	9.29	53	11.65	59	15.72	66	18.24	69
8	9.53	50	12.32	57	16.40	64	18.85	67
9	9.65	47	12.85	55	16.93	62	20.21	66
10	10.00	45	13.27	53	17.32	60	20.50	64
11	9.90	42	14.08	52	19.05	60	19.84	61
12	10.07	40	14.30	50	19.20	58	20.78	60
13	10.16	38	14.44	48	19.27	56	21.64	59
14	9.80	35	14.50	46	19.27	54	22.40	58
15	9.74	33	15.00	45	19.91	53	23.10	57
16	9.61	31	14.92	43	20.48	52	22.85	55
17	9.04	28	15.31	42	20.99	51	23.40	54
18	8.78	26	15.65	41	21.45	50	23.89	53
19	8.86	25	15.94	40	21.86	49	25.21	53
20	7.68	21	15.07	37	21.45	47	25.60	52
21			14.70	35	21.75	46	25.93	51
22			14.84	34	22.00	45	26.22	50
23			14.94	33	22.21	44	27.41	50
24			14.42	31	22.38	43	26.65	48
25			14.43	30	22.51	42	26.81	47
26			13.82	28	21.82	40	27.88	47
27			13.17	26	22.66	40	27.96	46
28			13.06	25	21.88	38	28.00	45
29			12.91	24	21.85	37	28.00	44
30			12.73	23	21.80	36	28.97	44
31					21.71	35	28.91	43
32					21.58	34	28.81	42
33					21.43	33	28.69	41
34					21.25	32	28.53	40
35					21.03	31	28.34	39
36					20.78	30	29.15	39
37					20.51	29	28.91	38
38					20.20	28	28.64	37
39					19.87	27	29.39	37
40					19.51	26	29.06	36
41					19.12	25	29.79	36
42					18.70	24	30.51	36
43					18.25	23	30.11	35
44					18.68	23	28.57	33
45					18.18	22	29.22	33
46							28.74	32
47							28.24	31
48							27.71	30
49							28.29	30
50							28.87	30
51							28.27	29
52							28.82	29
53							29.38	29
54							28.71	28
55							28.02	27
56							27.31	26
57							26.58	25
58							25.82	24
59							25.04	23
60							25.47	23

Table 6. Height versus horizontal distance using protection angle method.

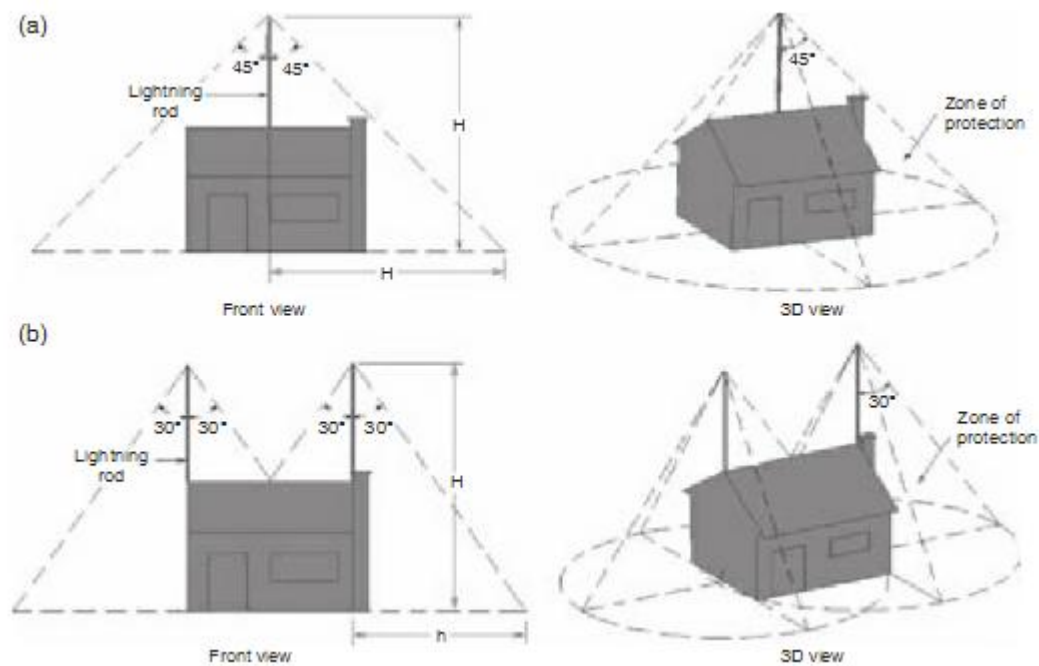


Figure 14. Protective angle method for the protection of a common house for an angle of (a)  $45^\circ$  and (b)  $30^\circ$

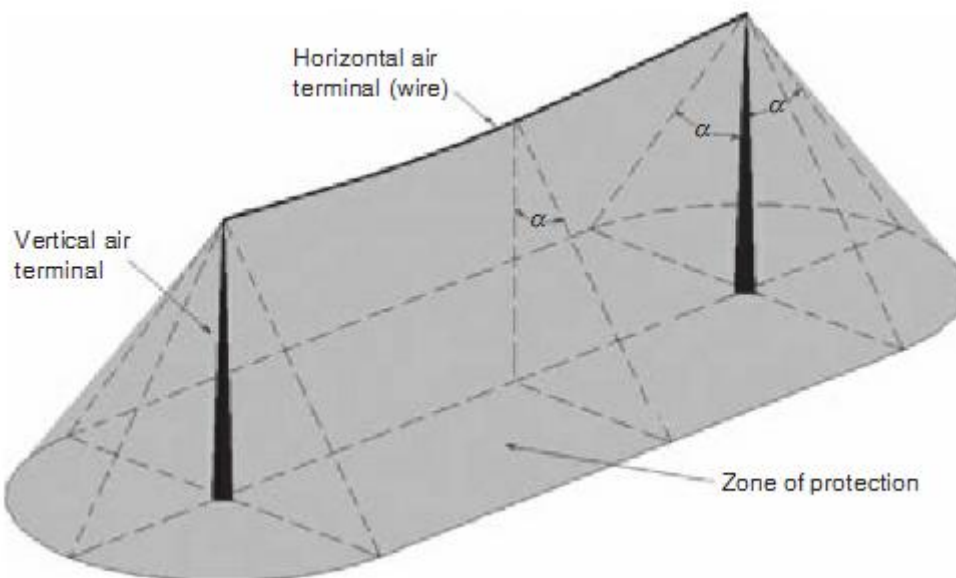


Figure 15. The volume of space protected according to the angle-of-protection method by a horizontal conductor connected to two vertical conductors at the ends.

#### ***Background of the protection angle method:***

While the protection angle method appears to be similar to the historic and simple cone of protection method, the protection angle method is actually a derivative of the rolling sphere method. The angles for the protection angle method are obtained

from a rolling sphere analysis as shown in Figure 16. This is why the protection angle method is limited to the maximum height of the equivalent rolling sphere.

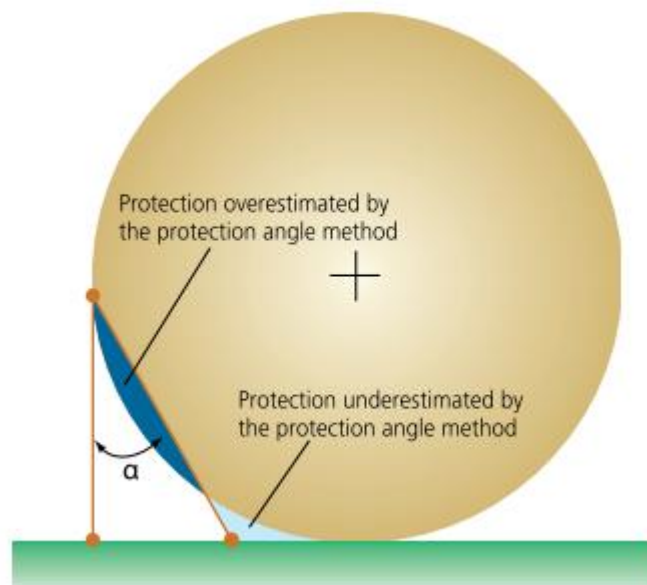


Figure 16. Origin of protection angle.

LPL	h(m) R (m)	20	30	45	60
		$\alpha$	$\alpha$	$\alpha$	$\alpha$
I	20	25	-	-	-
II	30	35	25	-	-
III	45	45	35	25	-
IV	60	55	45	35	25

This method should be used when the height (h) of the rod to the reference plane is greater than the notional sphere radius (R).

Consider a 50 m structure with rod air-termination. As a 45 m rolling sphere (LPL III) would touch the side of the structure, protection to objects at the ground level can not be protected using protection angle with LPL III. Considering LPL IV, a 60 m rolling sphere would not touch the side of the structure, thus protection angle LPL IV

can be used with the rod air-termination to determine what objects at the ground level would be protected.

The virtue of the protection angle method is its simplicity in application, but its drawback is that it is a further simplification of the rolling sphere method, hence may not be as reliable or efficient.

The knowledge that the protection angle method is derived from the rolling sphere method helps to understand a common question about its implementation. With reference to Figure 11, it may not be apparent why a  $\alpha_2$  is less than a  $\alpha_1$ . If a second air-terminal is installed to the left of the existing air-terminal, then a  $\alpha_1$  and a  $\alpha_2$  for the second terminal would be equal. The reason that  $h_2$  is used for a  $\alpha_2$  is an attempt to duplicate the protection indicated by the rolling sphere method.

### ***1.5.3 The rolling sphere method – “geometric-electrical model”***

For lightning flashes to earth, a downward leader grows step-by-step in a series of jerks from the cloud towards the earth. When the leader has got close to the earth within a few tens, to a few hundreds of metres, the electrical insulating strength of the air near the ground is exceeded. A further “leader” discharge similar to the downward leader begins to grow towards the head of the downward leader: the upward leader. This defines the point of strike of the lightning strike.

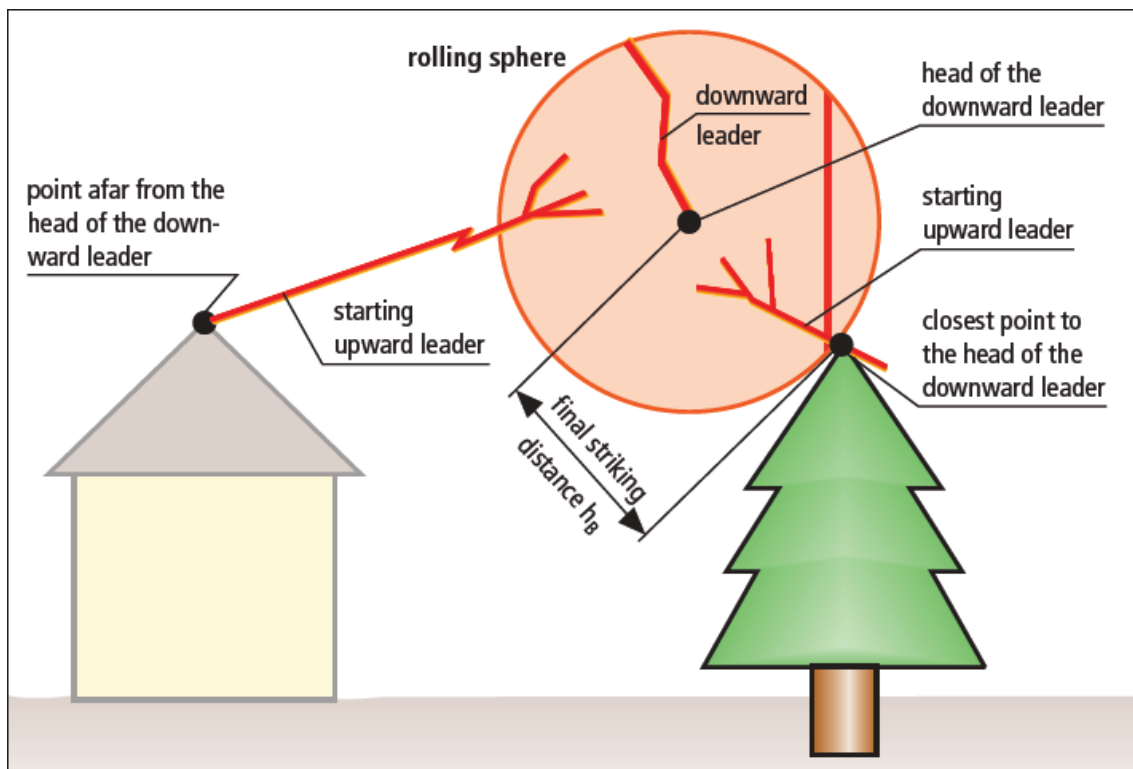


Figure 17. Starting upward leader defining the point of strike

The starting point of the upward leader and hence the subsequent point of strike is determined mainly by the head of the downward leader. The head of the downward leader can only approach the earth within a certain distance. This distance is defined by the continuously increasing electrical field strength of the ground as the head of the downward leader approaches. The smallest distance between the head of the downward leader and the starting point of the upward leader is called the final striking distance  $hB$  (corresponds to the radius of the rolling sphere).

Immediately after the electrical insulating strength is exceeded at one point, the upward leader which leads to the final strike and manages to cross the final striking distance, is formed. Observations of the protective effect of guard wires and pylons were used as the basis for the so-called **“geometric-electrical model”**.

This is based on the hypothesis that the head of the downward leader approaches the objects on the ground, unaffected by anything, until it reaches the final striking distance.

The point of strike is then determined by the object closest to the head of the downward leader. The upward leader starting from this point “forces its way through”.

### ***Classification of the lightning protection system and radius of the rolling sphere***

As a first approximation, a proportionality exists between the peak value of the lightning current and the electrical charge stored in the downward leader. Furthermore, the electrical field strength of the ground as the downward leader approaches is also linearly dependent on the charge stored in the downward leader, to a first approximation. Thus there is a proportionality between the peak value  $I$  of the lightning current and the final striking distance  $hB$  (= radius of the rolling sphere):

$$r = 10 \cdot I^{0.65}$$

“ $r$ ” in m.

“ $I$ ” in kA.

The protection of structures against lightning is described in IEC 62305-1 (EN 62305-1). Among other things, this standard defines the classification of the individual lightning protection system and stipulates the resulting lightning protection measures. It differentiates between four classes of lightning protection system. A Class I lightning protection system provides the most protection and a Class IV, by comparison, the



least. The interception effectiveness  $E_i$  of the air-termination systems is concomitant with the class of lightning protection system, i.e. which percentage of the prospective lightning strikes is safely controlled by the air-termination systems. From this results the final striking distance and hence the radius of the “rolling sphere”. The correlations between class of lightning protection system, interception effectiveness  $E_i$  of the air-termination systems, final striking distance / radius of the “rolling sphere” and current peak value are shown in the next table.

Lightning protection level LPL	Probabilities for the limit values of the lightning current parameters		Radius of the rolling sphere (final striking distance $h_B$ ) $r$ in m	Min. peak value of current $I$ in kA
	< Max. values acc. to Table 5 IEC 62305-1 (EN 62305-1)	> Min. values acc. to Table 6 IEC 62305-1 (EN 62305-1)		
IV	0.84	0.97	60	16
III	0.91	0.97	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

Table 7. Relations between lightning protection level, interception criterion  $E_i$ , final striking distance  $h_B$  and min. peak value of current  $I$

Taking as a basis the hypothesis of the “geometric-electrical model” that the head of the downward leader approaches the objects on the earth in an arbitrary way, unaffected by anything, until it reaches the final striking distance, a general method can be derived which allows the volume to be protected of any arrangement to be inspected. Carrying out the rolling sphere method requires a scale model (e.g. on a scale of 1:100) of the building / structure to be protected, which includes the external contours and, where applicable, the air-termination systems. Depending on the location of the object under investigation, it is also necessary to include the surrounding structures and objects, since these could act as “natural protective measures” for the object under examination.

Furthermore, a true-to-scale sphere is required according to the class of lightning protection system with a radius corresponding to the final striking distance (depending on the class of lightning protection system, the radius  $r$  of the “rolling sphere” must correspond true-to-scale to the radii 20, 30, 45 or 60 m). The centre of the “rolling sphere” used corresponds to the head of the downward leader towards which the respective upward leaders will approach.

The “rolling sphere” is now rolled around the object under examination and the contact points representing potential points of strike are marked in each case. The “rolling sphere” is then rolled over the object in all directions. All contact points are marked again. All potential points of strike are thus shown on the model; it is also

possible to determine the areas which can be hit by lateral strikes. The naturally protected zones resulting from the geometry of the object to be protected and its surroundings can also be clearly seen. Air-termination conductors are not required at these points as we can see in the next picture.

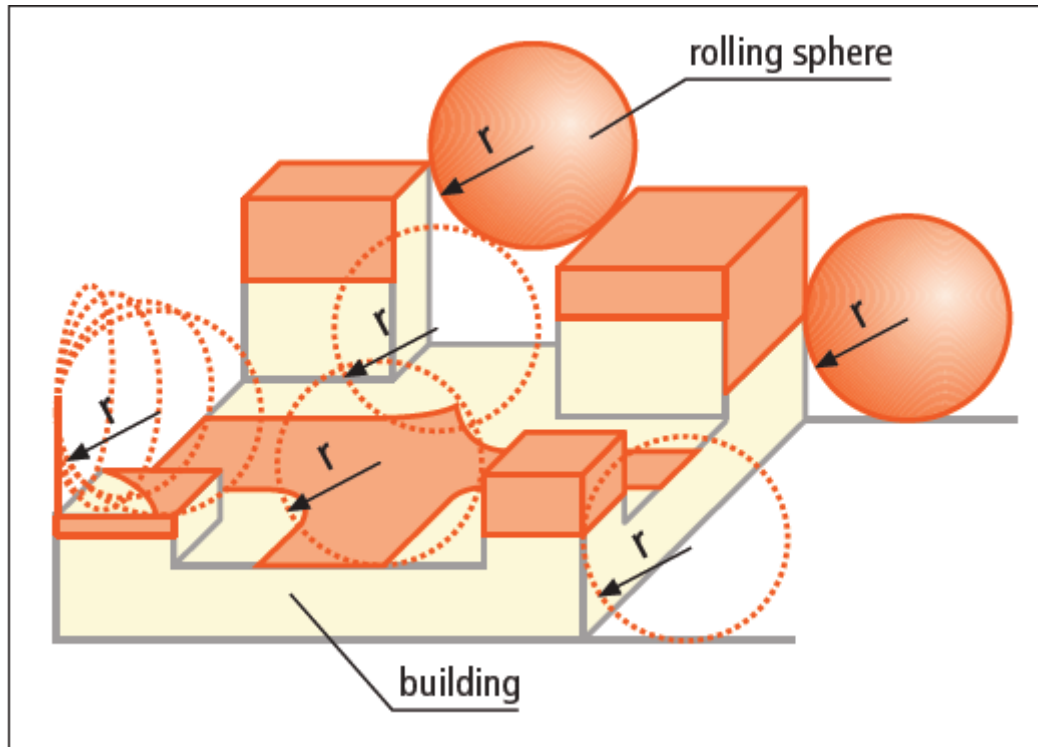


Figure 18. Schematic application of the “rolling sphere” method at a building with considerably structured surface

It must be borne in mind, however, that lightning footprints have also been found on steeples in places not directly touched as the “rolling sphere” rolled over. This is traced to the fact that, among other things, in the event of multiple lightning flashes, the base of the lightning flash moves because of the wind conditions. Consequently, an area of approx. one metre can come up around the point of strike determined where lightning strikes can also occur.

In other hand, the “rolling sphere” with the smaller radius (according to a class of lightning protection system with a higher lightning protection level) naturally touches also the model at all points already touched by the “rolling sphere” with the larger radius. Thus, it is only necessary to determine the additional contact points.

As demonstrated, when dimensioning the air-termination system for a structure, or a structure mounted on the roof, the sag of the rolling sphere is decisive.

The following formula can be used to calculate the penetration depth  $p$  of the rolling sphere when the rolling sphere rolls “on rails”, for example. This can be achieved by using two spanned wires, for example.

$$p = r - [r^2 - (d/2)^2]^{1/2}$$

“ $r$ ” Radius of the rolling sphere.

“ $d$ ” Distance between two air-termination rods or two parallel air-termination conductors.

The next picture illustrates this consideration.

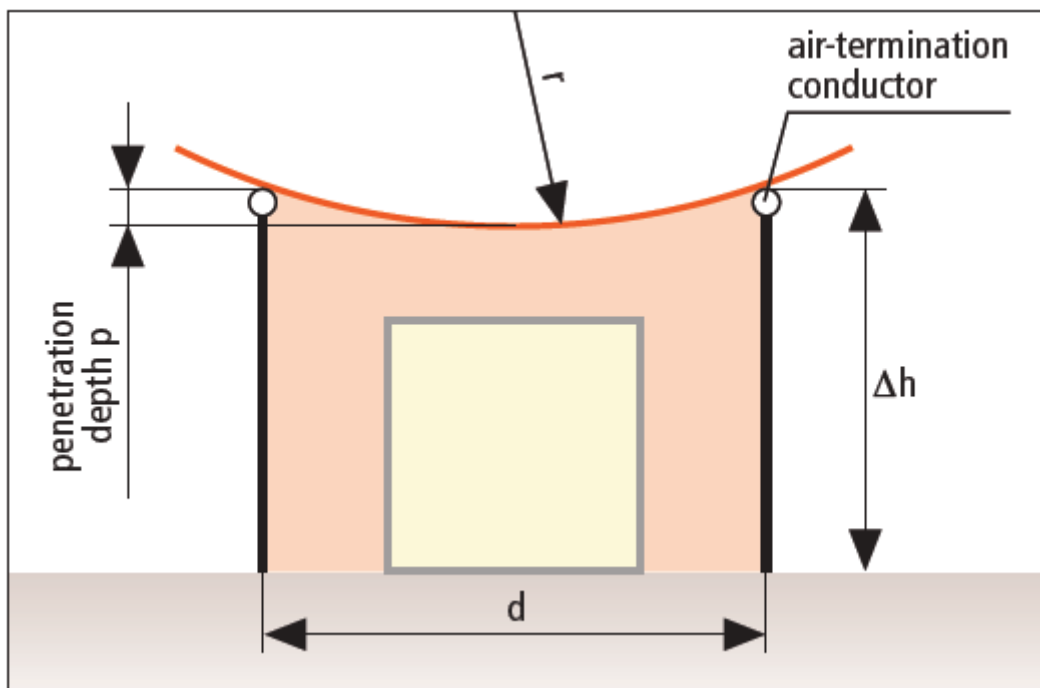


Figure 19. Penetration depth  $p$  of the rolling sphere

Air-termination rods are frequently used to protect the surface of a roof, or installations mounted on the roof, against a direct lightning strike. The square arrangement of the air-termination rods, over which no cable is normally spanned, means that the sphere does not “roll on rails” but “sits deeper” instead, thus increasing the penetration depth of the sphere, we can see this in the next figure.

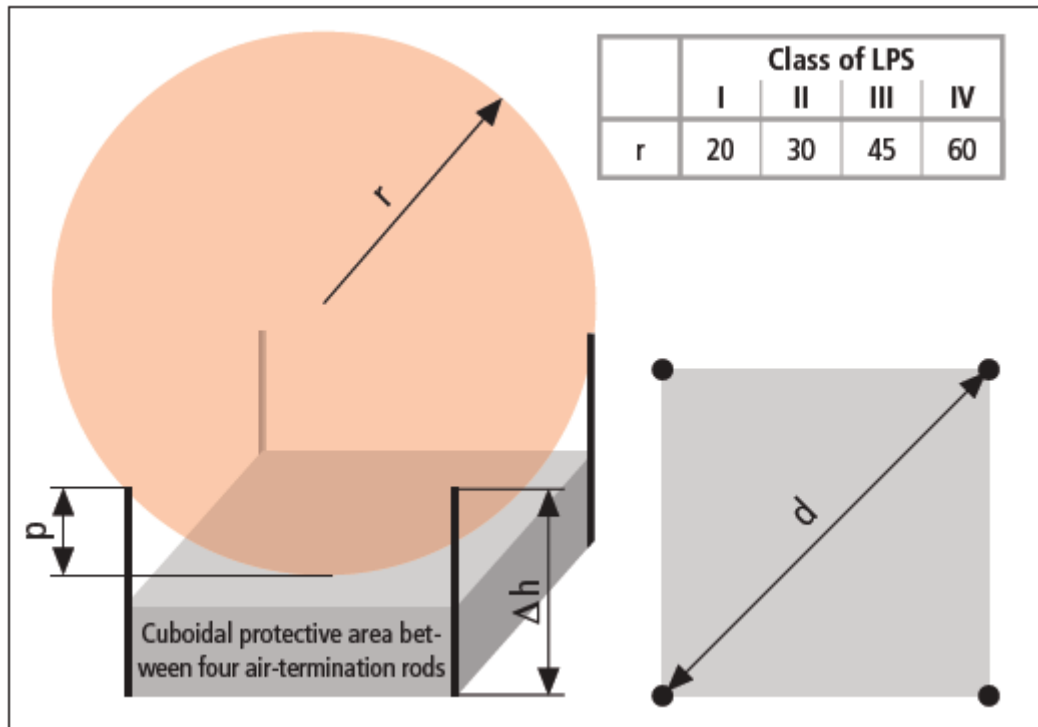


Figure 20. Air-termination system for installations mounted on the roof with their protective area

The height of the air-termination rods  $\Delta h$  should always be greater than the value of the penetration depth  $p$  determined, and hence greater than the sag of the rolling sphere. This additional height of the air-termination rod ensures that the rolling sphere does not touch the structure to be protected.

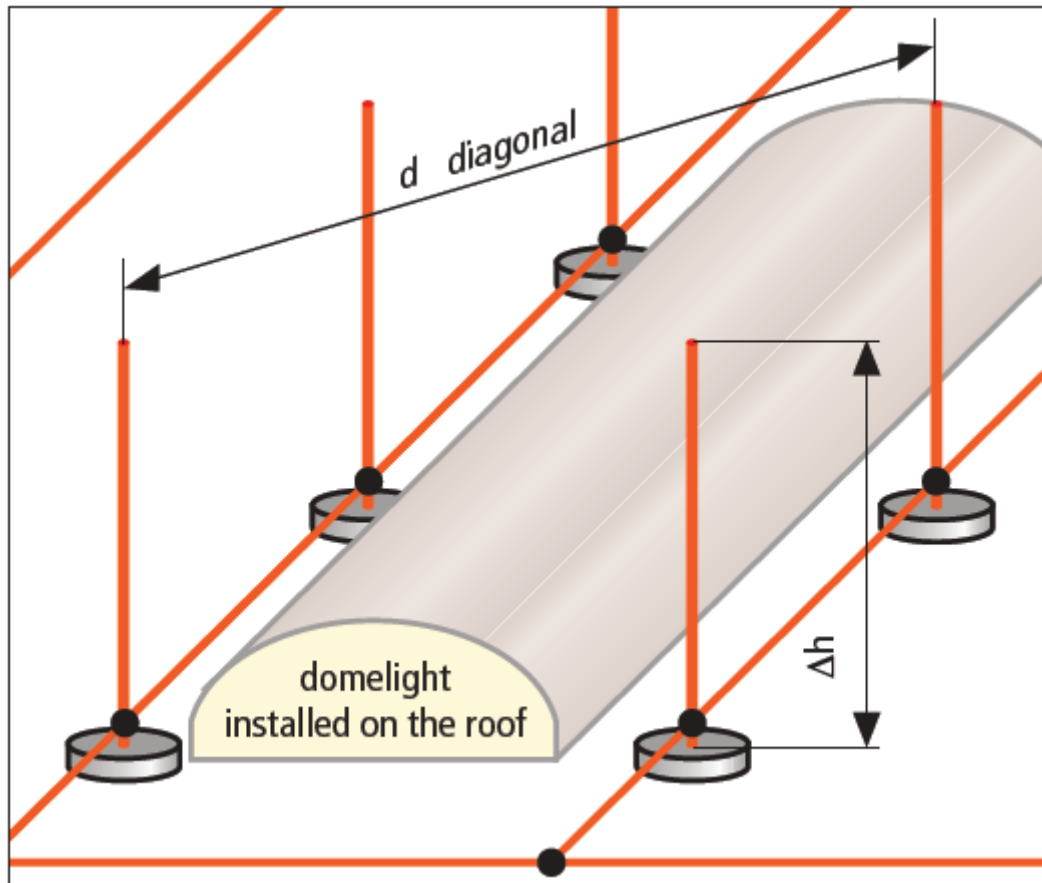


Figure 21. Calculation  $\Delta h$  for several air-termination rods according to rolling sphere method

Another way of determining the height of the air-termination rods is using the following table. The penetration depth of the rolling sphere is governed by the largest distance of the air-termination rods from each other. Using the greatest distance, the penetration depth  $p$  (sag) can be taken from the table. The air-termination rods must be dimensioned according to the height of the structures mounted on the roof (in relation to the location of the air-termination rod) and also the penetration depth what is shown in the previous figure.

<b>d</b>	<b>Sag of the rolling sphere [m] (rounded up)</b>			
<b>Distance between air- termniation rods [m]</b>	<b>Class of LPS with rolling sphere radius in meters</b>			
	<b>I (20 m)</b>	<b>II (30 m)</b>	<b>III (45 m)</b>	<b>IV (60 m)</b>
2	0.03	0.02	0.01	0.01
4	0.10	0.07	0.04	0.03
6	0.23	0.15	0.10	0.08
8	0.40	0.27	0.18	0.13
10	0.64	0.42	0.28	0.21
12	0.92	0.61	0.40	0.30
14	1.27	0.83	0.55	0.41
16	1.67	1.09	0.72	0.54
18	2.14	1.38	0.91	0.68
20	2.68	1.72	1.13	0.84
23	3.64	2.29	1.49	1.11
26	4.80	2.96	1.92	1.43
29	6.23	3.74	2.40	1.78
32	8.00	4.62	2.94	2.17
35	10.32	5.63	3.54	2.61

Table 8. Sag of the rolling sphere over two air-termination rods or two parallel air-termination conductors

## ***1.6 Lightning damage***

### ***1.6.1 What does lightning do to people?***

Cloud-to-ground lightning can kill and injure people by direct or indirect means. It is not known if all people are killed who are directly struck by the flash itself. The lightning current can branch off to a person from a tree, fence, pole, or other tall object. In addition, flashes may conduct their current through the ground to a person after the flash strikes a nearby tree, antenna, or other tall object. The current also may travel through power or telephone lines to a person who is in contact with electric appliances, tools, electronics, or a corded telephone. Lightning can also travel through plumbing pipes and water to a person in contact either with a plumbing fixture or a person in water, including bathtubs, pools, and the running water of a shower.

### ***1.6.2 Damage to the human body***

Lightning affects the many electrochemical systems in the body. People struck by lightning can suffer from nerve damage, memory loss, personality change, and emotional problems. There is a national support group for lightning and electric shock survivors.

An example is some single nerve cells, such as those extending from the brain to the foot, can be as long as 6 feet or more. These types of cells are most prone to lightning damage due to the instantaneous potential difference across the length of the cell as lightning begins to enter the body.

The intense heat of the lightning stroke can turn sweat instantly to steam and the tremendous pressure of the steam has been known to blow people's boots, shoes, and clothing off them. In places where metal is in contact with or close proximity to the body, such as jewelry or belt buckles, burn marks are found. Likewise, burn marks are found in places where the body had been sweaty, such as the feet, underarms, and chest.

According to a study of Ronald L. Holle and Raúl E. López, males account for 84% of lightning fatalities and 82% of injuries.

Men can take comfort in the fact that the actual number of deaths and injuries from lightning strikes has decreased in the past 35 years. Holle's team attributes 30 percent of the decrease in lightning deaths to improved forecasts and warnings, better lightning awareness, more substantial buildings, and socioeconomic changes. They attribute an additional 40 percent to improved medical care and communications.

The National Weather Service publication *Storm Data* recorded 3,239 deaths and 9,818 injuries from lightning strikes between 1959 and 1994. Only flash floods and river floods cause more weather-related deaths. But according to Dr. Elisabeth Gourbière of the Electricité de France, Service des Etudes Médicales, only 20 percent of lightning victims are immediately struck dead. Still, many doctors do not fully understand how to treat the injuries of the other 80 percent of lightning victims who survive a strike.

Says Gourbière, "The pathology of lightning, or keraunopathy, is known only to a few specialists."

Most doctors are more familiar with electrical shocks, such as those received by industrial workers when they have an accidental run-in with high-voltage equipment. But lightning injuries are not the same as electrical shocks. For one thing, the contact voltage of a typical industrial electrical shock is 20 to 63 kilovolts, while a lightning strike delivers about 300 kilovolts.

Industrial shocks rarely last longer than half a second (500 milliseconds) because a circuit breaker opens or the person is thrown far from the live conductor. Lightning strikes have an even shorter duration, only lasting up to a few milliseconds. Most of the current from a lightning strike passes over the surface of the body in a process called "external flashover."

Both industrial shocks and lightning strikes result in deep burns at point of contact - for industry the points of contact are usually on the upper limbs, hands and wrists, while for lightning they are mostly on the head, neck and shoulders. Industrial shock victims sometimes exhibit deep tissue destruction along the entire current path, while lightning victims' burns seem to center at the entry and exit points. Both industrial shock and lightning victims may be injured from falling down or being thrown, and the leading cause of immediate death for both is cardiac or cardiopulmonary arrest.

If you survive a shock, you still have to deal with the consequences of the electrical burns. Industrial shock burns can lead to kidney failure, infection, muscle and tissue damage, or amputation. Lightning burns are exceptionally life threatening.

Gourbière says that 70 percent of lightning survivors experience residual effects, most commonly affecting the brain (neuropsychiatric, vision and hearing). These effects can develop slowly, only becoming apparent much later.



## ***1.6.2 Most typical disorders associated with lightning strikes***

### Lightning deaths (~20%)

- Asystole/Ventricular fibrillation
- Inhibition of brainstem respiratory centers
- Multi-system failure (delayed death)

### Cardio-pulmonary injuries

- Arrhythmias - Arterial pressure changes
- Electrocardiographic changes
- Myocardial damages (infarction)
- Cardiac dysfunction
- Pulmonary edema - Respiratory distress syndrome

### Neurologic/psychiatric injuries

- Loss of consciousness/coma
- Amnesia/Anxiety/Confusion/Aphasia/Seizures
- Electroencephalographic abnormalities
- Brain/Cerebellum damages
- Numbness/Weakness in limbs/Partial or complete (but temporary) paralysis
- Neuropathy/Pain syndromes
- Spinal cord injury/Parkinsonism
- Sleep and memory disorders/Concentration disturbances/Irritability/Depression/Various other disturbances such as headaches, tiring easily, lightning storm phobia, etc.
- Post traumatic Stress Disorder

### Burns and Cutaneous marking

- Small, deep entry/exit points (typical)
- Contact, metal chain heating (typical)
- Superficial linear
- Flash
- Lichtenberg figures (arborescent, fern-like markings):pathognomonic(on trunk, arms, shoulders)

### Clothing, shoes

- Exploded off, torn off, shredded, singed...

### Blunt traumas (explosion)

- Contusion, internal hemorrhage (brain, lungs, liver, intestine...)
- (rarely) Fractures (skull, cervical spinal column, extremities...)

### Auditory and ocular injuries

- Tympanic membrane ruptured (typical)
- Deafness/Tinnitus/Vertigo
- Transient blindness/Photophobia-Conjunctivitis - Corneal damage
- Retinal abnormalities (macular hole) - optic neuritis
- Cataract

Lightning injuries are varied and take many different forms. The most dangerous (and possibly fatal) immediate complications are cardiovascular and neurologic. It must be kept in mind that only immediate and effective cardiorespiratory resuscitation (started by rescuers), followed as soon as possible by emergency medical treatment, can save victims who are in cardiopulmonary arrest, or avert the serious consequences of cerebral hypoxia. Some victims remain in a coma despite intensive resuscitation and die of secondary causes including hemorrhages and multiple lesions (encephalic, cardiac, pulmonary, intra-abdominal).

## **1.6.4 Lightning disasters**

### ***Jun 26, 1807. Lightning strikes in Luxembourg***

On this day in 1807, lightning hits a gunpowder factory in the small European country of Luxembourg, killing more than 300 people. Lightning kills approximately 73 people every year in the United States alone, but victims are almost always killed one at a time. The Luxembourg disaster may have been the most deadly lightning strike in history.

The earth experiences 8 to 9 million lightning strikes every single day. In a typical year, the United States will see about 70,000 thunderstorms somewhere in its territory. This produces approximately 20 million lightning strikes annually. A bolt of lightning can reach 50,000 degrees Fahrenheit in instant heat. There are 100 million volts in an average lightning bolt, which can be as much as five miles long.

In 1807, Luxembourg was occupied by Napoleon's army. The French dictator used the country to stockpile weapons and ammunition. Many underground bunkers were built for this purpose. In the southern Luxembourg city of Kirchberg, a fortress built in 1732 was used as an armory.

When lightning struck the fortress on June 26, the ammunition housed within ignited on contact, causing a massive explosion. Two entire blocks were completely

razed by the blast, which caused several other fires to rage nearby. The *London Times* later reported, this city has been plunged into the greatest consternation and distress.

#### ***Jul 1, 2011. School in Uganda***

Eighteen children and a teacher have been killed after lightning struck a school in the Masindi area of Uganda. It is the second time the Runyanya Primary School has been hit.

Across Uganda, another 12 people have been killed by lightning during that last week. Meteorologists say the reason for the strikes is a surge of moist air coming through the Congo Basin, but the government has also admitted that many buildings are not fitted with lightning conductors.

#### ***Aug, 1769. Brescia lightning***

In August of 1769, lightning struck the tower of the Church of the Nazaire in Brescia, Italy. The current passed through the vaults where 207,000 pounds of gunpowder had been stored for safekeeping. You can tell where this is going. The aftermath destroyed a sixth of the city and killed 3,000 residents. The British parliament responded by passing two acts establishing standards for the manufacture and storage of gunpowder in private hands, eventually leading to an argument over how to best protect arsenal from lightning strikes.

#### ***Dec 8, 1963. Pan American Flight 214***

The worst lightning strike death toll occurred when lightning hit a Pan American Boeing 707 en route from Puerto Rico to Philadelphia, killing all 81 on board. It's the only US airliner lost to lightning. Lightning struck the left wing of the 707 and hit the fuel vapor mixture stored in a reserve fuel tank, igniting it. The airplane exploded midair and crashed near Elkton, Maryland.

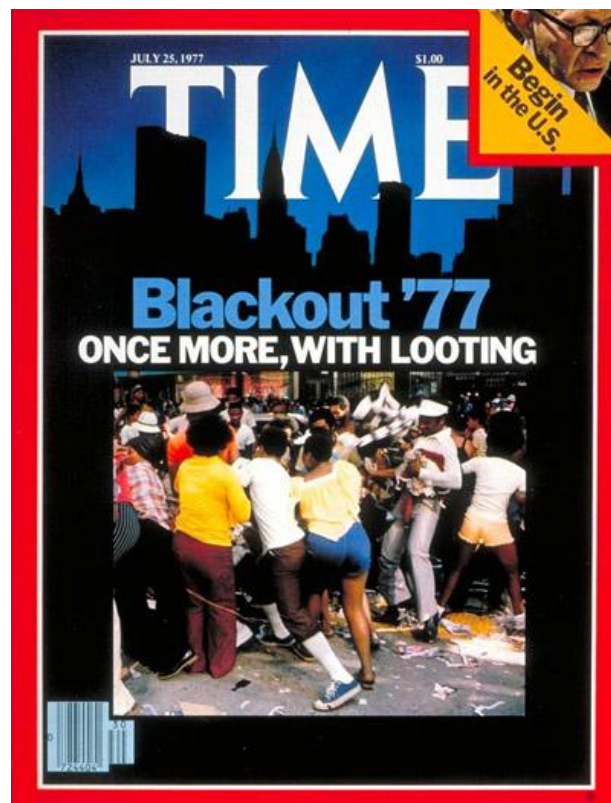
Flight 214 was in a holding pattern, awaiting approval to land at Philadelphia International Airport when it was struck. On fire, a large portion of the left wing separated in flight. The pilot managed to maintain control for a few seconds before the plane crashed. While examining the wreckage, officials noticed numerous spots where the metal surface and rivet heads appeared melted. Also, an irregular-shaped hole surrounded by fused metal indicated the presence of high heat.

Lightning charges can be hazardous to airplane fuel systems because lightning is able to ignite the fuel vapor in the tanks. As a result of this tragedy, the FAA insisted that all commercial jet liners be fitted with lightning discharge wicks. Still, on average, every commercial airliner is struck in flight at least once per year.



***Jul 13, 1977. New York City Blackout***

Chaos hit New York City in the summer of 1977 when lightning struck the Consolidated Edison electrical transmission line in northern Westchester County. The strike occurred near the ConEd power plant and as a result, major transmission lines were short-circuited. After an investigation, officials determined that several “massive lightning bolts” had struck the 345,000-volt power lines numerous times. The power was out for 25 hours, trapping people in subways and elevators, with violent looting, rioting and arson peppering the city.



### ***Mar 26, 1987. Lightning in Space***

The Atlas-Centaur 67 was a 137-foot, \$78 million rocket carrying \$83 million of military communication equipment. Spinning out of control 51 seconds after liftoff, the rocket had to be destroyed immediately to prevent any off-course veering that might have endangered populated areas along the Florida coast. The flaming wreckage fell into the Atlantic Ocean three miles from Cape Canaveral.

Afterwards, videotape released by NASA showed a lightning bolt clearly flashing out of the rain clouds into which the Atlas-Centaur had vanished. Safety officials determined that at 14,250 feet the rocket disappeared into the clouds, losing control and disrupting all communications. Lightning experts said that a rocket penetrating a storm cloud could attract electrical charges much like a tree or a tall building, such as the Empire State Building. NASA officials blamed the Air Force for shoddy weather reports, and defended their decision to launch a rocket into cloudy skies.

This was not the first time lightning and NASA butted heads. On November 14, 1969, the Apollo 12 was struck thirty seconds into liftoff. Systems failed temporarily, but the astronauts managed to regain control.

### ***Sep 8, 1988. The Yellowstone Fires***

A combination of drought, high winds, and multiple lightning strikes caused one of the largest fire seasons in Yellowstone history. Fires affected 36% of the park (approx. 793,800 acres)—nine fires because of human error, 42 by lightning. 300 mammals perished (mostly elk). Yellowstone residents, firefighters, and tourists remember the harrowing months of flames licking above the treetops, evacuations, closed roads, and hillsides glowing with embers. Dubbed “Black Saturday,” August 20 marked the single most active fire day of the 1988 season. Several Rangers and visitors found themselves stranded at the visitor center, the exit paths blocked by downed trees and 100 foot tall windblown flames.

Even ten years later, hikers still had to take caution, especially on windy days, for falling dead trees burned in the 1988 fires. As of 2008, new trees are growing in thick and tall, covering the views opened up by the fires.



### ***Jul 23, 2011. Wenzhou train collision***

On 23 July, at roughly 20:00 CST, CRH train D3115 (CRH1-046B), carrying 1,072 people and travelling from Hangzhou to Fuzhou South came to a halt over a viaduct near the Ou River. Shortly after, CRH train D301 (CRH2-139E), carrying 558 people and running from Beijing South to Fuzhou, crashed into the rear-end of the stationary D3115.

The cause of the crash was initially said to be a lightning storm occurring 20 miles (32 km) south and 60 miles (97 km) west of the viaduct. Lightning reportedly struck the first train, which caused it to stop on the tracks. However, five days after the incident, the Beijing National Railway Research & Design Institute of Signals and Communications Co. Ltd., a railway research institute, claimed responsibility, stating in a report that a signal on the track failed to turn red, and staff failed to notice the error.

A much more detailed description of what happened in the accident, correcting earlier accounts, was published in the December 2011 report of the official investigation. The first train D3115 was stopped not by losing power as a result of the lightning strike, but was stopped by the signal system, the Automatic Train Protection (ATP). The lightning had struck a trackside LKD2-T1 signal assembly, burning out its fuses, and violating the rule that it should be 'fail-safe' this had caused an incorrect indication in the control center that the track section containing train D3115 was unoccupied (the so-called 'green signal'). The driver He Li of train D3115 worked to override the ATP, and after more than seven minutes of waiting, at 8.29 p.m. he got the train moving again, overriding the ATP. As train D3115 entered the next section of track, where the track circuits which indicate the presence of the train were working correctly, the control center now saw that the track section was occupied. But driver Pan Yiheng of the following train D301 had already been given instructions to proceed onto the section of track where D3115 had been stopped, when the control center had a false indication that the track was unoccupied. Despite a message from the control center that D301 should proceed with caution, less than half a minute later train D301 running at 99 km/h (62 mph) collided with train D3115.

The fifteenth and sixteenth coaches at the rear of D3115 and the front four coaches of D301 were derailed — four coaches fell off the viaduct. Three carriages came to rest horizontally on the ground below while the fourth came to rest vertically, one end on the ground and one end leaning against the viaduct.

The various medical teams responding to the accident consisted of staff from Zhejiang No. 1 Hospital, Zhejiang No. 2 Hospital, Zhejiang Provincial People's Hospital and Taizhou Hospital. The evening of the event, 500 Wenzhou residents gave blood in response to early radio appeals by the local blood bank.

A survivor, Liu Hongtaohe, recalled that "the train suddenly shook violently, casting luggage all around. Passengers cried for help but no crew responded" in an interview with China Central Television. CCTV reported on 25 July that the Railways Ministry had declared that 39 people were killed and 192 injured. Two-year-old Xiang Weiyi was the last person rescued, 21 hours after the train crash. Her parents had been killed in the crash.



***May 15, 2012. French Hollande changes plane after lightning strike***

A presidential jet carrying newly inaugurated French President Francois Hollande was hit by lightning en route to Berlin and forced to turn back to Paris, but the Socialist was unharmed and took off again in another plane, a presidential source said.

Hollande, who was sworn in as president on Tuesday morning, was expected to arrive with a delay of one and a half hours for his first meeting with German Chancellor Angela Merkel after he set off in the second aircraft.







## **2. SPECIFICATION**

### **2.1 Weather**

The building we are considering is located in Santander, a city on the seashore. Santander is the capital of Cantabria, in northern of Spain.

In first place we are going to focus on Spain climate.

The climate varies tremendously in Spain, due to its large size.

The vast central plateau, or Meseta, has a continental climate with hot, dry summers and cold winters. Rain generally falls in spring and autumn. The mountains surrounding the plateau have a higher rainfall and often they experience heavy snowfalls in winter.

On the Mediterranean coast, the climate is moderate with rain in spring and autumn. Murcia has an almost African climate and is characterized by numerous palm trees. Rainfall is low and the calina, or heat haze, is common during summer.

On the Atlantic coast, the summers are cooler and fairly heavy rainfall occurs during winter.

North of the Cantabrian Mountains, the Basque Country, Cantabria, Asturias and Galicia have a maritime climate, with cool summers and mild winters. The weather is often cloudy with frequent rainfall.

We can observe the [figure 1](#), where the average annual thunderstorms in Spain appear. In Cantabria, on the north as we see in the [figure](#), there is a high average storm, of 15 to 20 days in a year.

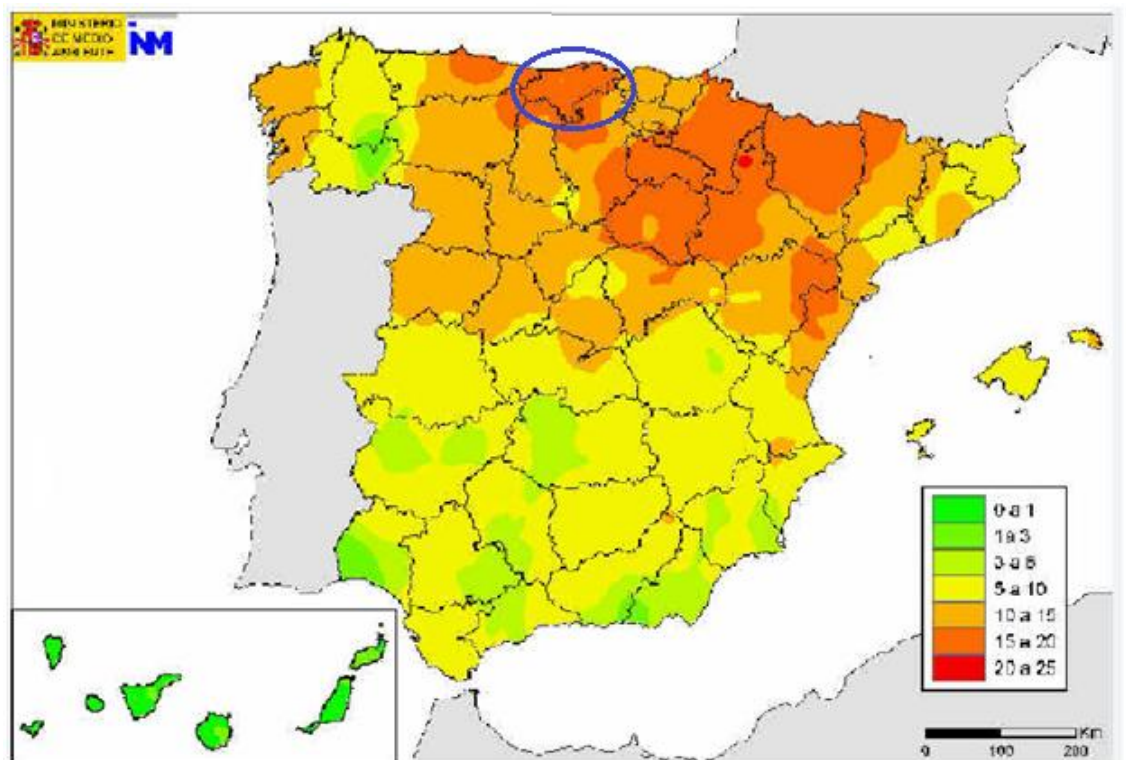


Figure 1. Average annual days with thunderstorm

In the table below we can see data on the storms in different parts of the region, paying special attention to Santander.

LOCALIDAD	DTORM	TORMF	RAY/A	HMAX	HMIN	MAX	min	COORDENADAS	ALTITUD
SAN VICENTE BARQUERA	20.3	0.4	129	15Z	10Z	JUL	díc	43.395 4.391	39m
COMILLAS.....	20.0	0.3	141	16Z	7Z	JUL	díc	43.385 4.299	24m
LA HERMIDA.....	20.7	0.9	182	15Z	7Z	MAY	oct	43.256 4.405	200m
ESPINAMA.....	21.6	1.2	245	16Z	6Z	JUN	feb	43.133 4.774	877m
TAMA.....	22.1	0.8	211	16Z	7Z	AGO	feb	43.180 4.594	270m
UZNAYO.....	21.4	1.0	233	16Z	7Z	JUL	feb	43.088 4.405	905m
REINOSA.....	18.2	1.4	245	18Z	8Z	JUN	feb	43.001 4.138	855m
Embalse del Ebro....	18.4	1.6	252	18Z	8Z	SEP	feb	42.968 4.058	845m
POLIENTES.....	16.7	1.0	225	18Z	1Z	SEP	nov	42.807 3.941	716m
CORRALES DE BUELNA..	19.0	0.6	190	17Z	8Z	SEP	mar	43.259 4.063	100m
MOLLEDO.....	19.0	0.9	194	17Z	10Z	SEP	feb	43.145 4.035	242m
CABEZON DE LA SAL...	20.6	0.3	164	17Z	7Z	JUN	díc	43.300 4.238	128m
TORRELAVEGA.....	19.9	0.4	155	17Z	8Z	SEP	abr	43.364 4.035	70m
SANTANDER.....	18.2	0.6	136	17Z	8Z	SEP	díc	43.465 3.820	65m
SANTANDER-PARAYAS...	17.8	0.7	142	17Z	8Z	SEP	díc	43.428 3.820	1m
VILLACARRIEDO.....	19.4	1.0	182	16Z	10Z	SEP	ene	43.230 3.805	212m
S.MARIA DE CAYON....	19.0	0.6	148	17Z	4Z	SEP	ene	43.309 3.858	100m
ARREDONDO.....	22.1	0.8	207	18Z	2Z	JUL	mar	43.272 3.602	160m
VEGA DE PAS.....	19.4	1.1	204	18Z	0Z	SEP	ene	43.159 3.782	380m
RAMALES VICTORIA....	21.0	0.8	215	18Z	3Z	JUL	mar	43.253 3.466	84m
HOZ DE ANERO.....	19.3	0.3	125	16Z	10Z	SEP	díc	43.405 3.669	40m
SANTOÑA.....	19.8	0.4	178	18Z	3Z	SEP	ene	43.442 3.461	7m
CASTRO-URDIALES....	20.0	0.3	166	15Z	11Z	JUL	díc	43.386 3.216	16m
MAR 43,5 4,5.....	19.0	0.2	102	16Z	6Z	JUL	díc	43.500 4.500	0m
MAR 44,0 4,5.....	13.3	0.2	79	19Z	10Z	JUL	mar	44.000 4.500	0m
MAR 43,5 4,0.....	18.2	0.4	151	18Z	8Z	SEP	díc	43.500 4.000	0m
MAR 44,0 4,0.....	15.4	0.3	97	18Z	12Z	SEP	mar	44.000 4.000	0m
MAR 44,0 3,5.....	13.8	0.2	83	21Z	13Z	SEP	ene	44.000 3.500	0m

- DTORM: Average annual number of thunderstorm days (days with lightning within 10 Km).
- TORMF: Annual days of storms.
- RAY/A: Average annual number of lightning around 10 km.
- HMAX: Maximum activity hour.
- HMIN: Minimum activity hour.
- MAX: The most stormy month.
- Min: The less stormy month.
- Coordenadas: Coordinates
- Altitud: Altitude

Cantabria has a medium-high stormy activity. The stormiest areas are the coast and the westernmost part of the province, but it is striking that there are similar values on the coast and in the mountains. The reason is that the values of coastal storminess strongly influence of the numerous cases of storms formed during the cold and unstable north air advections, where there are small stormy cells that primarily affect the sea and the coast, but that dissipate when they hit the mountain. Significantly lower values are observed at sea.

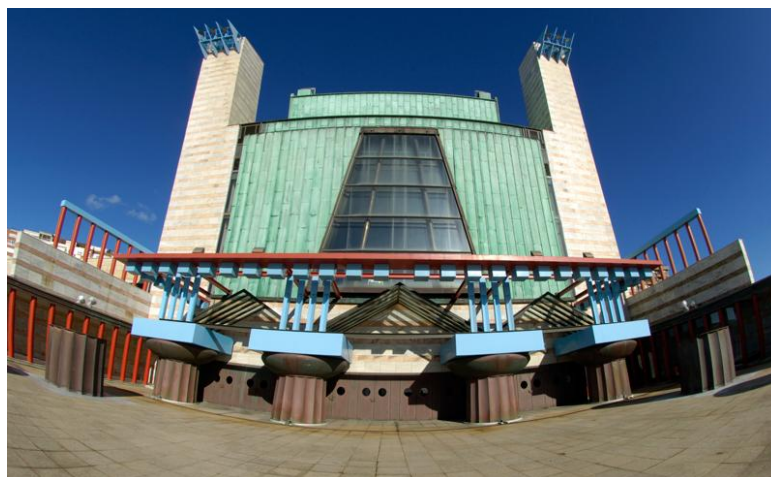
The busiest hours are strangely very similar throughout territory, despite their diversity of heights and conditions, being the evening (17-18z), whereas the lowest activity is observed

during the morning. The most stormy month is September and July in many places, including sea. Stand out as months less stormy January and February.

## ***2.2 Palace of Festivals of Cantabria***

“Cantabria Festival Palace” (Palacio de festivales de Cantabria, PFC) is a landmark theater in the city of Santander, in Cantabria (Spain) and facing the Bay of Santander.

“Cantabria Festival Palace” is a suitable place for holding conferences, meetings and conventions of any kind, due to its extensive facilities and technical infrastructure. With a multidisciplinary approach, this cultural center offers an ongoing arts programming throughout the year, attracting personalities from the scene, both nationally and internationally.



On the land occupied by the old shipyard, hanging over the sea of the Bay of Santander, the architect Francisco Javier Sáenz de Oiza built the palace between 1986 and 1990, seat to the major international festival of classical music.

The predominant materials are marble and copper. The cover is full of skylights to illuminate the interior naturally. We can understand its main entrance, inspired by Greek theater of Epidauros, as a clear example of the attempted synthesis between tradition and avant-garde classical.





As Sáenz de Oiza said, "the palace will be a building hanging over the sea" and will be located next to Nautical School of Cantabria University, not far "Puertochico" area.

The palace will house two principal rooms: one large with capacity for 2,000 people (Sala Argenta), and another small, with 600 locations (Sala Pereda), and the stage will measure approximately 21 by 23 meters.



*"Sala Argenta" and "Sala Pereda"*

The palace has other rooms such as the "Sala Griega" and the exhibition areas. The amphitheater-shaped arrangement of the "Sala Griega" makes it an ideal space for conferences, presentations, press conferences, receptions and exhibit.



*"Sala Griega" and exhibition areas.*

One of the most important events held at the Palace of Festivals is the "Festival Internacional de Santander" (FIS). This festival was installed in the city of Santander in 1952, but was in 1990 when the Palace of Festivals became its headquarters.

FIS is, together with that of Granada, the oldest of those held in our country, and also the longest: more than thirty days fast-paced, filled with music, dance, theater, concerts, etc... Member of the European Festivals Association in Geneva, and to which are attached the major festivals worldwide such as Salzburg, Florence and Verona to put several examples, makes his name is respected and followed with interest in cultural environments Europe and America.



For all this, Palace of Festivals of Santander has become a symbol of architectural and cultural Santander century.

### **2.2.1 Risks**

Once having the knowledge about position, weather in its location, main characteristics of the building, principal uses, influx of people, etc. we can analyze the different kind of risks and with all of these, select the protection level in order to design the lightning protection system.

As we have explained in the Risk point, there are four types of risk depending on the four types of losses:

L1- Loss of human life.

L2- Loss of essential service to the public.

L3- Loss of cultural heritage.

L4 – Economic loss (structure and its contents, service and loss of activity)

In the case of the Palace of Festival of Cantabria, there is an important risk of human life losses because, as we have commented previously, this building has a capacity of 3,000 people. Furthermore, it's a place with a limited mobility (a theater), so that in case of damage the evacuation would be complicated.

The Loss of essential service to the public has to be also considered. If the building were damaged and its facilities were closed, it would be a huge cultural and economical loss because of the large influx of people, especially during August when "Festival Internacional de Santander" takes place.

Economic losses are not only a consequence of the lack of activity. A fail in the lightning protection system would induce to a huge damage in the structure of the building and in all of its electricity and electronic systems.

And finally we can point that all of these damages will turn into very important economic losses, and due to the financial crisis we are living in, these losses would result in an unaffordable expense.

Regarding the source of damage, as it's explained previously, there are two of them that are very important and they must be considered.

First, the case of "lightning flash to the structure". Palace of Festival is a High-rise building, especially the towers, surrounded by buildings of lesser height.

On the other hand, "Lightning flash near the structure " is also important since both the building itself as those found around have a great cultural and economic importance (Faculty

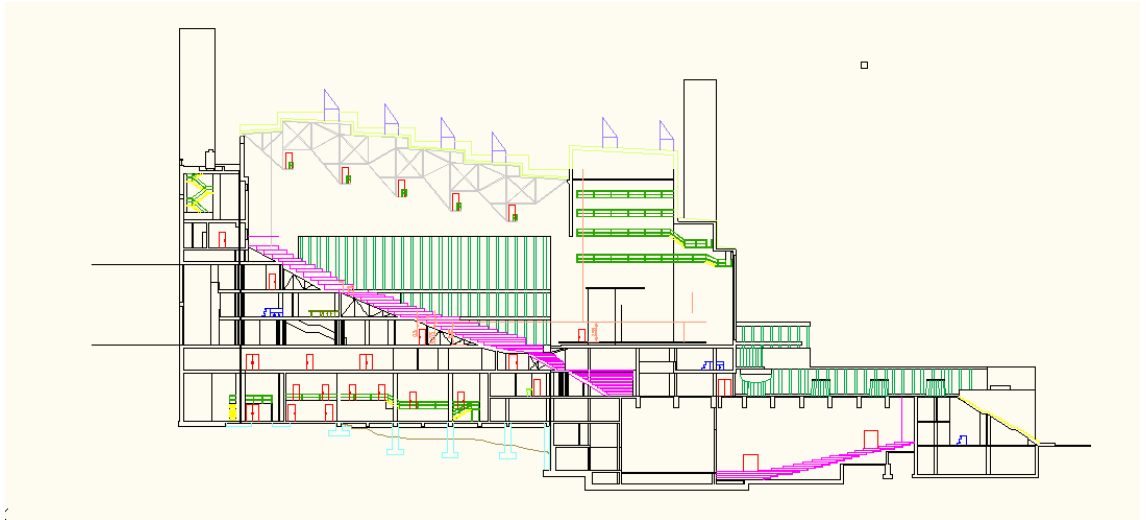
of Nautical, planetarium, Center for High Performance Sailing) and have a huge influx of people every day of the year.

Finally, we have to emphasize the fact that the Palace is located on reclaimed land, which the ground is not rock, is therefore very close to the sea, which is an excellent conductor of electricity (and risks involved).

Taking into account all these aspects, we would consider a lightning protection level (LPL) II.

### **3. MEASUREMENT CONDITIONS**

Once we have considered the risks and the level protection to be applied, we are going to calculate the "protection area", which all of it will be at the same potential.



For calculating of this area, we use the following expressions:

$$A = a \cdot b + 2 \cdot (a + b) \cdot m \cdot h + \pi \cdot m^2 \cdot h^2$$

$$m = 13.4 \cdot h^{-0.5}$$

Being the parameters:

Width → "a"

Length → "b"

High → "h"

Two options are possible to calculate this area:

- Considering all the building as one block.
- Considering the building as the sum of two blocks smaller.



Data are showing in the following table:

	<b>h</b>	<b>m</b>	<b>a</b>	<b>b</b>	<b>A</b>
<b>High block</b>	38	2,17376704	40	70	42408,7089
<b>Lower block</b>	14	3,58130064	40	40	17519,5932
<b>The building</b>	38	2,17376704	40	110	50616,9607

In this case, the best option is when the building is considered as two blocks.

Calculating the approximate area of the building and taking into account there is about 3 strikes per kilometer and year in Santander, we can obtain the probability that one strike falls upon the building along one hundred years:

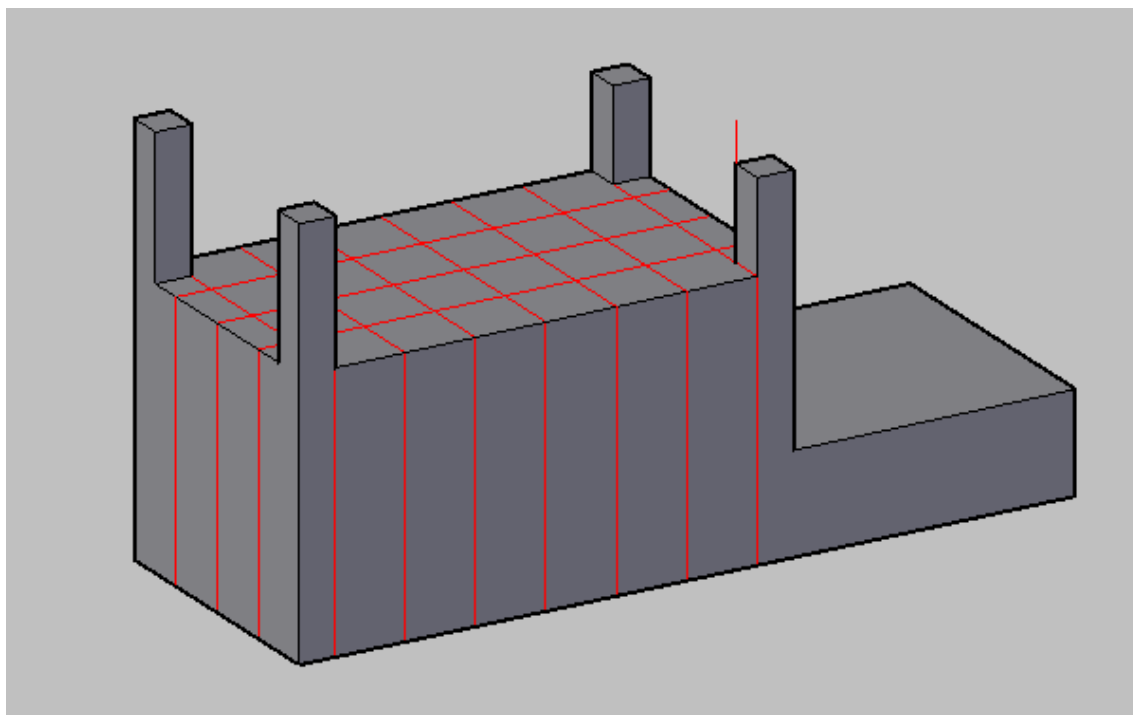
Surface of the building:

$$110\text{m} \times 40\text{m} = 4400\text{m}^2 = 0.0044\text{km}^2$$

Number of strikes during 100 years:

$$3 \times 0.0044 \times 100 = \mathbf{1.32 \text{ strikes in 100 years}}$$

For all of this, the best option for our Lightning Protection System is implant a mesh and a rod. The mesh will be dimensions 10m x 10m. About the rod, one possibility is it will be put on one cross on the mesh:



## **4. ECONOMICAL ASPECTS**

Once we have decided the kind of lightning protection we are going to use in our building, we have to analyze the economical aspects of our design. Depending on the type of level protection assigned to our building, the lightning protection design will be more complex, and in fact, more expensive.

In the case of the Palace of Festivals, the level protection which I assigned was "II". As we can see in the following picture, the lightning protection system consists in one mesh system which forms squares of  $10 \times 10 \text{ m}^2$  and one six meter mast intelligently distributed on the roof.

At first, we have to explain that the mesh cage protection is only established on the higher block, due the fact that the lower block is used as a terrace, as we see in the picture. We have estimated the following cost for the mesh:

**33.000 €** (excluding taxes but including installation)

At second, we are going to explain the cost of the mast. As we said, we are going to install only one, in one of the lower towers. The height of the masts will be six meters. We have estimated the following cost:

**7000 €** (excluding taxes but including installation)

So the final budget will be the sum of both costs. As we see in the next calculation, the result is:

$$33.000 \text{ €} + 7.000 \text{ €} = \mathbf{40.000 \text{ €}}$$

As conclusion we can say that the final budget is quite elevated (although we have to know that the installation is included, which would be an extra cost) but for a building like this is required a high lightning protection level in order to protect the human life and all the expensive equipment (specially light and sound) that serve the artistic community of Santander.

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