3. Designing a lightning protection system

3.1 Necessity of a lightning protection system – legal regulations

The purpose of a lightning protection system is to protect buildings from direct lightning strikes and possible fire, or from the consequences of the load-independent active lightning current (non-igniting flash of lightning).
If national regulations, e.g. building regulations, special regulations or special directives require lightning protection measures, they must be installed.
Unless these regulations contain specifications for lightning protection measures, a lightning protection system (LPS) Class III meeting the requirements of IEC 62305-3 (EN 62305-3) is recommended as minimum.

Otherwise, the need for protection and the choice of appropriate protection measures, should be determined by risk management.
The risk management is described in IEC 62305-2 (EN 62305-2) (see subclause 3.2.1).

Of course other additional corresponding national standards and legal requirements may be applicable and have to be taken into account. In the following some examples of German directives, standards and legal regulations.

In Germany further information on how to determine the type of lightning protection systems for general buildings and structures can be found in the following directive of the VdS:

⇒ VdS-Richtlinie 2010 "Risikoorientierter Blitz- und Überspannungsschutz, Richtlinien zur Schadenverhütung". [engl.: "Risk orientated lightning and surge protection, guideline for prevention of damage"]

For example, the building regulations of the State of Hamburg (HbauO § 17, Abs. 3) require a lightning protection system to be installed if lightning can easily strike a building because of:

⇒ its length,

⇒ its height or

⇒ the use to which it is put,

or if

⇒ it is expected that a lightning strike would have serious consequences.

This means:
"A lightning protection system must be built even if only one of the requirements is met."

A lightning strike can have particularly **serious consequences** for buildings and structures owing to their location, type of construction or the use to which they are put.
A nursery school, for example, is a building where a lightning strike can have serious consequences because of the use to which the building is put.
The interpretation to be put on this statement is made clear in the following court judgement:

Extract from the Bavarian Administrative Court, decision of 4 July 1984 – No. 2 B 84 A.624.

1. A nursery school is subject to the requirement to install effective lightning protection systems.
2. The legal requirements of the building regulations for a minimum of fire-retardant doors when designing staircases and exits also apply to a residential building which houses a nursery school.

For the following reasons:
According to the Bavarian building regulations, buildings and structures whose location, type of construction or the use to which they are put, make them susceptible to lightning strikes, or where such a strike can have serious consequences, must be equipped with permanently effective lightning protection systems. This stipulates the requirement for effective protective devices in two cases. In the first case, the buildings and structures are particularly susceptible to lightning strikes (e.g. because of their height or location); in the other case, any lightning strike (e.g. because of the type of construction or the use to which it is put) can have particularly serious consequences. The plaintiff´s building falls within the latter category because of its present use as a nursery school. A nursery school belongs to the group of buildings where a lightning strike can have serious consequences because of the use to which the building is put. It is of no consequence that, in the annotations to the Bavarian building regulations, nursery school are not expressly mentioned in the illustrative list of buildings and structures which are particularly at risk, alongside meeting places.

The risk of serious consequences if lightning strikes a nursery school arises because, during the day, a large number of children under school age are present at the same time.

The fact that the rooms where the children spend their time are on the ground floor, and that the children could escape to the outside through several windows – as put forward by the plaintiff – is not a deciding factor. In the event of fire, there is no guarantee that children of this age will react sensibly and leave the building via the windows if necessary. In addition, the installation of sufficient lightning protection equipment is not too much to expect of the operator of a nursery school. A further section of the Bavarian building regulations requires that, amongst other things, staircases must have entrances to the cellar which have self-closing doors which are, at least, fire-retardant. The requirements do not apply to residential buildings with up to two flats. The respondent only made the demand when the plaintiff converted the building, which was previously residential, into a nursery school as well, in accordance with the authorised change of use. The exemption provision cannot be applied to buildings which were built as residential buildings with up to two flats, but which now (also) serve an additional purpose which justifies the application of the safety requirements.

Serious consequences (panic) can also arise when lightning strikes assembly rooms, schools, hospitals.
For these reasons, it is necessary that all buildings and structures which are at risk of such events are equipped with permanently effective lightning protection systems.

Lightning protection systems always required
Buildings and structures where a lightning protection system must always be included because, in these cases, the German law has affirmed the need, are

1. Assembly places with stages or covered stage areas and assembly places for the showing of films, if the accompanying assembly rooms in each case, either individually or together, can accommodate more than 100 visitors;
2. Assembly places with assembly rooms which individually or together can accommodate more than 200 visitors; in the case of schools, museums and similar buildings, this regulation only applies to the inspection of technical installations in assembly rooms which individually can accommodate more than 200 visitors, and their escape routes;
3. Sales areas whose sales rooms have more than 2000 m^2 of floor space;
4. Shopping centres with several sales areas which are connected to each other either directly or via escape routes, and whose sales rooms individually have less than 2000 m^2 of floor space but having a total floor space of more than 2000 m^2;
5. Exhibition spaces whose exhibition rooms individually or together have more than 2000 m^2 of floor space;
6. Restaurants with seating for more than 400 customers, or hotels with more than 60 beds for guests;
7. High-rise buildings as defined in the Hamburg building regulations (HbauO);
8. Hospitals and other buildings and structures having a similar purpose;
9. Medium-sized and large-scale garages as defined in the Hamburg regulations for garages (Hamburgisches Gesetz- und Verordnungsblatt);
10. Buildings and structures

10.1 with explosive materials, such as ammunition factories, depots for ammunition and explosives,

10.2 with factory premises which are at risk of explosion, such as varnish and paint factories, chemical factories, larger depots of combustible liquids and larger gas holders,

10.3 particularly at risk of fire, such as
- larger woodworking factories,
- buildings with thatched roofs, and
- warehouses and production plants with a high fire load,

10.4 for larger numbers of people such as
- schools,
- homes for the elderly and children´s homes,
- barracks,

– correctional facilities
– and railway stations,

10.5 with cultural assets, such as
– buildings of historic interest,
– museums and archives,

10.6 towering above their surroundings, such as
– high chimneys,
– towers
– high buildings.

The following list provides an overview of the relevant "General Provisions" in Germany which deal with the issue of requirement, design and inspection of lightning protection systems.

General international and national (German) provisions:

DIN 18384: 2000-12
Contract procedure for building works
Part C: General technical specifications for building works; Lightning protection systems

Lightning protection systems:

Standardleistungsbuch für das Bauwesen (StLB)
Leistungsbereich 050, Blitzschutz- und Erdungsanlagen (Translation: Standard services book for the construction industry, Service sector 050, lightning protection and earth-termination systems)
The purpose of this standard services book is to ensure conformity of the texts used in the service descriptions, and also to facilitate data processing. The texts are used for public tenders by all building authorities, and by federal, state and local governments.

IEC 62305-1: 2006-01
EN 62305-1: 2006-02
Lightning protection – Part 1: General principles

IEC 62305-2: 2006-01
EN 62305-2: 2006-02
Lightning protection – Part 2: Risk management

IEC 62305-3: 2006-01
EN 62305-3: 2006-02
Lightning protection – Part 3: Physical damage to structures and life hazard

IEC 62305-4: 2006-01
EN 62305-4: 2006-02
Lightning protection – Part 4: Electrical and electronic systems within structures

DIN 48805 ... 48828
Components for external lightning protection
This series of standards specifies dimensions and material thicknesses.
It is being replaced step by step by the following standard.

EN 50164-1: 1999-09
Lightning protection components (LPC)
Part 1: Requirements for connection components
Defines the requirements which metal connection components such as connectors, terminals and bridging components, expansion pieces and measuring points for lightning protection systems have to meet.

EN 50164-2: 2002-08
Lightning protection components (LPC)
Part 2: Requirements for conductors and earth electrodes
This standard describes, for example, dimensions and tolerances for metal conductors and earth electrodes as well as the test requirements to the electrical and mechanical values of the materials.

Special standards for earth–termination systems:

DIN 18014: 2007-09
Foundation earth electrode – General planning criteria

DIN VDE 0151: 1986-06
Material and minimum dimensions of earth electrodes with respect to corrosion
This VDE guideline applies to corrosion protection when installing and extending earth electrodes and earthing-termination systems. It provides information on how to avoid or reduce the risk of corrosion to earth electrodes and with earth electrodes of other systems installed. Moreover, it provides information to assist in making the correct choice of earth electrode materials, and also about special anticorrosion measures.

EN 50162: 2004-08
Protection against corrosion by stray current from direct current systems
Among others this standard requires that for underground storage tanks being electrically separated from the electrical installation in the house by insulating parts, the connection between the tank and the lightning protection system must be effected via an isolating spark gap.

HD 637 S1: 1999-05
Power installations exceeding 1 kV

EN 50341-1: 2001-10
Overhead electrical lines exceeding a.c. 45 kV – Part 1: General requirements; Common specifications;
Special consideration also is given to the requirements of protection against lightning.
Reference is made to the risk of back flashover, and a relationship is established between the impulse earthing resistance of the mast or framework earthing, the impulse withstand voltage of the insulation and the peak value of the lightning current.
Furthermore attention is drawn to the fact that it is more effective to install several individual earth electrodes (meshed or star-type earth electrodes) than a single, very long earth rod or surface earth electrode.

Special standards for internal lightning and surge protection, equipotential bonding:

IEC 60364-4-41: 2005, mod
HD 60364-4-41: 2007
Erection of power installations – Part 4-41: Protection against electric shock

IEC 60364-5-54: 2002, mod
HD 60364-5-54: 2007
Erection of low voltage installations – Part 5-54: Selection and erection of electrical equipment – earthing arrangements, protective conductors, equipotential bonding.

IEC 60364-5-53/A2: 2001
IEC 64/1168/CDV: 2001-01
Erection of low voltage installations – Part 5: Selection and erection of electrical equipment; Chapter 53: Switchgear and controlgear; Section 534: Devices for protection against overvoltages; Amendment A2
This standard deals with the use of surge protective devices Type I, II and III in low-voltage consumer's installations in accordance with the protection at indirect contact.

IEC 60364-4-44: 2001 + A1: 2003, mod
HD 60364-4-443: 2006
Erection of low voltage installations – Part 4: Protection for safety; Chapter 44: Protection against overvoltages; Section 443: Protection against overvoltages of atmospheric origin or due to switching.

IEC 109/44/CD: 2005
EN 60664-1: 2003-04
Isolation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests (IEC 60664-1: 1992 + A1: 2000 + A2: 2002)
This standard defines the minimum insulation distances, their selection and the rated impulse voltages for overvoltage categories I to IV.

VDEW Directive: 2004-08
(German Directive)
Surge protective devices Type 1 – Use of surge protective devices (SPD) Type 1 (previously Class B) in the upstream area of the meter.
Describes the use and the installation of surge protective devices Type 1 in the upstream area of the meter.

Especially for electronic systems such as television, radio, data systems technology (telecommunications systems):

IEC 60364-5-548: 1996
Electrical installations of buildings – Part 5: Selection and erection of electrical equipment – Section 548: Earthing arrangements and equipotential bonding for information technology installations.

IEC/DIS 64(CO)1153: 1981
MOD IEC 60364-4-41: 1982
Earthing and equipotential bonding
Part 2 summarises all requirements on the function of a telecommunications system with respect to earthing and equipotential bonding.

DIN VDE 0800-10: 1991-03
(German standard)
Transitional requirements on erection and operation of installations
Part 10 contains requirements for the installation, extension, modification and operation of telecommunications systems. Section 6 of this part lays down the requirements for surge protective measures.

IEC 61643-21: 2000-08 + Corrigendum: 2001
EN 61643-21: 2001-07
Low-voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks; Performance requirements and testing methods.

IEC 60728-11: 2005-01
EN 60728-11: 2005-05
Cable networks for television signals, sound signals and interactive services – Part 11: Safety
Part 11 requires measures to protect against atmospheric discharges (earthing of the antenna mounting, equipotential bonding).

VDE 0855 Part 300: 2002-07
(German standard)
Transmitting / receiving systems for transmitter RF output power up to 1 kW;
Safety requirements
Section 12 of Part 300 describes the lightning and surge protection and the earthing of antenna systems.

IEC 61663-1: 1999-07
EN 61663-1: 1999-11
Lightning protection – Telecommunication lines, Part 1: Fibre optic installations
On this subject, the standard describes a method for calculating the possible number of incidences of damage for selecting the protective measures which can be used, and gives the permissible frequency of incidences of damage. Only primary faults (interruption of operations) and not secondary faults (damage to the cable sheath (formation of holes)), however, are considered.

IEC 61663-2: 2001-03
EN 61663-2: 2001-06
Lightning protection – Telecommunication lines, Part 2: Lines using metallic conductors.
This standard must only be applied to the lightning protection of telecommunication and signal lines with metal conductors which are located outside buildings (e.g. access networks of the landline providers, lines between buildings).

Special installations:

EN 1127-1: 1997-08
Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology
This standard is a guide on how to prevent explosions, and protect against the effects of explosions by employing measures during the drafting and design of devices, protection systems and components.
Part 1 requires also protection against the effects of a lightning strike which put the installations at risk.

pr EN 1127-1: 2004-12
Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology.

IEC 60079-14: 2002
EN 60079-14: 2003-08
Electrical apparatus for explosive gas atmospheres – Part 14: Electrical installations in hazardous areas (other than mines)
Section 6.5 draws attention to the fact that the effects of lightning strikes must be taken into consideration.
Section 12.3 describes the detailed stipulations for installations for the ex zone 0.
Extremely extensive equipotential bonding is required in all ex zones.

IEC 31J/120/CDV: 2006
pr EN 60079-14: 2006-06
Explosive atmospheres – Part 14: Electrical installations design, selection and erection

IEC 61241-17: 2005-01
EN 61241-17: 2005-05
Electrical apparatus for use in the presence of combustible dust – Part 17: Inspection and maintenance of electrical installations in hazardous areas with explosive atmospheres (other than mines)

VDE document series 65: "Elektrischer Explosionsschutz nach DIN VDE 0165"; VDE Verlag Berlin [engl.: "Electrical explosion protection according to DIN VDE 0165"], Annex 9: "PTB-Merkblatt für den Blitzschutz an eigensicheren Stromkreisen, die in Behälter mit brennbaren Flüssigkeiten eingeführt sind" [engl.: "PTB bulletin for protection of intrinsically safe circuits installed in containers with flammable liquids against lightning"]

In Germany standards can be obtained from the following addresses:

VDE VERLAG GMBH
Bismarckstraße 33
10625 Berlin
Germany
Phone: +49 30 34 80 01-0
Fax: +49 30 341 70 93
eMail: vertrieb@vde-verlag.de
Internet: www.vde-verlag.de

or

Beuth-Verlag GmbH
Burggrafenstraße 4-10
10787 Berlin
Germany
Phone: +49 30 2601-2240
Fax: +49 30 2601-1724
Internet: www.din.de/beuth

3.2 Assessment of the risk of damage and selection of protective components

3.2.1 Risk management

Risk management with foresight includes calculating the risks for the company. It provides the basis on which decisions can be made in order to limit these risks, and it makes clear which risks should be covered by insurance. When considering the management of insurances, it should be borne in mind, however, that insurance is not always a suitable means of achieving certain aims (e.g. maintaining the ability to deliver). The probabilities that certain risks will occur cannot be changed by insurance.
Companies which manufacture or provide services using extensive electronic installations (and nowadays this applies to most companies), must also give special consideration to the risk presented by lightning strikes. It must be borne in mind that the damage caused by the non-availability of electronic installations, production and services, and also the loss of data, is often far greater than the damage to the hardware of the installation affected.
In the case of lightning protection, innovative thinking about damage risks is slowly gaining in importance. The aim of risk analysis is to objectify and quantify the risk to buildings and structures, and their contents, as a result of direct and indirect lightning strikes. This new way of thinking has been embodied in the international standard IEC 62305-2: 2006 or the European standard EN 62305-2: 2006.

The risk analysis presented in IEC 62305-2 (EN 62305-2) ensures that it is possible to draw up a lightning protection concept which is understood by all parties involved, and which meets optimum technical and economic requirements, i.e. the necessary protection can be guaranteed with as little expenditure as possible. The protective measures which result from the risk analysis are then described in detail in the later parts of the standard, in the new IEC 62305 (EN 62305) series.

3.2.2 Fundamentals of risk assessment

According to IEC 62305-2 (EN 62305-2), risk R of lightning damage can generally be found using the relationship:

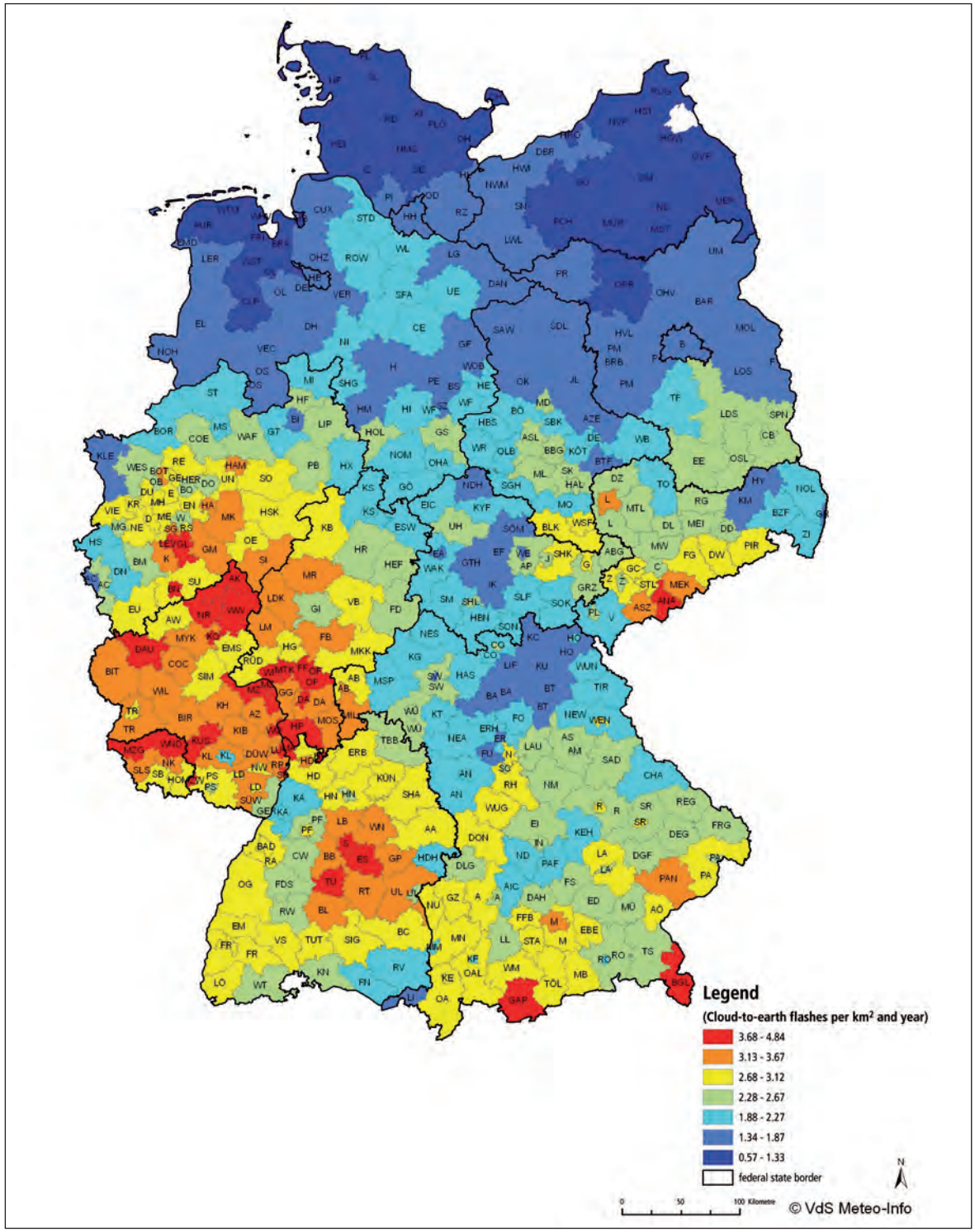


Fig. 3.2.3.1 Lightning density in Germany (average of 1999 – 2005)

$$R = N \cdot P \cdot L$$

N Number of hazardous events, i.e. frequency of lightning strikes in the area under consideration (How many lightning strikes occur per year in the area under consideration?);

P Probability of damage (What is the probability that a lightning strike causes a quite specific type of damage?);

L Loss, i.e. the quantitative evaluation of the damage (What are the effects, amount of loss, extent, and consequences of a very specific type of damage?).

The task of the risk assessment therefore involves the determination of the three parameters N, P and L for all relevant risk components. This involves establishing and determining of many individual parameters. A comparison of the risk R thus established with a tolerable risk R_T then enables a statement to be made about the requirements and the dimensioning of lightning protection measures.
An exception is the consideration of the economic losses. For this kind of damage the protective measures have to be justified strictly by the economical point of view. There is no tolerable risk R_T, but rather a cost-benefit analysis. An exception is the consideration of the economic losses. For this kind of damage the protective measures have to be justified strictly by the economical point of view. There is no tolerable risk R_T, but rather a cost-benefit analysis.

3.2.3 Frequency of lightning strikes

We distinguish between the following frequencies of lightning strikes which can be relevant for a building or structure:

N_D Frequency of direct lightning strikes to the building or structure;

N_M Frequency of close lightning strikes with electromagnetic effects;

N_L Frequency of direct lightning strikes in utility lines entering the building or structure;

N_I Frequency of lightning strikes adjacent to utility lines entering the building or structure.

The calculation of the frequencies of lightning strikes is given in detail in Annex A of IEC 62305-2 (EN 62305-2). For practical calculations it is recommendable to take the annual density of the cloud-to-earth flashes N_g for the region under consideration from **Figure 3.2.3.1**. If a finer grid is used, the local values of the lightning densities can still deviate noticeably from these averages. Owing to the relatively short time of seven years the map has been recorded, and to the large area averaging according to licence plate number areas, the application of a safety factor of 25 % to the values given in **Figure 3.2.3.1** is recommended.

For the frequency of **direct** lightning strikes N_D to the building or structure we have:

$$N_D = N_g \cdot A_d \cdot C_d \cdot 10^{-6}$$

$\mathbf{A_d}$ is the equivalent interception area of the isolated building or structure (**Figure 3.2.3.2**), C_d a site factor so that the influence of the surroundings (built-up, terrain, trees, etc.) can be taken into account (**Table 3.2.3.1**).

Similarly, the frequency of close lightning strikes N_M can be calculated:

$$N_M = N_g \cdot A_m \cdot 10^{-6}$$

Relative site of the building or structure	**C_d**
Object is surrounded by higher objects or trees	0.25
Object is surrounded by objects or trees of the same or lower height	0.5
Free-standing object: no further objects near by (within a distance of 3H)	1
Free-standing object on top of a moutain or a rounded hilltop	2

Table 3.2.3.1 Site factor C_d

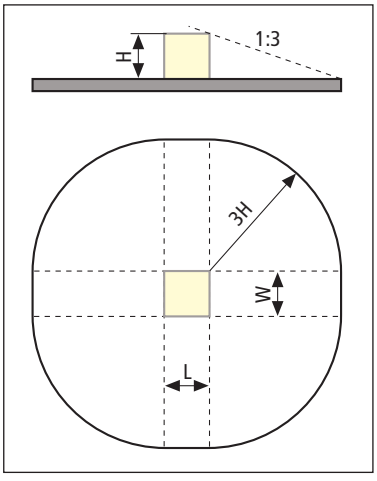


Fig. 3.2.3.2 Equivalent interception area A_d for direct lightning strikes into a stand-alone structure

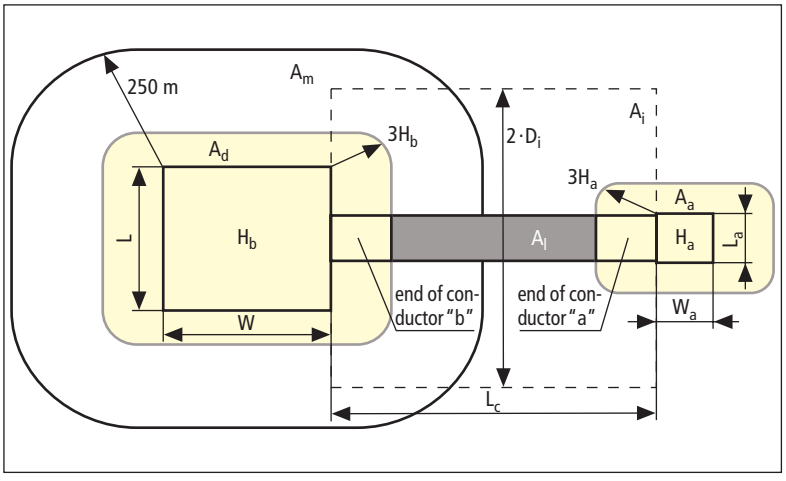


Fig. 3.2.3.3 Equivalent interception areas A_d, A_l, A_a for direct lightning strikes into structures/supply lines and A_m, A_i for indirect lightning strikes near the structures/supply lines

A_m is arrived at by drawing a line at a distance of 250 m around the building or structure (**Figure 3.2.3.3**). The equivalent interception area A_d C_d of the building or structure estimated using the environmental coefficients is then subtracted from the area thus enclosed. Lightning strikes on the area A_m lead exclusively to magnetically induced surges in installation loops in the interior of the building or structure.

The frequency of direct lightning strikes in a utility line entering a building or structure N_L is:

$$N_L = N_g \cdot A_l \cdot C_e \cdot C_t \cdot 10^{-6}$$

The area **A_l** (**Figure 3.2.3.3**) is a function of the type of line (overhead line, cable), the length L_C of the line; in the case of cables, it is a function of the earth resistivity ρ; and for overhead lines it is a function of height H_C of the line above ground level (**Table 3.2.3.2**). If the length of the line is not known, or if it is very time-consuming to ascertain it, then, as a worst-case scenario, a value of L_C = 1000 m can be set.

H_C Height (m) of the line above ground level;

ρ Earth resistivity (Ωm) in, or on, which the line is laid, up to a maximum value of ρ = 500 Ωm;

L_C Length (m) of the line, measured from the building or structure to the first distribution junction, or to the first location where surge protective devices are installed, up to a maximum length of 1000 m;

H Height (m) of the building or structure;

H_b Height (m) of the building or structure;

H_a Height (m) of the neighbouring building or structure connected via the line.

If, within the area A_l there is a medium voltage line rather than a low voltage one, then a transformer reduces the intensity of the surges at the entrance to the building or structure. In such cases, this is taken into account by the correction factor C_t = 0.2. The correction factor C_e (environment factor) is ultimately a function of the building density (**Table 3.2.3.3**).

The frequency N_L must be determined individually for each utility line entering the building or structure. In the building or structure under consideration, lightning strikes within the area A_l lead, as a rule, to a high energy discharge which can generate a fire, an explosion, a mechanical or chemical reaction. The frequency N_L therefore, does not comprise pure surges which result in faults or damage to the electrical and electronic systems, but mechanical and thermal effects which arise when lightning strikes.

Surges to utility lines entering the building or structure are described by the frequency of lightning strikes next to such a utility line N_l:

	Overhead line	Underground cable
A_l	$\left[L_C - 3 \cdot (H_a + H_b)\right] \cdot 6 \cdot H_C$	$\left[L_C - 3 \cdot (H_a + H_b)\right] \cdot \sqrt{\rho}$
A_i	$1000 \cdot L_C$	$25 \cdot L_C \cdot \sqrt{\rho}$

Table 3.2.3.2 Equivalent interception areas A_l and A_i in m^2

Environment	C_e
Urban with high buildings or structures (higher than 20 m)	0
Urban (buildings or structures of heights between 10 m and 20 m)	0.1
Suburban (buildings or structures not higher than 10 m)	0.5
Rural	1

Table 3.2.3.3 Environment factor C_e

$$N_l = N_g \cdot A_i \cdot C_t \cdot C_e \cdot 10^{-6}$$

The area A_i (**Figure 3.2.3.3**) is again a function of the type of line (overhead line, underground cable), the length L_C of the line; in the case of cables, it is a function of the earth resistivity ρ; and for overhead lines it is a function of the height H_C of the line above ground level (**Table 3.2.3.3**). The same worst-case scenario applies. The area A_i is usually significantly larger than A_l. This makes allowance for the fact that surges resulting in faults or damage to electrical and electronic systems can also be caused by lightning strikes further away from the line.

The correction factors C_t und C_e correspond to those already stated above. The frequency N_l must then also be determined individually for each utility line entering the building or structure.

3.2.4 Probabilities of damage

The damage probability parameter gives the probability that a supposed lightning strike will cause a quite specific type of damage. It is therefore assumed that there is a lightning strike on the relevant area; the value of the damage probability can then have a maximum value of 1. We differentiate between the following eight damage probabilities:

P_A Electric shock suffered by living beings as a result of a direct lightning strike to the building or structure;

P_B Fire, explosion, mechanical and chemical reactions as a result of a direct lightning strike to the building or structure;

P_C Failure of electrical / electronic systems as a result of a direct lightning strike to the building or structure; $P_C = P_{SPD}$

P_M Failure of electrical / electronic systems as a result of a lightning strike to the ground next to the building or structure;

P_U Electric shock suffered by living beings as a result of a direct lightning strike to the utility lines entering the building or structure;

P_V Fire, explosion, mechanical and chemical reactions as a result of a direct lightning strike to a utility line entering the building or structure;

P_W Failure of electrical / electronic systems as a result of a direct lightning strike to a utility line entering the building or structure;

P_Z Failure of electrical / electronic systems as a result of a lightning strike to the ground next to a utility line entering the building or structure.

This damage probabilities are presented in detail in Annex B of IEC 62305-2 (EN 62305-2). They can be taken either directly from tables or they are the resulting function of a combination of further

Characteristics of building or structure	Class of lightning protection system (LPS)	P_B
Building or structure is not protected by LPS	–	1
Building or structure is protected by LPS	IV	0.2
	III	0.1
	II	0.05
	I	0.02
Building or structure with air-termination system according to class of LPS and a metal facade or a concrete reinforcement as natural down conductor system		0.01
Building or structure with metal roof or with air-termination system, preferably including natural components, which protect all roof superstructues entirely against direct lightning strikes, and a metal facade or concrete reinforcement a natural down conductor system.		0.001

Table 3.2.4.1 Damage factor P_B to describe the protective measures against physical damage

Lightning protection level (LPL)	Damage factor P_{SPD}
No coordinated surge protection	1
III – IV	0.03
II	0.02
I	0.01
Surge protective devices (SPD) having a protective characteristic better than for LPL I (higher lightning current carrying capability, lower protection level, etc.)	0.005 – 0.001

Table 3.2.4.2 Damage factor P_{SPD} to describe the protective measures surge protective devices as a function of the lightning protection level

influence factors. There is no more subdivision into simple (basic) probabilities and reduction factors. Some reduction factors now rather have been assigned to the Annex C, i.e. to the losses, for example P_B and P_C representing damage factors. Both parameter values are presented in **Tables 3.2.4.1** and **3.2.4.2**. Attention still is drawn to the fact that also other, deviating values are possible, if based on detailed examinations or estimations.

3.2.5 Types of loss and sources of damage

Depending on the construction, use and substance of the building or structure, the relevant types of damage can be very different. IEC 62305-2 (EN 62305-2) recognises the following four types of damage:

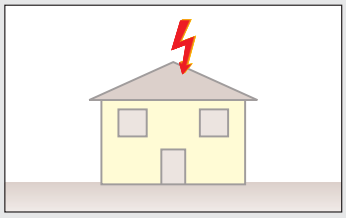
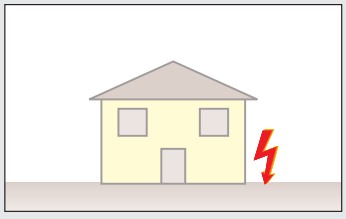
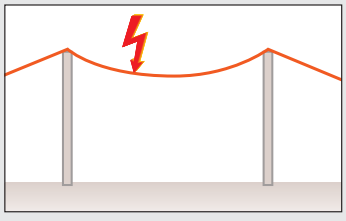
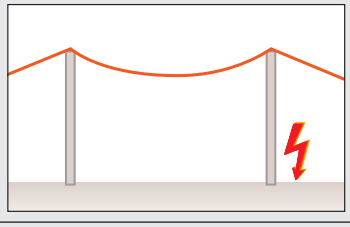
L1 Loss of human life (injury to, or death of, persons);

L2 Loss of services for the public;

L3 Loss of irreplaceable cultural assets;

L4 Economic losses.

The types of loss stated can arise as a result of the different **sources of damage**: The sources of damage thus literally represent the "cause" in a causal relationship, the type of loss the "effect" (see **Table 3.2.5.1**). The possible sources of damage for one type of loss can be manifold. It is therefore necessary to first define the relevant types of damage for a building or structure. It is then subsequently possible to stipulate the sources of damage to be determined.

			Building or structure	
Point of Strike	**Example**	**Source of damage**	**Type of damage**	**Type of loss**
Building or structure		S1	D1 D2 D3	L1, L4[b] L1, L2, L3, L4 L1[a], L2, L4
Earth next to the structure		S2	D3	L1[a], L2, L4
Entering supply line		S3	D1 D2 D3	L1, L4[b] L1, L2, L3, L4 L1[a], L2, L4
Earth next to the entering supply line		S4	D3	L1[a], L2, L4

[a] For hospitals and buildings or structures with hazard of explosion
[b] For agricultural properties (loss of animals)

Source of damage in relation to the point of strike
S1 Direct lightning strike to the building or structure;
S2 Lightning strike to the earth near the building or structure;
S3 Direct lightning strike to the entering supply line;
S4 Lightning strike to the earth close to the entering supply line.

Type of damage
D1 Electric shock to living beings as a result of contact and step voltage;
D2 Fire, explosion, mechanical and chemical reactions as a result of the physical effects of the lightning discharge;
D3 Failure of electrical and electronic sytems as a result of surges.

Type of loss
L1 Injury to, or death of, persons;
L2 Loss of services for the public;
L3 Loss of irreplaceable cultural assets;
L4 Economic losses.

Table 3.2.5.1 Sources of damage, types of damage and types of loss according to the point of strike

3.2.6 Loss factor

If a particular type of damage has occurred in a building or structure, then the effect of this damage must be assessed. It is possible, for example, for a fault or damage to a DP system (L4 type of loss: economic losses) to have very different consequences. If no data appertaining to the business is lost, then the claim will only be for the damage to the hardware to the value of a few thousand Euro. If, however, the complete business of a company is dependent on the permanent availability of the DP system (call centre, bank, automation engineering) then, in addition to the hardware damage, there is also disproportionately high consequential damage as a result of customer dissatisfaction, customers going to other suppliers, overlooked business processes, loss of production, etc.
The effects of the damage are assessed using the loss factor L.

Basically divided up into the following:

L_t Loss by injury as a result of contact and step voltages;

L_f Loss as a result of physical damage;

L_o Loss as a result of failure of electrical and electronic systems.

Depending on the relevant type of damage, this enables the extent of the damage, its value or the consequences to be assessed. Annex C of IEC 62305-2 (EN 62305-2) gives the fundamentals of the calculation of the loss of the four types of damage. It is frequently the case, however, that it is extremely time-consuming to apply the equations. For usual cases, the aforementioned Annex C therefore also provides suggestions for typical values for the damage factor L, depending on the underlying causes of the damage.

In addition to the actual loss factors Annex C also outlines three reduction factors r_x and an increasing factor h:

r_a Reduction factor for effects of step and contact voltages depending on the kind of ground or floor;

r Reduction factor for measures to mitigate the consequences of fire;

r_f Reduction factor to describe the risk of fire to a building or structure;

h Factor increasing the relative value of a loss, if there is special hazard (e.g. as a result of panic, potential endangering of the environment by the building or structure).

Although shifted from IEC 62305-2 (EN 62305-2) Annex B (damage factors) to Annex C now, the parameter values, however, remained almost unchanged.

3.2.7 Relevant risk components for different lightning strikes

There is close correlation between the cause of the damage, the type of damage and the resulting relevant risk components. Initially, it serves to represent the dependence on the point of strike of the lightning discharge, and the risk components which are derived from this.

If lightning directly strikes a building or structure, the following risk components arise (**Table 3.2.7.1**):

R_A Risk component for electric shocks to living beings as a result of direct lightning strikes;

R_B Risk component for physical damage as a result of direct lightning strikes;

R_C Risk of malfunctioning of electrical and electronic systems as a result of surges caused by direct lightning strikes.

If lightning strikes the earth near a building or structure, or neighbouring buildings, the following risk component is created:

R_M Risk of malfunctioning of electrical and electronic systems as a result of surges caused by direct lightning strikes to the ground next to the building or structure.

If lightning directly strikes utility lines entering a building or structure, the following risk components arise:

R_U Risk components for electric shocks to living beings in the event of direct lightning strikes to utility lines entering the building or structure;

R_V Risk components for physical damage in the event of direct lightning strikes to utility lines entering the building or structure;

Source of damage / Type of damage	Lightning strike (with regard to the structure)				
	Direct	Indirect			
	S1	S2	S3	S4	
	Direct lightning strike into the structure	Lightning strike into the earth next to the structure	Direct lightning strike into the entering supply line	Lightning strike into the earth next to the entering supply line	
D1 Electric shock to living beings	$R_A = N_D \cdot P_A \cdot r_a \cdot L_t$		$R_U = (N_L + N_{DA}) \cdot P_U \cdot r_a \cdot L_t$		$R_s = R_A + R_U$
D2 Fire, explosions, mechanical and chemical effects	$R_B = N_D \cdot P_B \cdot r \cdot h \cdot r_f \cdot L_f$		$R_V = (N_L + N_{DA}) \cdot P_V \cdot r \cdot h \cdot r_f \cdot L_f$		$R_f = R_B + R_V$
D3 Interferences on electrical and electronic systems	$R_C = N_D \cdot P_C \cdot L_o$	$R_M = N_M \cdot P_M \cdot L_o$	$R_W = (N_L + N_{DA}) \cdot P_W \cdot L_o$	$R_Z = (N_I - N_L) \cdot P_Z \cdot L_o$	$R_o = R_C + R_M + R_W + R_Z$
	$R_d = R_A + R_B + R_C$	$R_i = R_M + R_U + R_V + R_W + R_Z$			

Table 3.2.7.1 In addition to the risk components R_U, R_V and R_W, there is the frequency of direct lightning strikes into the supply line N_L and the frequency of direct lightning strikes into the connected building or structure N_{DA} (compare **Figure 3.2.3.3**). In case of the risk component R_Z, however, the frequency of lightning strikes next to the supply line N_I has to be reduced by the frequency of direct lightning strikes into the supply line N_L.

R_W Risk of failure of electrical and electronic systems as a result of surges caused by direct lightning strikes to utility lines entering the building or structure.

If lightning eventually strikes the ground next to the utility lines entering a building or structure, the following risk component is created:

R_Z Risk of failure of electrical and electronic systems as a result of surges caused by direct lightning strikes to the ground next to the utility lines entering the building or structure.

The eight risk components in total (which basically must be determined individually for each type of damage) can now be combined according to two different criteria: the point of strike of lightning and the cause of the damage.

If the combination according to the point of strike is of interest, i.e. the evaluation of **Table 3.2.7.1** according to columns, then the risk

⇒ as a result of a direct lightning strike to the building or structure is:

$$R_d = R_A + R_B + R_C$$

⇒ as a result of an indirect lightning strike next to the building or structure is:

$$R_i = R_M + R_U + R_V + R_W + R_Z$$

If, on the other hand, it is desired to investigate the cause of the damage, then the risks can be combined as follows:

⇒ For electric shock to humans or animals as a result of contact and step voltages:

$$R_s = R_A + R_U$$

Types of loss		R_T
L1	Loss of human life (injury to, or death of, persons)	10^{-5}/year
L2	Loss of services for the public	10^{-3}/year
L3	Loss of irreplaceable cultural asset	10^{-3}/year

Table 3.2.8.1 Typical values for the tolerable risk R_T

⇒ For fire, explosion, mechanical and chemical reaction, caused by mechanical and thermal effects of a lightning strike:

$$R_f = R_B + R_V$$

⇒ For failure of electrical and electronic systems due to surges:

$$R_o = R_C + R_M + R_W + R_Z$$

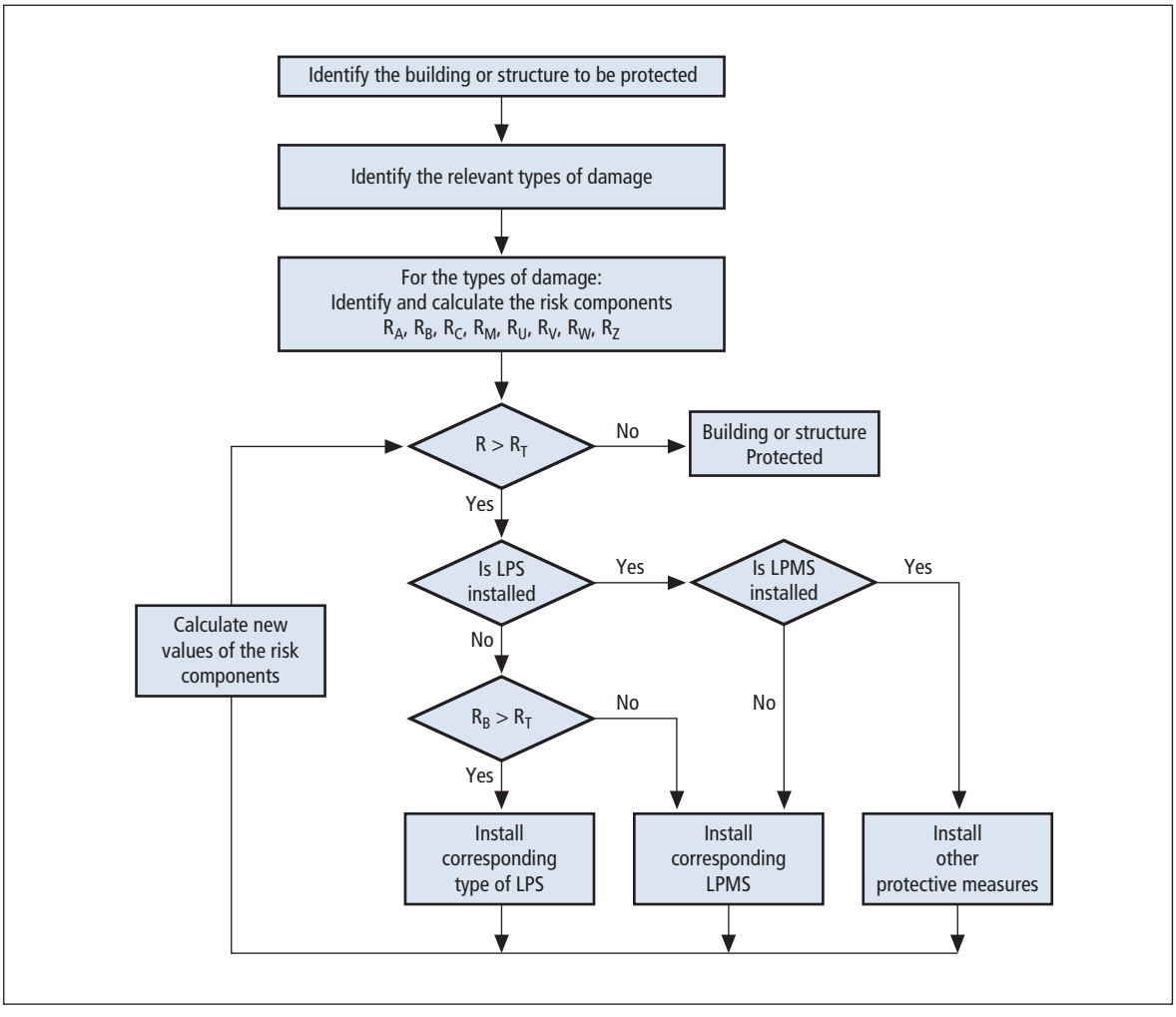


Fig. 3.2.9.1 Flow chart for selection of protective measures for the types of loss L1 ... L3

3.2.8 Tolerable risk of lightning damage

When making a decision on the choice of lightning protection measures, one has to examine whether the damage risk R determined for each relevant type of damage exceeds a tolerable (i.e. a still acceptable) value R_T or not. This, however, is only applicable for the three types of loss L1 – L3, which are of so-called public interest. For a building or structure which is sufficiently protected against the effects of lightning, then must hold:

$$R \leq R_T$$

R represents the sum over all risk components which are relevant for the respective type of loss L1 – L3:

$$R = \sum R_V$$

IEC 62305-2 (EN 62305-2) provides acceptable maximum values R_T for these three types of loss (**Table 3.2.8.1**).

3.2.9 Choice of lightning protection measures

The measures for protection against lightning are intended to lead to the limiting of the damage risk R to values below the tolerable risk of damage R_T. Using a detailed calculation of the damage risks for the types of damage which are relevant to a specific building or structure in each case, i.e. by dividing them into the individual risk components R_A, R_B, R_C, R_M, R_U, R_V, R_W and R_Z, it is possible to choose lightning protection measures in an extremely targeted way.
The flow chart in IEC 62305-2 (EN 62305-2) (**Figure 3.2.9.1**) illustrates the procedure. Starting from the fact that the calculated damage risk R exceeds the tolerable damage risk R_T, the first thing to be examined is whether the risk of physical damage caused by a direct lightning strike to a building or structure R_B exceeds the tolerable damage risk R_T. If this is the case, a complete lightning protection system with suitable external and internal lightning protection must be installed. If R_B is sufficiently small, the second step is to examine whether the risk can be sufficiently reduced by protective measures against the lightning electromagnetic pulse (LEMP).

Proceeding according to **Figure 3.2.9.1** makes it possible to choose those protective measures which lead to a reduction in the risk components which have relatively high values in each case, i.e. protective measures whose degrees of effectiveness in the case under inspection are comparatively high.

3.2.10 Economic losses / Economic efficiency of protective measures

The type of loss L4, economic losses, is relevant for many buildings or structures. Here it is no longer possible to work with a tolerable risk of damage R_T. One rather has to compare, whether the protective measures are justifiable from an economical point of view. Not an absolute parameter, such as a specified tolerable risk of damage R_T, is standard of comparison, but a relative one: Different states of protection of the building or structure are compared and the optimal solution, i.e. the cost of damage as a result of lightning strikes remaining as low as possible, will be realised. So several variants can and shall be examined.

The basic procedure is represented in **Figure 3.2.10.1**, **Figure 3.2.10.2** shows the corresponding flow chart from IEC 62305-2 (EN 62305-2). At the beginning this new method certainly will arouse new discussions among experts because it allows a (rough) estimation of costs even before the actual designing of lightning protection measures. Here a detailed and administered respective data base can render good service.

Usually not only the type of loss L4, but also one or several of the other types of loss L1 – L3 are relevant for a building or structure. In these cases first of all the proceeding represented in **Figure 3.2.9.1** is applicable, i.e. the damage risk R for the each of the losses L1 – L3 must be lower than the tolerable damage risk R_T. In this case a second step is to examine the efficiency of the planned protective measures according to **Figure 3.2.10.1** and **Figure 3.2.10.2**. Of course, also here again several variants of protection are possible, the most favourable one finally to be realised, however, provided that

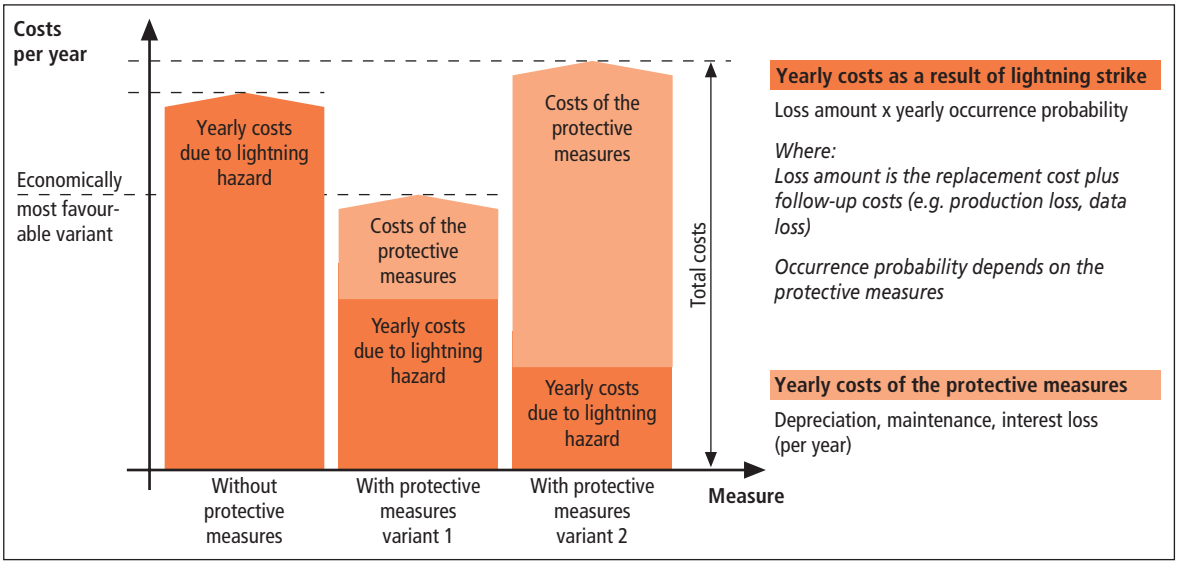


Fig. 3.2.10.1 Basic procedure in case of a purely economic consideration and calculation of the yearly costs

for all relevant types of loss of public interest L1 – L3 is always $R < R_T$.

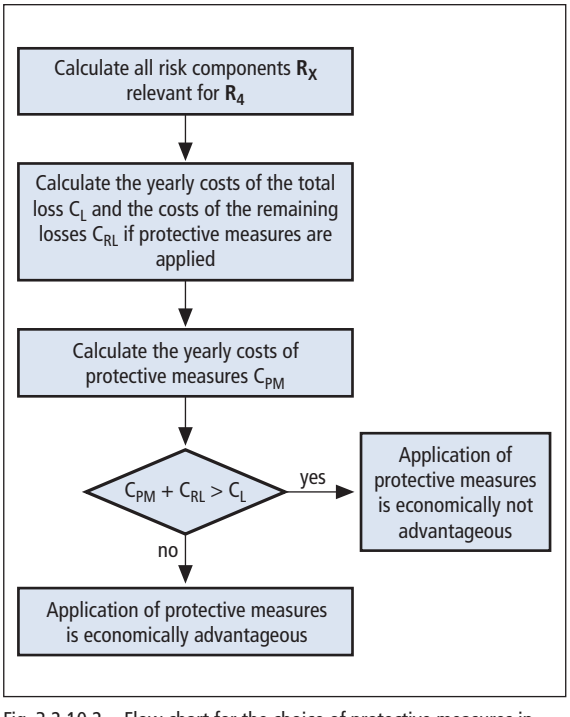


Fig. 3.2.10.2 Flow chart for the choice of protective measures in case of economic losses

3.2.11 Summary

In practice, it is time-consuming and not always easy to apply the procedures and data given. This should not prevent the experts in the field of lightning protection and, in particular, those at the sharp end, from studying this material. The quantitative assessment of the risk of lightning damage for a building or structure is a considerable improvement on the situation often encountered before, where decisions for or against lightning protection measures were frequently made solely on the basis of subjective considerations which were not always understood by all parties.

A quantitative assessment of this type is therefore an important pre-requirement for the decision whether to designate lightning protection measures for a building or structure and, if so, to what extent and which ones. In the long term it will thus make a contribution to the acceptance of lightning protection and damage prevention.

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3.2.12 Designing aids

For practical applications, the time-consuming and not always simple application of the procedure for assessing the risk of damage for buildings and structures can be noticeably improved by the use of a PC-aided solution. In "DEHNsupport" the procedures and date from IEC 62305-2 (EN 62305-2) have been converted into a user-friendly software. With "DEHNsupport" the user has a purposeful assistance for designing. The following designing aids are available:

⇒ Risk analysis according to IEC 62305-2 (EN 62305-2)

⇒ Calculation of the separation distance

⇒ Calculation of the length of earth electrodes

⇒ Calculation of the length of air-termination rods

3.3 Inspection and maintenance

3.3.1 Types of inspection and qualification of the inspectors

Other and additional national standards and legal requirements have to be taken into account.

To guarantee that the building or structure, the persons therein, and the electrical and electronic systems have permanent protection, the mechanical and electrical characteristics of a lightning protection system must remain completely intact for the whole of its service life. To ensure this case, a coordinated programme of inspection and maintenance of the lightning protection system shall be laid down by an authority, the designer of the lightning protection system, or the person installing the lightning protection system, and the owner of the building or structure. If faults are found during the inspection of a lightning protection system, the operator / owner of the building or structure is responsible for the immediate removal of the faults. The inspection of the lightning protection system must be carried out by a lightning protection specialist.

A lightning protection specialist is due to his technical training, knowledge and experience, also with regard to the applicable standards, able to design, install and inspect lightning protection systems.

The criteria – technical training, knowledge and experience – usually are met after several years of practical and professional experience and during an occupational activity in the field of lightning protection. The fields designing, installation and inspection require different skills from the lightning protection specialist.

A lightning protection specialist is a competent person who is familiar with the relevant safety equipment regulations, directives and standards to the extent that he is in a position to judge if technical work equipment is in a safe working condition. Competent persons are, for example, after-sales service engineers. A training course leading to recognition as a competent person for lightning and surge protection, as well as for electrical installations conforming to EMC (EMC approved engineer), is offered by the VdS Loss Prevention, which is part of the Joint Association of German Insurers (GDV e.V.), in cooperation with the Committee for Lightning Protection and Lightning Research of the Association of German Electrical Engineers (ABB of the VDE).

Note: A *competent person* is not an *expert*!

An *expert* has *special* knowledge because of his training and experience in the field of technical work equipment which requires testing. He is familiar with the relevant safety equipment regulations, directives and standards to the extent that he is in a position to judge if complex technical work equipment is in a safe working condition. He shall be able to inspect technical work equipment and provide an expert opinion. An expert is a specially trained, officially approved competent person. Persons who are eligible to be experts are, for example, engineers at the German Technical Inspectorate or other specialist engineers. Installations which are subject to monitoring requirements generally have to be inspected by *experts*.

Regardless of the required inspector's qualifications, the inspections shall ensure that the lightning protection system fulfils its protective function of protecting living beings, stock, technical equipment in the building or structure operational technology, safety technology, and the building or structure, against the effects of direct and indirect lightning strikes when combined with any maintenance and service measures which may be necessary. A design report of the lightning protection system containing the design criteria, design description and technical drawings shall therefore

be available to the inspector. The inspections which need to be carried out are distinguished as follows:

Inspection of the design
The inspection of the design shall ensure that all aspects of the lightning protection system with its components correspond to the state of the art in force at the time the designing is undertaken. It must be carried out before the service is provided.

Inspections during the construction phase
Sections of the lightning protection system which will not be accessible when the building work is complete must be inspected as long as this is possible. These include:

⇒ Foundation earth electrodes

⇒ Earth-termination systems

⇒ Reinforcement connections

⇒ Concrete reinforcements used as room shielding

⇒ Down-conductor systems and their connections laid in concrete

The inspection comprises the control of the technical documentation, and on-site inspection and assessment of the work carried out.

Acceptance inspection
The acceptance inspection is carried out when the lightning protection system has been completed. The following must be thoroughly inspected:

⇒ Compliance with the protection plan conforming to the standards (design),

⇒ the work done (technical correctness)

taking into consideration

⇒ the type of use,

⇒ the technical equipment of the building or structure and

⇒ the site conditions.

Repeat inspection
Regular repeat inspections are the precondition for a permanently effective lightning protection system. In Germany they shall be carried out every 2 to 4 years. **Table 3.3.1.1** contains recommendations for the intervals between the full inspections of a lightning protection system under average environmental conditions. If official instructions or regulations with inspection deadlines are in force, these deadlines have to be considered as minimum requirements. If official instructions prescribe that the electrical installation in the building or structure must be regularly inspected, then the functioning of the internal lightning protection measures shall be inspected as part of this inspection.

Visual inspection
Lightning protection systems Type I or II in buildings and structures, and critical sections of lightning protection systems (e.g. in cases where there is considerable influence from aggressive environmental conditions) have to undergo a visual inspection between repeat inspections (**Table 3.3.1.1**).

Additional inspection
In addition to the repeat inspections, a lightning protection system must be inspected if

⇒ fundamental changes in use,

⇒ modifications to the building or structure,

Type of LPS	Visual inspection (Year)	Complete inspection (Year)	Complete inspection of critical systems (Year)
I and II	1	2	1
III and IV	2	4	1
Note: In buildings or structures with hazard of explosion a visual inspection of the lightning protection system should be carried out every 6 months. Once in a year the electrical installations should be tested. A deviation from these yearly inspection plan is accepted if it makes sense to carry out the tests in intervals of 14 to 15 months in order to measure the conductivity of the ground at different times of the year in order to get knowledge of seasonal changes.			

Table 3.3.1.1 Longest interval between inspections of the LPS acc. to IEC 62305-3, Table E.2

⇒ restorations,

⇒ extensions or

⇒ repairs

on a protected building or structure have been carried out.

These inspections shall also be carried out when it is known that a lightning has struck the lightning protection system.

3.3.2 Inspection measures

The inspection comprises the control of the technical documentation, on-site inspection and measurement.

Control of the technical documentation

The technical documentation must be inspected to ensure it is

⇒ complete and

⇒ in accordance with the standards.

On-site inspection

The on-site inspection shall examine whether

⇒ the complete system corresponds to the technical documentation,

⇒ the complete system of external and internal lightning protection is in an acceptable condition,

⇒ there are any loose connections and interruptions in the lines of the lightning protection system,

⇒ all earthing connections (if visible) are in order,

⇒ all lines and system components are correctly secured, and units with a mechanical protective function are in working order,

⇒ modifications requiring additional protective measures have been made at the protected building or structure,

⇒ the surge protective devices installed in power supply systems and information systems are correctly installed,

⇒ there is any damage, or whether there are any disconnected surge protective devices,

⇒ upstream overcurrent protection devices of surge protective devices have tripped,

⇒ in the case of new supply connections or extensions which have been installed in the interior of the building or structure since the last inspection, the lightning equipotential bonding was carried out,

⇒ equipotential bonding connections within the building or structure are in place and intact,

⇒ the measures required for proximities of the lightning protection system to installations have been carried out.

Note: For existing earth-termination systems which are more than 10 years old, the condition and quality of the earth conductor line and its connections can only be assessed by exposing it at certain points.

Measurements

Measurements are used to inspect the conductivity of the connections and the condition of the earth-termination system.

⇒ **Conductivity of the connections**
Measurements must be made to examine whether all the conductors and connections of air-termination systems, down-conductor systems, equipotential bonding lines, shielding measures etc. have a low-impedance conductivity. The recommended value is < 1 Ω.

⇒ **Condition of the earth-termination system**
The contact resistance to the earth-termination system at all measuring points must be measured to establish the conductivity of the lines and connections (recommended value < 1 Ω).
Further, the conductivity with respect to the metal installations (e.g. gas, water, ventilation, heating), the total earthing resistance of the lightning protection system, and the earthing resistance of individual earth electrodes and partial ring earth electrodes must be measured.

The results of the measurements must be compared with the results of earlier measurements. If they deviate considerably from the earlier measurements, additional examinations must be performed.

3.3.3 Documentation

A report must be compiled for each inspection. This must be kept together with the technical documentation and reports of previous inspections at the installation/system operator´s premises or at the offices of the relevant authority.

The following technical documentation must be available to the inspector when, for example, he carries out his assessment of the lightning protection system:

⇒ Design criteria

⇒ Design descriptions

⇒ Technical drawings of the external and internal lightning protection

⇒ Reports of previous services and inspections

An inspection report shall contain the following information:

⇒ **General**

a) Owner, address

b) Installer of the lightning protection system, address

c) Year of construction

⇒ **Information about the building or structure**

a) Location

b) Use

c) Type of construction

d) Type of roofing

e) Lightning protection level (LPL)

⇒ **Information about the lightning protection system**

a) Material and cross section of the lines

b) Number of down conductors, e.g. inspection joints (designation corresponding to the information in the drawing)

c) Type of earth-termination system (e.g. ring earth electrode, earth rod, foundation earth electrode)

d) Design of the lightning equipotential bonding to metal installations, to electrical installations and to existing equipotential busbars

⇒ **Inspection fundamentals**

a) Description and drawings of the lightning protection system

b) Lightning protection standards and provisions at the time of the installation

c) Further inspection fundamentals (e.g. regulations, instructions) at the time of the installation

⇒ **Type of inspection**

a) Inspection of the design

b) Inspections during the construction phase

c) Acceptance inspection

d) Repeat inspection

e) Additional inspection

f) Visual inspection

⇒ **Result of the inspection**

a) Any modifications to the building or structure and / or the lightning protection system determined

b) Deviations from the standards, regulations, instructions and application guidelines applicable at the time of the installation

c) Defects determined

d) Earthing resistance or loop resistance at the individual inspection joints, with information about the measuring method and the type of measuring device

e) Total earthing resistance (measurement with or without protective conductor and metal building installation)

⇒ **Inspector**

a) Name of inspector

b) Inspector´s company / organisation

c) Name of person accompanying

d) Number of pages in inspection report

e) Date of inspection

f) Signature of the inspector´s company / organisation

3.3.4 Maintenance

The maintenance and inspection of lightning protection systems must be coordinated.
In addition to the inspections, regular maintenance routines should therefore also be established for all lightning protection systems. How frequently the maintenance work is carried out depends on the following factors:

⇒ Loss of quality related to weathering and the ambient conditions

⇒ Effects of direct lightning strikes and possible damage arising therefrom

⇒ Class of lightning protection system required for the building or structure under consideration

The maintenance measures should be determined individually for each lightning protection system and become an integral part of the complete maintenance programme for the building or structure.

A maintenance routine should be drawn up. This allows a comparison to be made between results recorded now, and those from an earlier service. These values can also be used for comparison with a subsequent inspection.

The following measures should be included in a maintenance routine:

⇒ Inspection of all conductors and components of the lightning protection system

⇒ Measuring of the electrical conductivity of installations of the lightning protection system

⇒ Measuring of the earthing resistance of the earth-termination system

⇒ Visual inspection of all surge protective devices (relates to surge protective devices on the lines of the power supply and information system entering the building or structure) to determine if there has been any damage or if any disconnections are present

⇒ Refastening of components and conductors

⇒ Inspection to ascertain that the effectiveness of the lightning protection system is unchanged after installation of additional fixed equipment or modifications to the building or structure

Complete records should be made of all maintenance work. They should contain modification measures which have been, or are to be, carried out.

These records serve as an aid when assessing the components and installation of the lightning protection system. They can be used to examine and update a maintenance routine. The maintenance records should be kept together with the design and the inspection reports of the lightning protection system.