UTM UNIVERSITI TEKNOLOGI MALAYSIA

LPS Design

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1. Introduction to LPS

1.1 Protection Measures

Protection Measures to

- **reduce injury of living beings by electric shock**
  - Possible protection measures include:
    - **Adequate insulation of exposed conductive parts**
    - Equipotentialization by means of a meshed earthing system
    - **Physical restrictions and warning notices**
    - Lightning equipotential bonding (EB)

Protection Measures to

- **to reduce physical damage**
  - Protection is achieved by the **LPS** which includes the following **features**:
  - **Air-termination system**
  - Down-conductor system
  - **Earth-termination system**
  - Lightning equipotential bonding (EB)
  - **Electrical insulation (and hence separation distance) against the external LPS**

Protection Measures to

- **reduce failure of electrical and electronic systems**
  - Possible system protection measures (SPM) include
    - **Earthing and bonding measures**
    - Magnetic shielding
    - **Line routing**
    - Isolating surfaces
    - **Coordinated SPD system**

Protection Measures Selection

- The listed protection measures together form the **overall LP**
- Selection of the **most suitable protection measures** shall be made by the **designer** of the protection measures and the **owner** of the structure to be protected according to the **type and amount of each kind of damage**, the **technical and economic aspects** of the different protection measures and the **results of risk assessment**

1.2 Basic Criteria for Protection of Structures

General

- An **ideal** protection for structures would be to **enclose the structure** to be protected **within an earthed and perfectly conducting continuous shield** of **adequate thickness**, and to provide **adequate bonding** at the entrance point into the shield, of the lines connected to the structure.
- This would prevent the **penetration of lightning current and related electromagnetic field** into the structure to be protected and **prevent dangerous thermal and electrodynamic effects** of **current** as well as **dangerous sparkings and overvoltages for internal systems**.
- It is neither possible nor cost effective.
- Lack of **continuity of the shield** and/or its inadequate **thickness** allows the lightning current to penetrate the shield causing:
  - Physical damage and life hazard
  - Failure of internal systems

Lightning Protection Levels (LPL) and LPS Class

- Protection measures adopted to reduce such damages and relevant consequential loss, are designed for the defined set of lightning current parameters against which protection is required(LPL)
- **Four LP levels (I to IV)** are introduced. **Four classes** of LPS (I, II, III and IV) are defined as **a set of construction rules**, based on the corresponding LPL.
- **Each set includes level-dependent** (e.g. rolling sphere radius, mesh width etc.) and **level-independent** (e.g. cross-sections, materials etc.) construction rules.
- For **each LPL**, a set of **maximum** and **minimum** lightning current parameters is fixed.
- The **minimum** values of lightning current amplitude for the different LPL are <u>**used to derive the rolling sphere radius**</u> in order <u>**to define the lightning protection zone LPZ 0B which cannot be reached by direct strike**</u> (see Fig. 3).

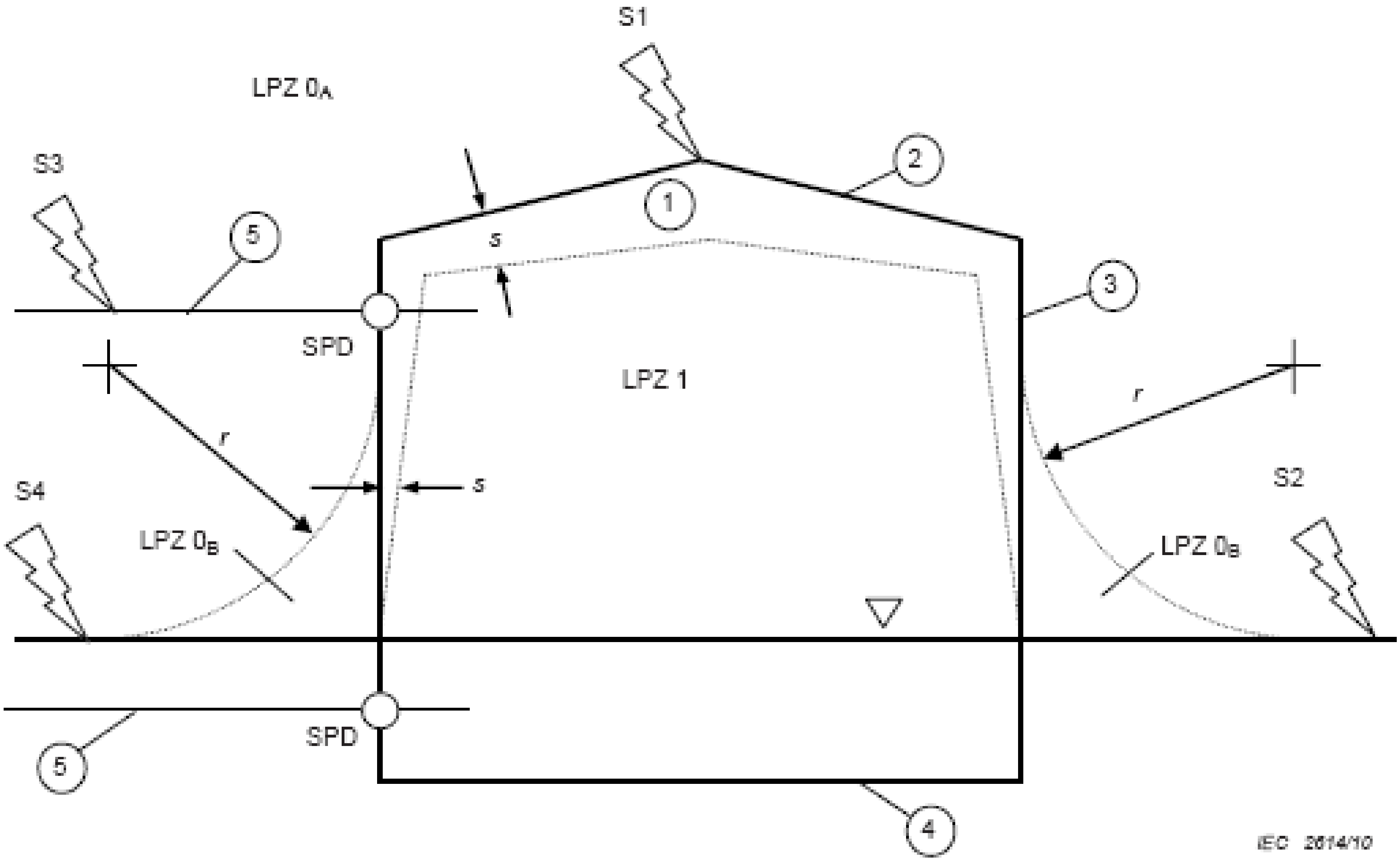


Figure 3 – LPZ defined by an LPS (IEC 62305-3)

Key

1	structure	S1	flash to the structure
2	air-termination system	S2	flash near to the structure
3	down-conductor system	S3	flash to a line connected to the structure
4	earth-termination system	S4	flash near a line connected to the structure
5	incoming lines	*r*	rolling sphere radius
		s	separation distance against dangerous sparking

▽ ground level

○ lightning equipotential bonding by means of SPD

LPZ 0_A	direct flash, full lightning current
LPZ 0_B	no direct flash, partial lightning or induced current
LPZ 1	no direct flash, limited lightning or induced current
	protected volume inside LPZ 1 must respect separation distance *s*

Minimum peak current values according to LPL

Current parameters	LPL			
	I	II	III	IV
Mninimum peak current, *I* (kA)	3	5	10	16
Rolling sphere radius, *r* (m)	20	30	45	60

Maximum current values according to LPL

Current parameters	LPL			
	I	II	III	IV
First positive impulse peak current (kA)	200	150	100	100
First negative impulse peak current (kA)	100	75	50	na

Lightning Protection Zones (LPZ)

- **Protection measures** such as **LPS, shielding wires, magnetic shields and SPD determine the lightning protection zones (LPZ).**
- **LPZ downstream** of the protection measure are characterized by significant reduction of LEMP than that upstream of the LPZ.
- With respect to the threat of lightning, the following **LPZs are defined**

LPZ 0_A	zone where the threat is due to the direct lightning flash and the full lightning electromagnetic field. The internal systems may be subjected to full or partial lightning surge current;

LPZ 0_B	zone protected against direct lightning flashes but where the threat is the full lightning electromagnetic field. The internal systems may be subjected to partial lightning surge currents;

LPZ 1	zone where the surge current is limited by current sharing and by isolating interfaces and/or SPDs at the boundary. Spatial shielding may attenuate the lightning electromagnetic field;

LPZ 2, ..., n	zone where the surge current may be further limited by current sharing and by isolating interfaces and/or additional SPDs at the boundary. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

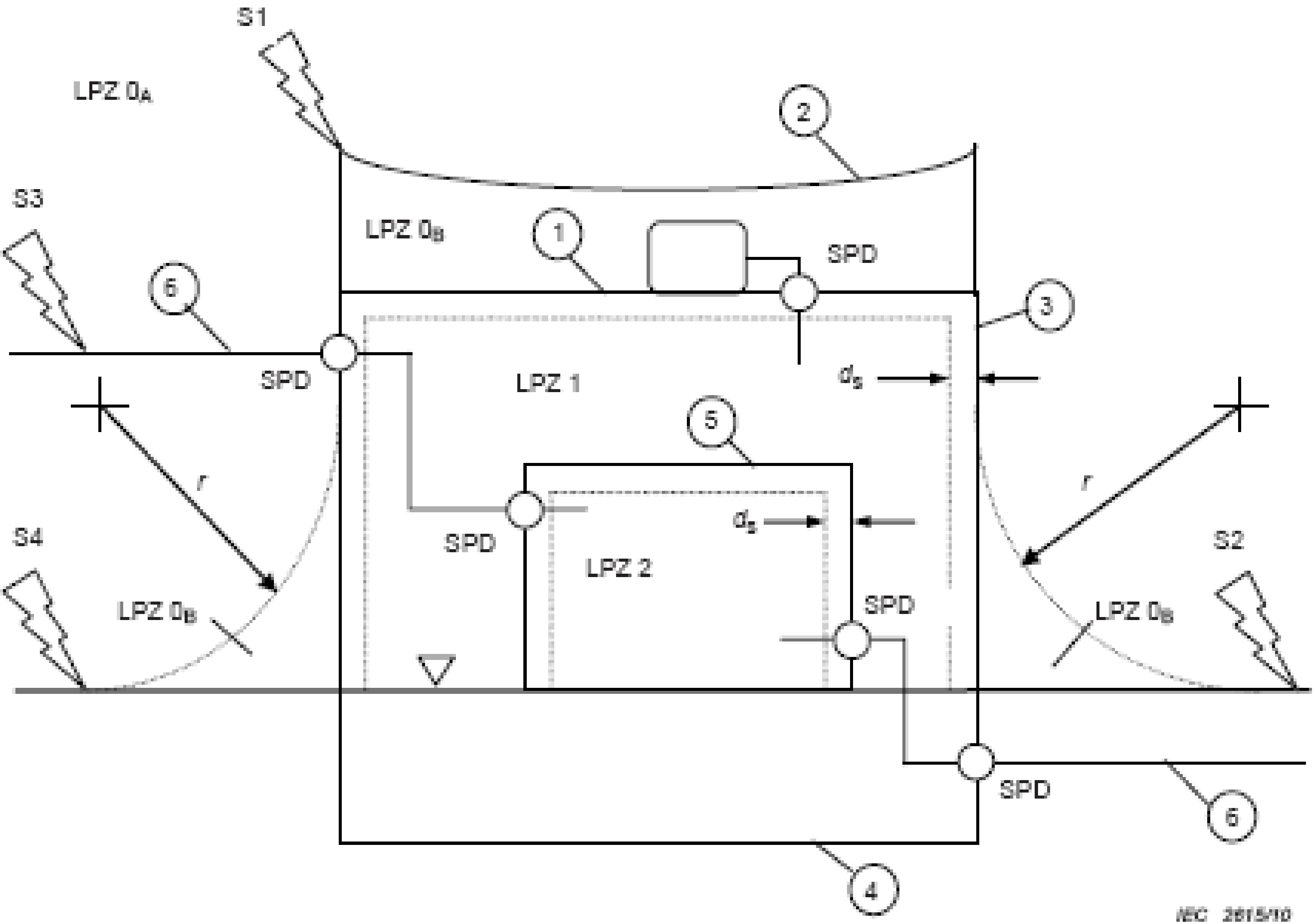


Figure 4 – LPZ defined by an SPM (IEC 62305-4)

Key

1	structure (shield of LPZ 1)	S1	flash to the structure
2	air-termination system	S2	flash near to the structure
3	down-conductor system	S3	flash to a line connected to the structure
4	earth-termination system	S4	flash near a line connected to the structure
5	room (shield of LPZ 2)	r	rolling sphere radius
6	lines connected to the structure	d_s	safety distance against too high magnetic field

▽ ground level

○ lightning equipotential bonding by means of SPD

LPZ 0_A	direct flash, full lightning current, full magnetic field
LPZ 0_B	no direct flash, partial lightning or induced current, full magnetic field
LPZ 1	no direct flash, limited lightning or induced current, damped magnetic field
LPZ 2	no direct flash, induced currents, further damped magnetic field
	protected volumes inside LPZ 1 and LPZ 2 must respect safety distances d_s

Electrical and Electronic System Protection Measures (SPM)

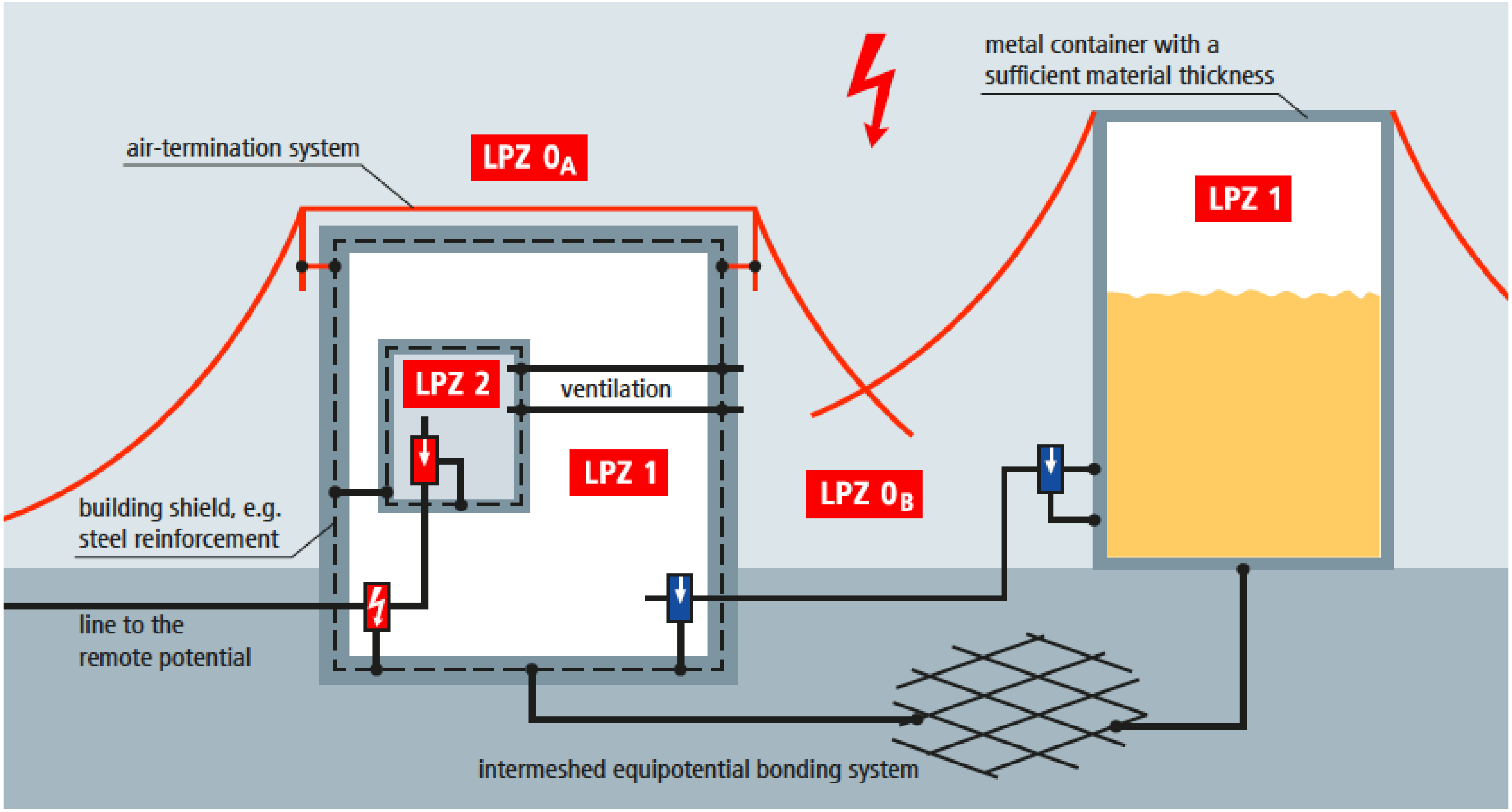
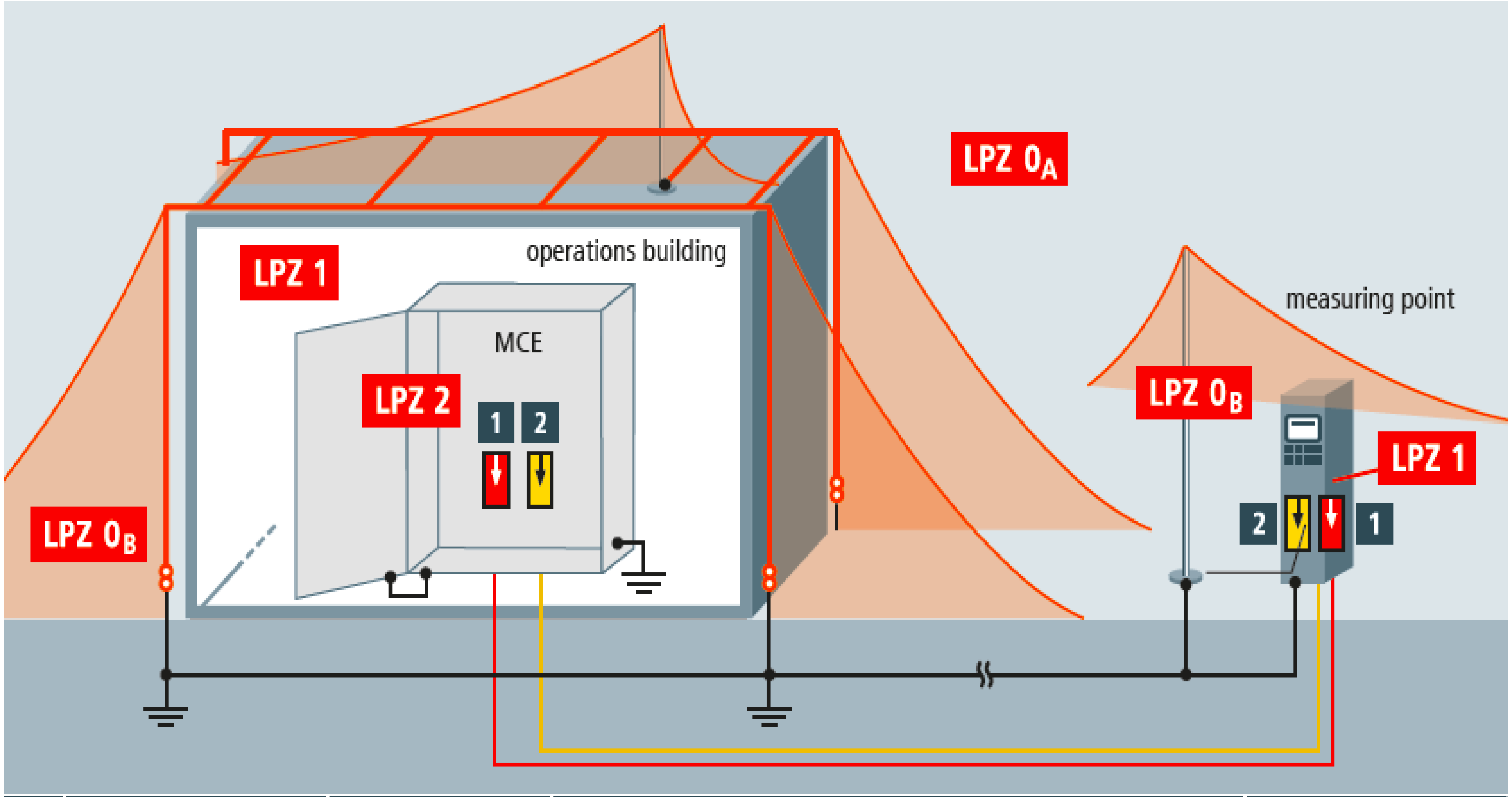
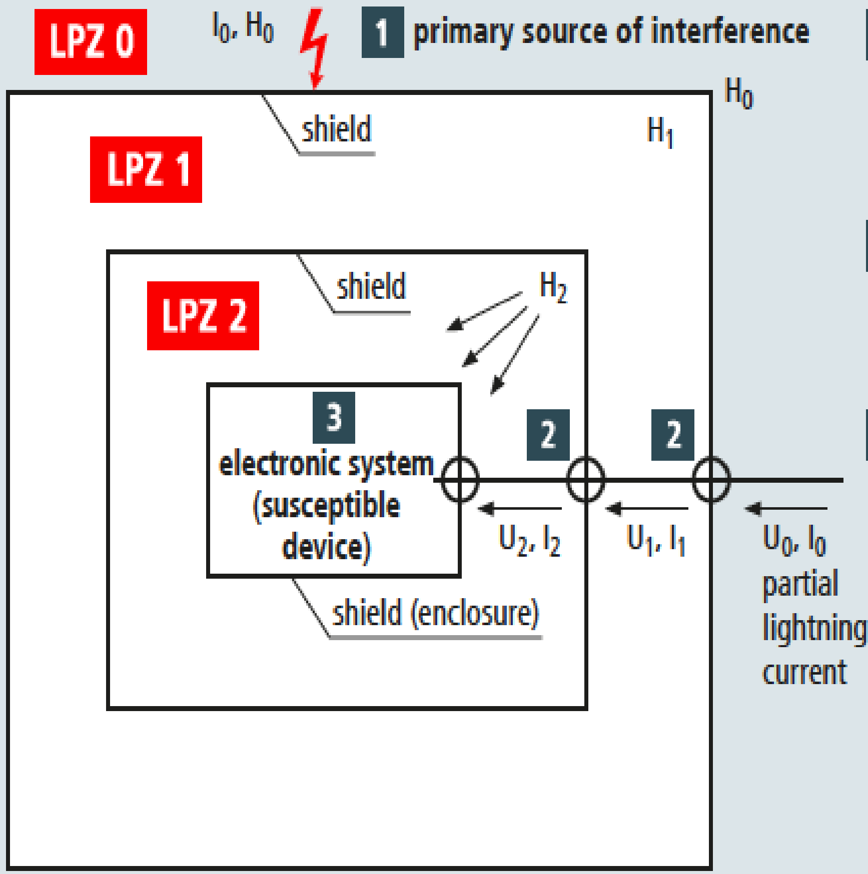


Figure 9.32.1 Basic division of an installation into lightning protection zones (LPZs)



	Protection for...		Type	Part No.
1	Power supply system	TN system	DEHNguard DG M TN 275 DEHNguard DG M TN 275 FM	952 200 952 205
		TT system	DEHNguard DG M TT 2P 275 or DEHNguard DG M TT 2P 275 FM	952 110 952 115
2	Oxygen measurement device	e.g. 4 to 20 mA	BLITZDUCTOR BXT ML4 BE S 24 + BXT BAS base part or BLITZDUCTOR BXT ML2 BE 24 + BXT BAS base part	920 224 + 920 300 920 324 + 920 300

Figure 9.4.2 Division of the operations building into lightning protection zones; example: selection of surge protective devices for the oxygen measurement device



1 Primary source of interference defined according to the lightning protection level chosen by means of:

IEC 62305-1 (EN 62305-1):
I_0 and H_0: 10/350 µs, 1/200 µs and 0.25/100 µs impulse

2 Power supply installation with an immunity defined by IEC 60604-1: Overvoltage categories I to IV; telecommunication installation with an immunity defined by the ITU-T recommendations K.20:2008, K.21:2003 and K.45:2003.

3 Electronic system (susceptible device) defined by the immunity to conducted (U, I) and radiated (H) lightning effects:

IEC 61000-4-5: U: 1.2/50 µs impulse, I: 8/20 µs impulse

IEC 61000-4-9: H: 8/20 µs impulse, (attenuated wave 25 kHz), T_p = 10 µs

IEC 61000-4-10: H: 0.2/5 µs impulse, (attenuated wave 1 MHz), T_p = 0.25 µs

Figure 7.7.2.1 Lightning protection system with spatial shielding and coordinated surge protection according to Figure A.1 of IEC 62305-4 (EN 62305-4)

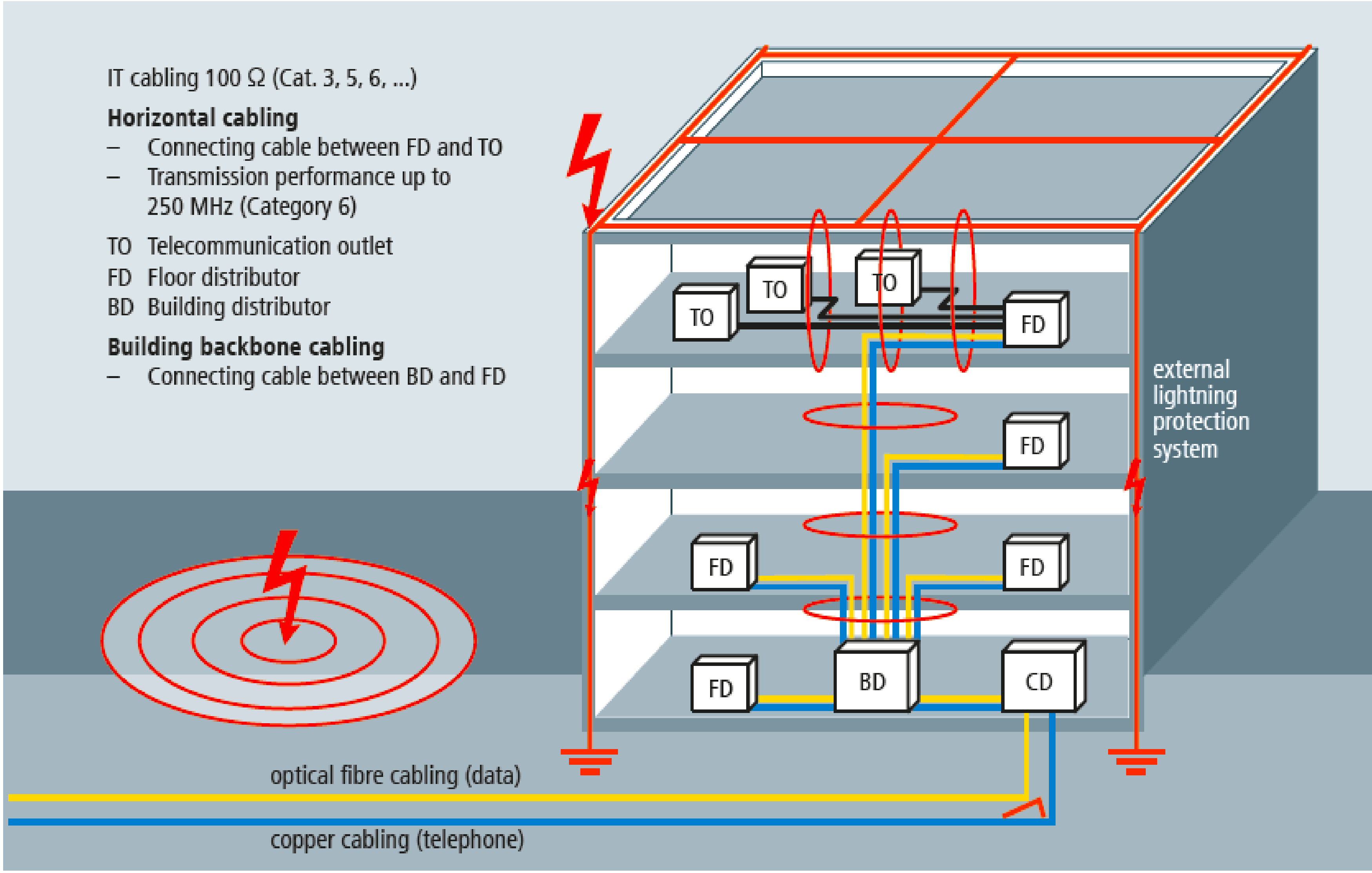


Figure 8.2.3.2 Lightning interference on the IT cabling

Basic Criteria for Protection of Structures

- As a general rule for protection, **the structure to be protected shall be in an LPZ whose electromagnetic characteristics are compatible with the capability of the structure to withstand stress** causing the damage to be reduced (physical damage, failure of electrical and electronic systems due to overvoltages)

Protection of Structures

Protection to reduce physical damage and life hazard

- The structure to be protected shall be inside an LPZ 0B or higher. This is achieved by means of a LPS.
- An LPS consists of both external and internal LPSs.
- The functions of the external LPS are
  - To intercept a lightning flash to the structure (with **an air-termination system**)
  - To conduct the lightning current safely to earth (with **down-conductor system**)
  - To disperse it into the earth (with **an earth-termination system**)
- The function of the internal LPS is to prevent dangerous sparking within the structure, using **equipotential bonding** or **a separation distance**, s, (and hence electrical isolation) between the LPS components and other electrically conducting elements internal to the structure

- Where **surface resistivity of the soil outside** and **of the floor inside** the structure is **kept low**, **life hazard due to touch and step voltages** is **reduced**:
  - Outside the structure, by **insulation of the exposed conductive parts**, by **equipotentialization of the soil** by means of a **meshed earthing** system, by **warning notices** and by **physical restrictions**
  - Inside the structure, by **equipotential bonding of lines at entrance point** into the structure

Protection to reduce failure of internal systems

- The protection against LEMP to reduce the risk of failure of internal systems shall **limit**
  - **Surges due to lightning flashes to the structure** resulting from **resistive and inductive coupling**
  - Surges due to lightning flashes **near** the structure resulting from **inductive coupling**
  - Surges **transmitted by lines near the structure** due to flashes to or near the lines
  - **Magnetic field directly coupling with apparatus**
- The system to be protected shall be located inside **an LPZ 1 or higher**.
- This is achieved by means of **electrical and electronic system protection measures (SPM)** consisting of **magnetic shields** attenuating **the inducing magnetic field** and/or suitable **routing of wiring to reduce the induction loop.**
- **Bonding** shall be provided at the boundaries of an LPZ for metal parts and systems crossing the boundaries.
- This bonding can be accomplished by means of **bonding conductors** or, when necessary, by **surge protective devices (SPDs).**

- Effective protection against overvoltages, causing failures of internal systems, may also be achieved by means of **isolating interfaces and/or a coordinated SPD system**, limiting overvoltages below the **rated impulse withstand voltage** of the system to be protected.

- **Isolating interfaces and SPD** shall be selected and installed according to the requirements of **IEC 62305-4** (Protection against lightning-part 4: Electrical and electronic systems within structures)

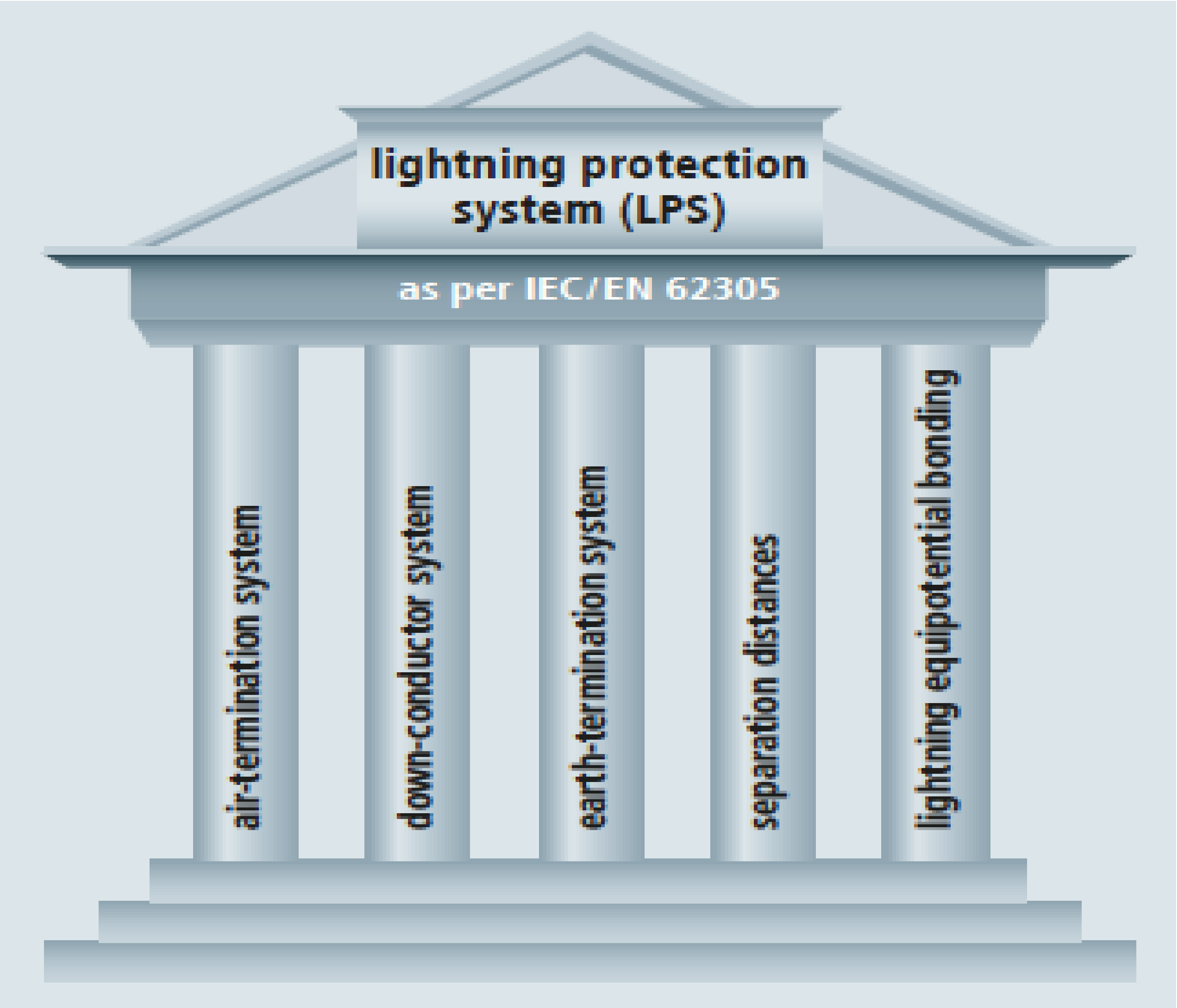


Figure 4.1 Components of a lightning protection system

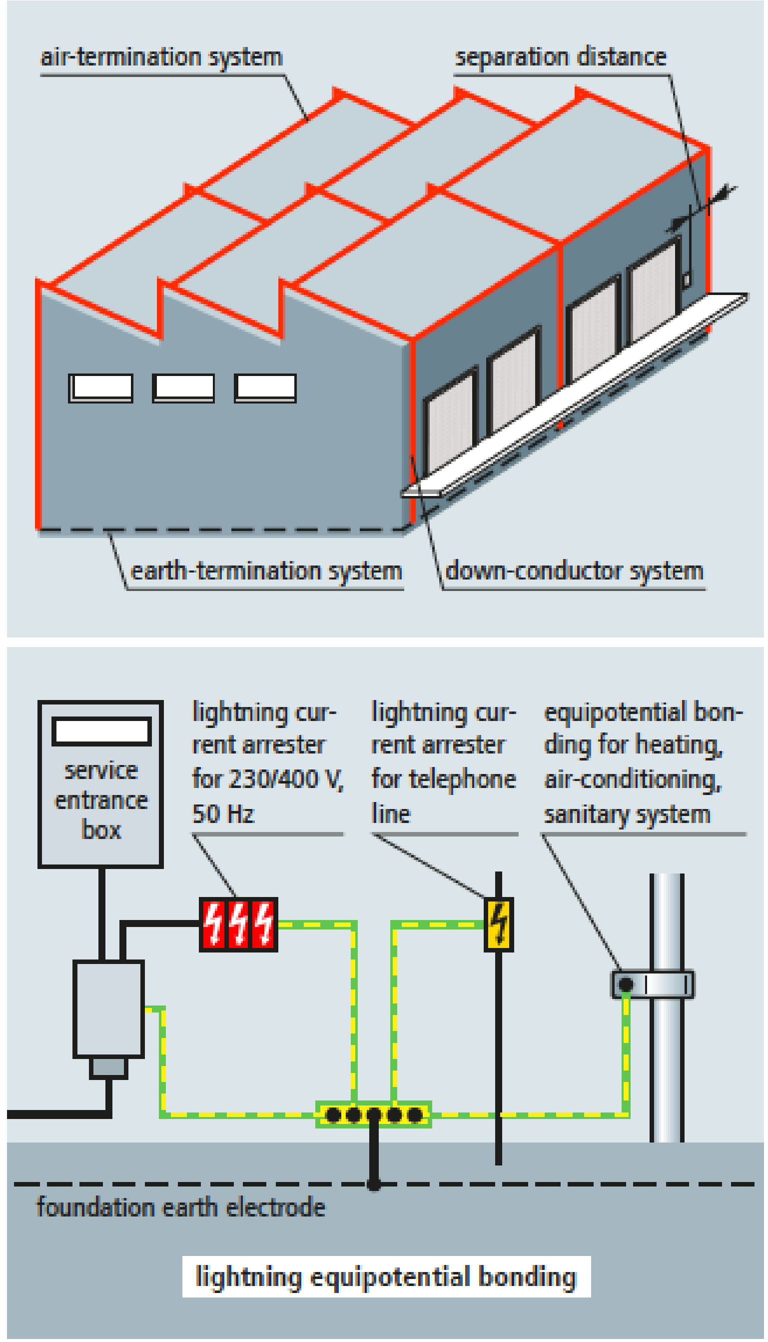


Figure 4.2 Lightning protection system (LPS)

1.3 LPS Design

- Lets see what are the requirements for protection of a structure against physical damage by means of a LPS, and for protection against injury to living beings due to **touch and step voltages** in the vicinity of an LPS

- In IEC 62305-3, we aim to cover the
  - Design, installation, inspection and maintenance of an LPS for structures without limitation of their height
  - Establishment of measures for protection against injury to living beings due to touch and step voltages.

- Each class of LPS is characterized by the following:

  a) Data dependent upon the class of LPS

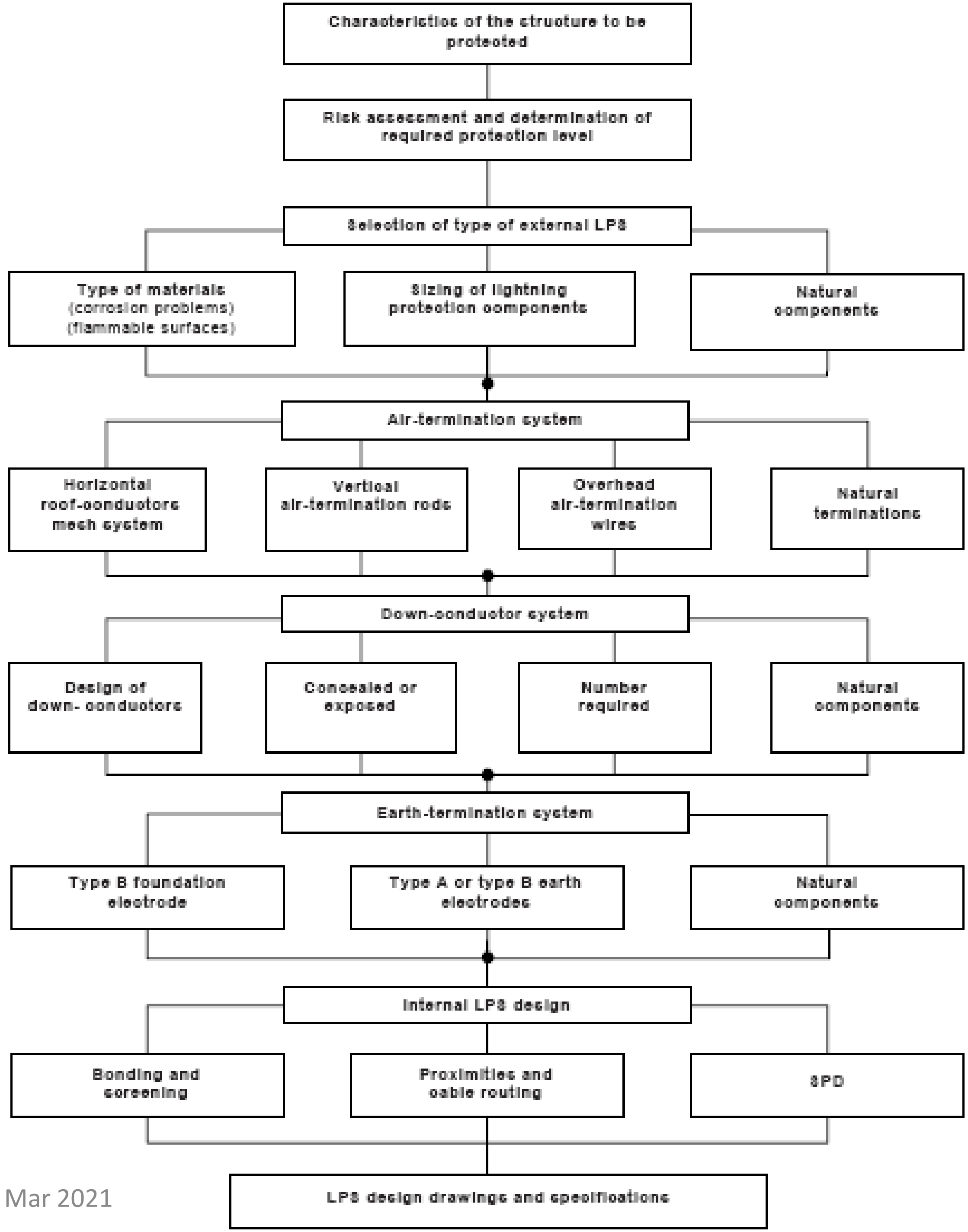
    - **Lightning parameters**
    - **Rolling sphere radius**, **mesh size** and **protection angle**
    - Typical preferred **distances between down-conductors**
    - **Separation distance** against dangerous sparking
    - **Minimum length of earth electrodes**

b) Factors not dependent upon the class of LPS

- lightning **equipotential bonding**
- **Minimum thickness of metal sheets** or metal pipes in air-termination systems
- **LPS materials** and conditions of use
- **Material, configuration and minimum dimensions** for **air-terminations, down-conductors and earth-terminations**
- Minimum dimensions of **connecting conductors**

The management of the LPS should be efficient if the steps in Fig. E1 are followed.

LPS design flow diagram



1.4 External LPS

Introduction

- The external LPS is intended to **intercept** direct lightning flashes to the structure, including flashes to the side of the structure, and **conduct** the lightning current from the point of strike to ground.
- The external LPS is also intended to disperse this current into the earth **without** causing thermal or mechanical **damage**, or dangerous sparking which may trigger fire or explosions.
- In most cases, the external LPS may be **attached** to the structure.
- An **isolated** external LPS should be considered when the thermal and explosive effects at the point of strike, or on the conductors carrying the lightning current, may cause damage to the structure or to the contents.
- Also when the contents warrants the reduction of the radiated EMF

Design of External LPS

- The **positioning of external LPS** is fundamental to the design of the LPS and depends on the shape of the structure to be protected, the level of protection required and the geometric design method employed.
- The **air-termination system design** generally **dictates** the design of the down-conductor system, the earth-termination system and the design of the internal LPS.
- If **adjoining buildings have an LPS**, those LPS, where permissible, should be connected to the LPS of the building under consideration.

Non-isolated LPS

- In most cases, the external LPS may be attached to the structure to be protected.
- Thermal effects – spacing should be at least 0.1m.

Isolated LPS

- An isolated external LPS should be used when the **flow of the lightning into bonded internal conductive parts** may cause damage to the structure or its contents.
- An isolated LPS is achieved either by installing **air-termination rods** or **masts adjacent to the structure** to be protected or by **suspending overhead wires** between the masts in accordance to the separation distance

Dangerous sparking

- Dangerous sparking **between an LPS** and **metal, electrical and telecommunication installations** can be avoided
  - By **separation distance** for isolated LPS
  - By **EB for non-isolated** LPS

2. Air Termination Systems and Design

2.1 Air-termination systems

- The probability of **structure penetration** by a lightning current is considerably decreased by the presence of a properly designed air-termination system
- Air-termination systems can be composed of any combination of the following elements:
  - **Rods (including free-standing masts**
  - **Catenary wires**
  - **Meshed conductors**
- The individual air-termination rods should be connected together at roof level to ensure current division
- Radioactive air terminals are not allowed

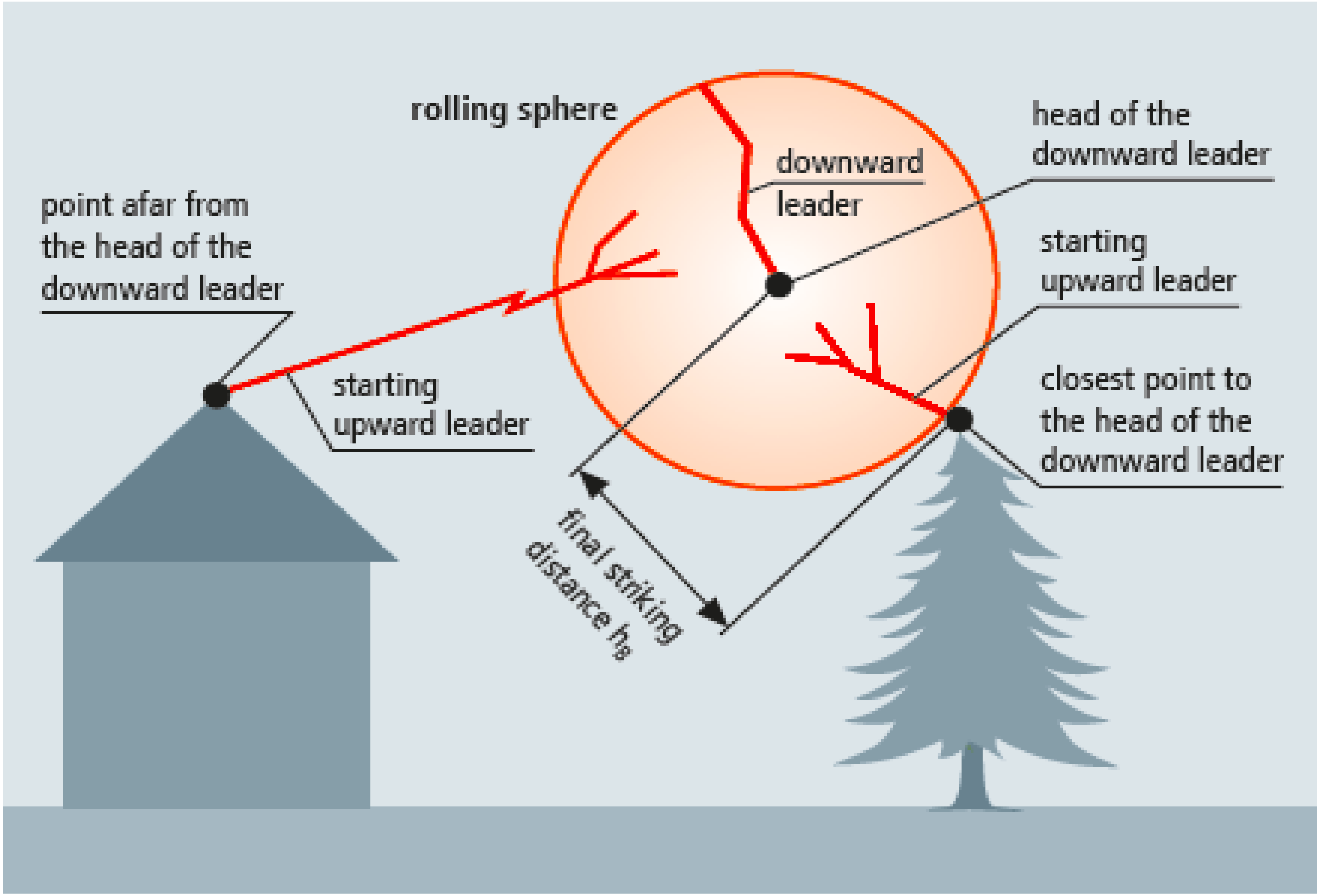


Figure 5.1.1.1 Starting upward leader defining the point of strike

Lightning protection level LPL	Probabilities for the limits of the lightning current parameters		Radius of the rolling sphere (final striking distance h_B) r in m	Minimum peak value of current I in kA
	> minimum values	< maximum values		
IV	0.84	0.95	60	16
III	0.91	0.95	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

Table 5.1.1.1 Relation between lightning protection level, interception probability, final striking distance h_B and minimum peak value of current I; source: Table 5 of IEC 62305-1 (EN 62305-1)

Class of LPS	Protection method			Typical down conductor spacing [m]
	Rolling sphere radius r [m]	Protective angle α	Mesh size w [m]	
I	20		5 x 5	10
II	30		10 x 10	10
III	45		15 x 15	15
IV	60		20 x 20	20

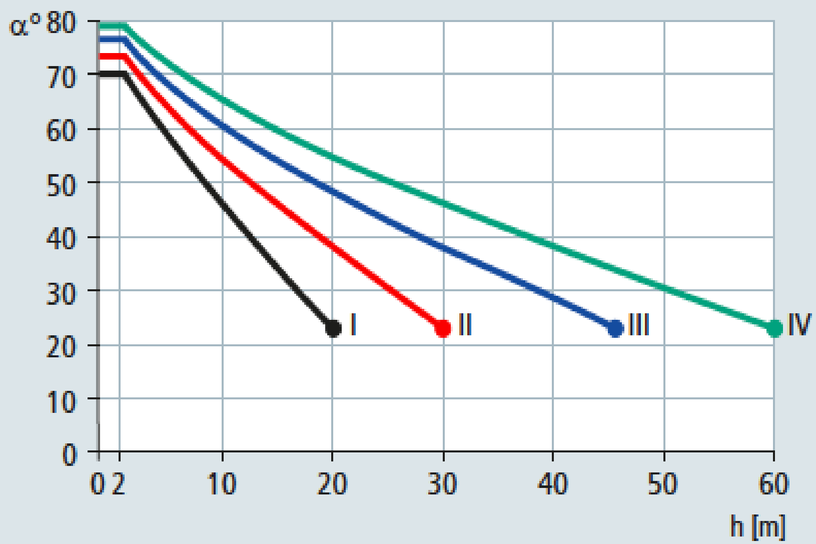
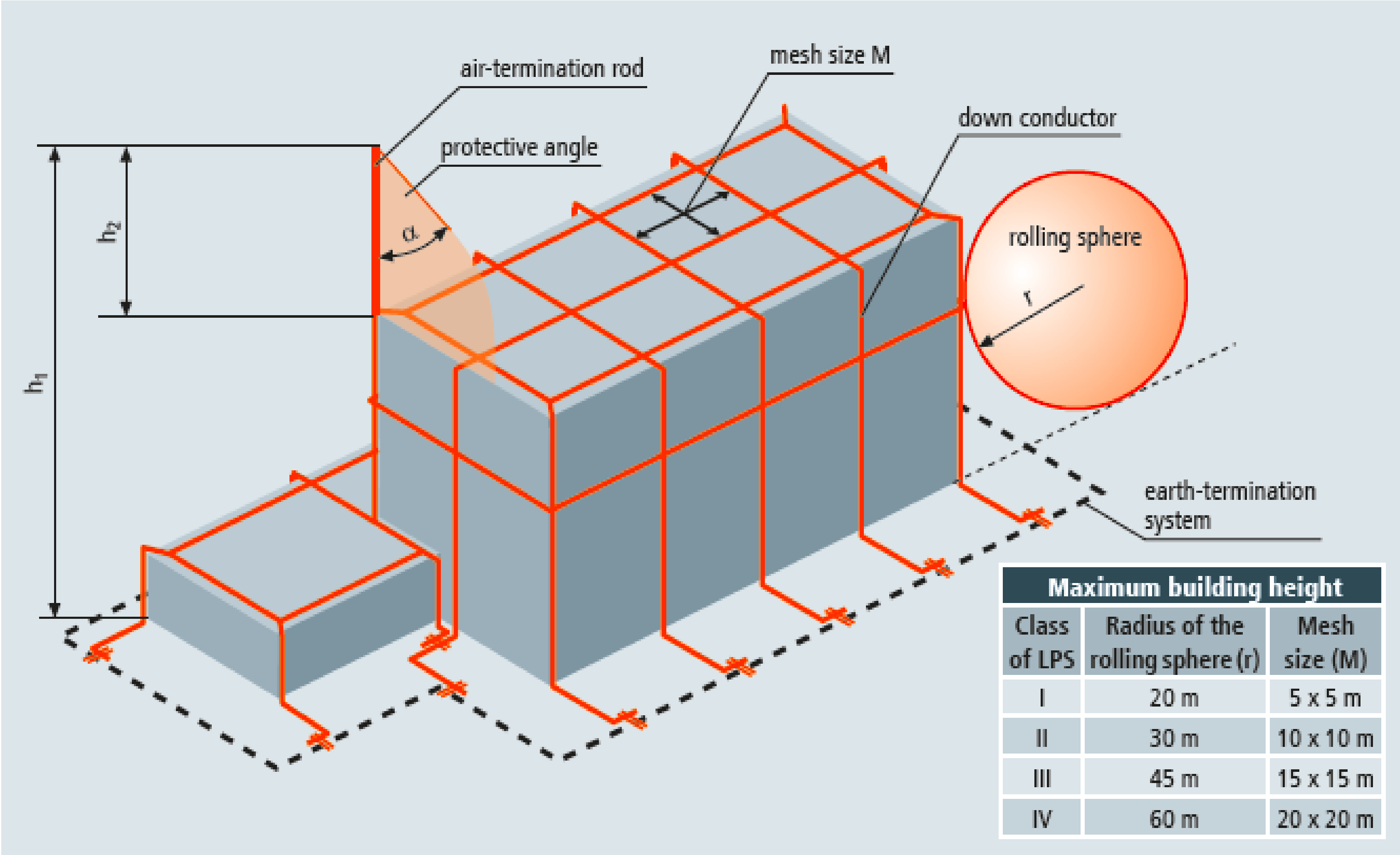


Table 9.32.1 Arrangement of air-termination systems according to the class of LPS



Maximum building height		
Class of LPS	Radius of the rolling sphere (r)	Mesh size (M)
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m

Figure 5.1.1 Method of designing air-termination systems for high buildings

2.2 Air Termination Positioning

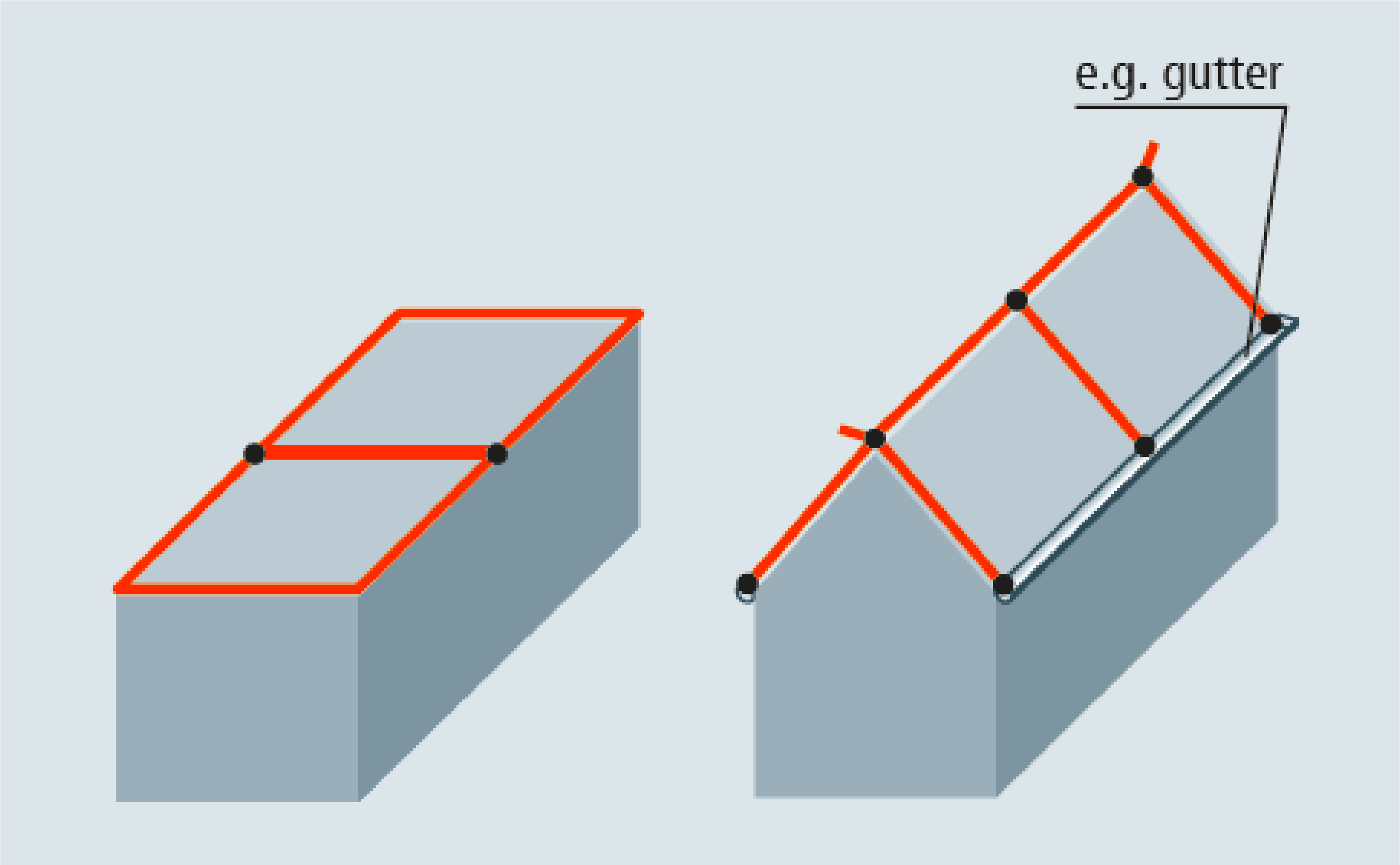
- Air-termination components installed on a structure shall be located at **corners**, **exposed points and edges** (especially on the upper level of any facades) in accordance with one or more of the following methods
    - The **protection angle** method
    - The **rolling sphere** method
    - The **mesh** method

  The rolling sphere method is suitable in all cases
- The **protection angle method** is suitable for **simple-shaped** buildings but it is subject to **limits** of air-termination **height** indicated in Table 2.

- The **mesh** method is a suitable form of protection where **plane** surfaces are to be protected

- The values for the protection angle, rolling sphere radius and mesh size for each class of LPS are given in Table 2 and Fig. 1.

Class of LPS	Mesh size
I	5 x 5 m
II	10 x 10 m
III	15 x 15 m
IV	20 x 20 m


e.g. gutter

Protection angle method

- The position of the air-termination system is considered to be adequate if the structure to be protected is fully situated within the protected volume provided by the air- termination system.

- The volume protected by a vertical rod is assumed to have the shape of a right circular **cone** with the vertex placed on the air-termination axis, semi-apex angle α, depending on the class of LPS and on the height of the air-termination system as given in Table 2.

  – Examples:

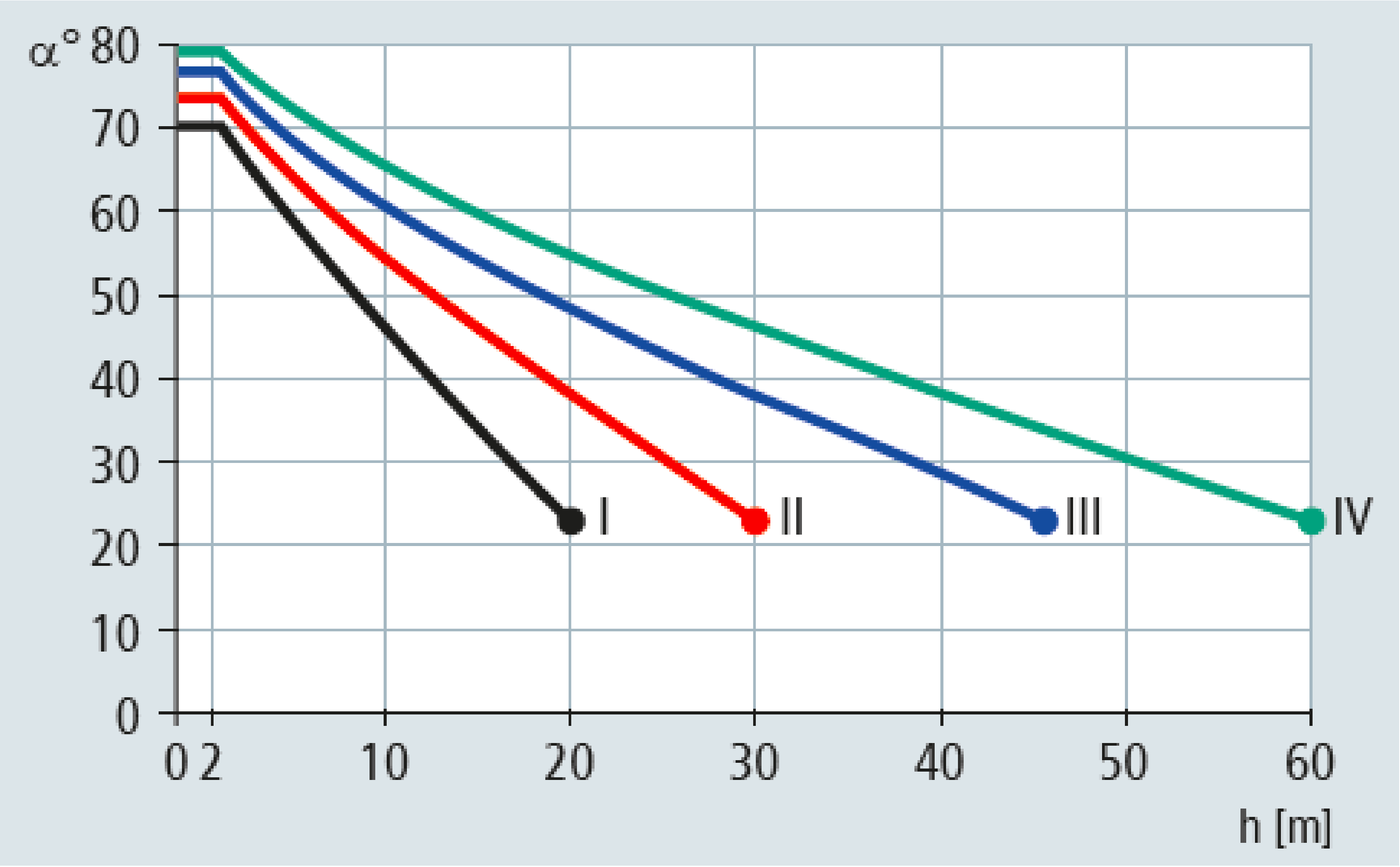


Figure 5.1.1.12 Protective angle α as a function of height h depending on the class of LPS

Height of the air-termination rod h in m	Class of LPS I		Class of LPS II		Class of LPS III		Class of LPS IV	
	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m
1	71	2.90	74	3.49	77	4.33	79	5.14
2	71	5.81	74	6.97	77	8.66	79	10.29
3	66	6.74	71	8.71	74	10.46	76	12.03
4	62	7.52	68	9.90	72	12.31	74	13.95
5	59	8.32	65	10.72	70	13.74	72	15.39
6	56	8.90	62	11.28	68	14.85	71	17.43
7	53	9.29	60	12.12	66	15.72	69	18.24
8	50	9.53	58	12.80	64	16.40	68	19.80
9	48	10.00	56	13.34	62	16.93	66	20.21
10	45	10.00	54	13.76	61	18.04	65	21.45
11	43	10.26	52	14.08	59	18.31	64	22.55
12	40	10.07	50	14.30	58	19.20	62	22.57
13	38	10.16	49	14.95	57	20.02	61	23.45
14	36	10.17	47	15.01	55	19.99	60	24.25
15	34	10.12	45	15.00	54	20.65	59	24.96
16	32	10.00	44	15.45	53	21.23	58	25.61
17	30	9.81	42	15.31	51	20.99	57	26.18
18	27	9.17	40	15.10	50	21.45	56	26.69
19	25	8.86	39	15.39	49	21.86	55	27.13
20	23	8.49	37	15.07	48	22.21	54	27.53
21			36	15.26	47	22.52	53	27.87
22			35	15.40	46	22.78	52	28.16
23			36	16.71	47	24.66	53	30.52
24			32	15.00	44	23.18	50	28.60
25			30	14.43	43	23.31	49	28.76
26			29	14.41	41	22.60	49	29.91
27			27	13.76	40	22.66	48	29.99
28			26	13.66	39	22.67	47	30.03
29			25	13.52	38	22.66	46	30.03
30			23	12.73	37	22.61	45	30.00
31					36	22.52	44	29.94
32					35	22.41	44	30.90
33					35	23.11	43	30.77
34					34	22.93	42	30.61
35					33	22.73	41	30.43
36					32	22.50	40	30.21
37					31	22.23	40	31.50
38					30	21.94	39	30.77
39					29	21.62	38	30.47
40					28	21.27	37	30.14
41					27	20.89	37	30.90
42					26	20.48	36	30.51
43					25	20.05	35	30.11
44					24	19.59	35	30.81
45					23	19.10	34	30.35
46							33	29.87
47							32	29.37
48							32	29.99
49							31	29.44
50							30	28.87
51							30	29.44
52							29	28.82
53							28	28.18
54							27	27.51
55							27	28.02
56							26	27.31
57							25	26.58
58							25	27.05
59							24	26.27
60							23	25.47

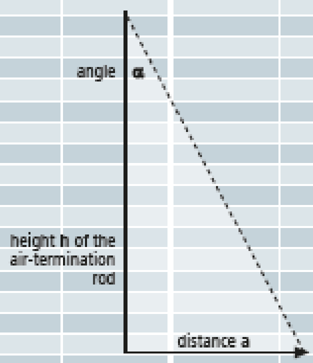


Table 5.1.1.4 Protective angle α depending on the class of LPS

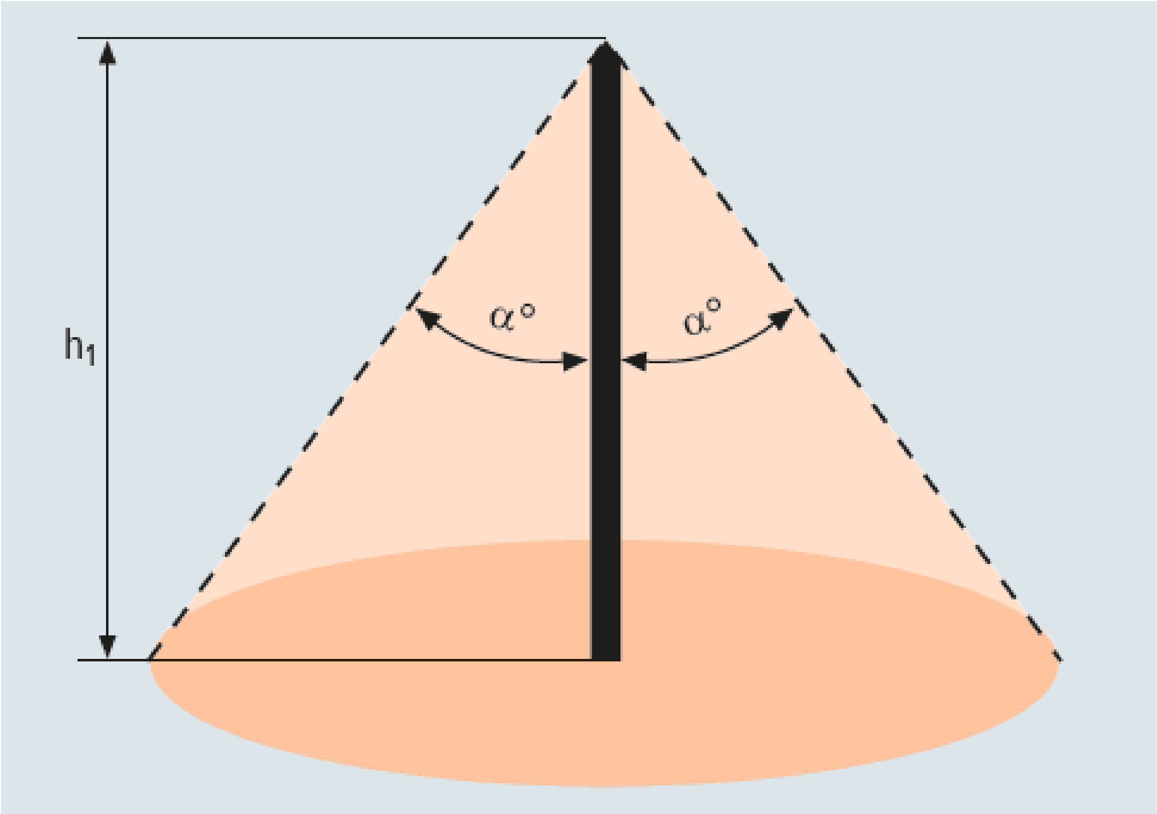
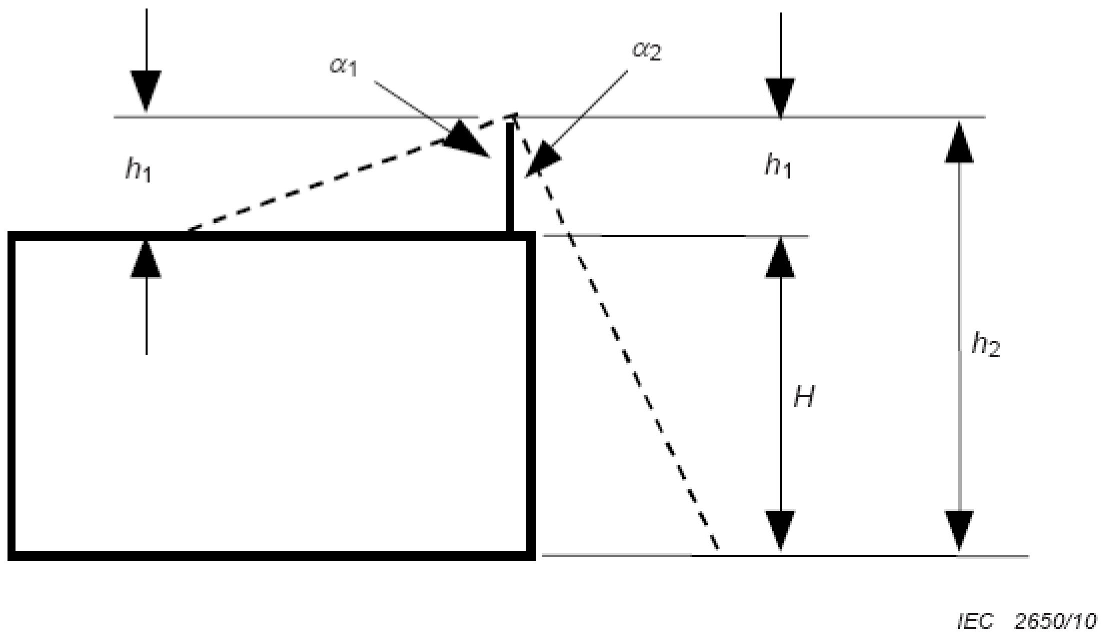


Figure 5.1.1.13 Cone-shaped protected volume

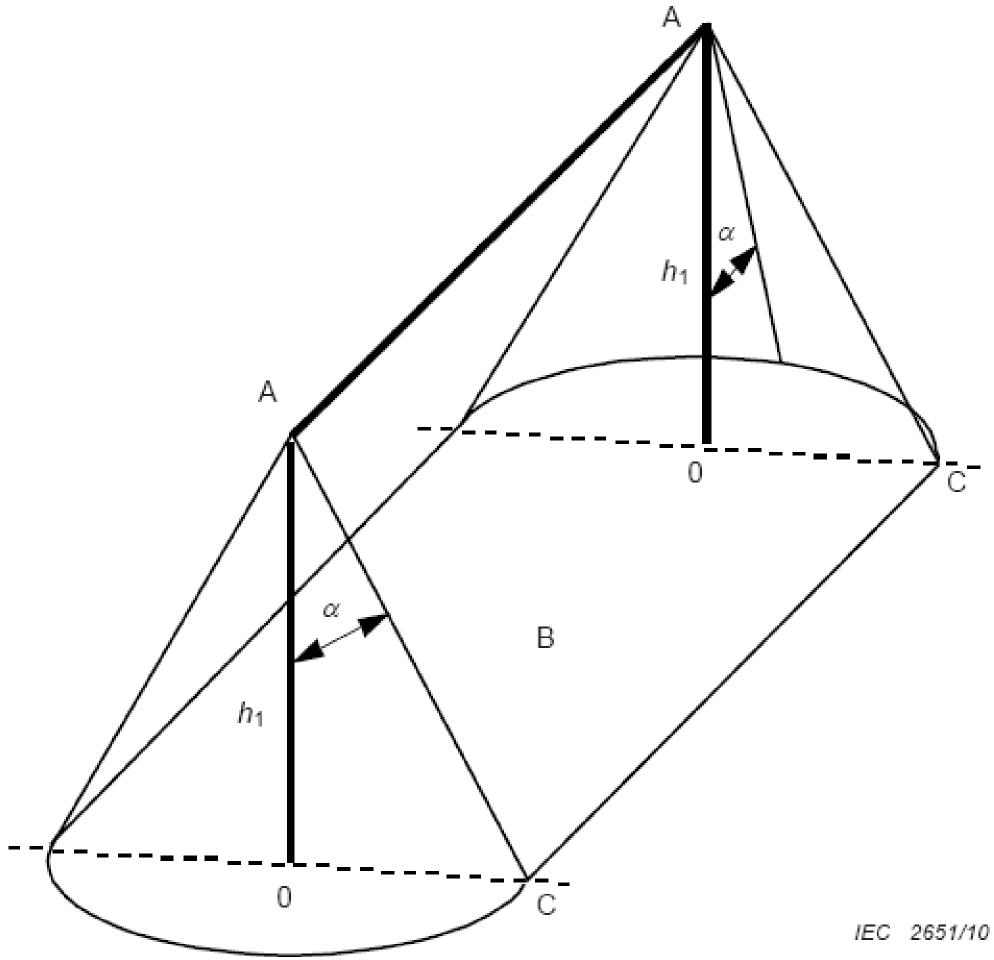


Key

h_1 physical height of an air-termination rod

NOTE The protection angle α_1 corresponds to the air-termination height h_1, being the height above the roof surface to be protected; the protection angle α_2 corresponds to the height $h_2 = h_1 + H$ the ground being the reference plane; α_1 is related to h_1 and α_2 is related to h_2.

Figure A.2 – Volume protected by a vertical air-termination rod



NOTE See Figure A.1 for key.

Figure A.3 – Volume protected by a wire air-termination system

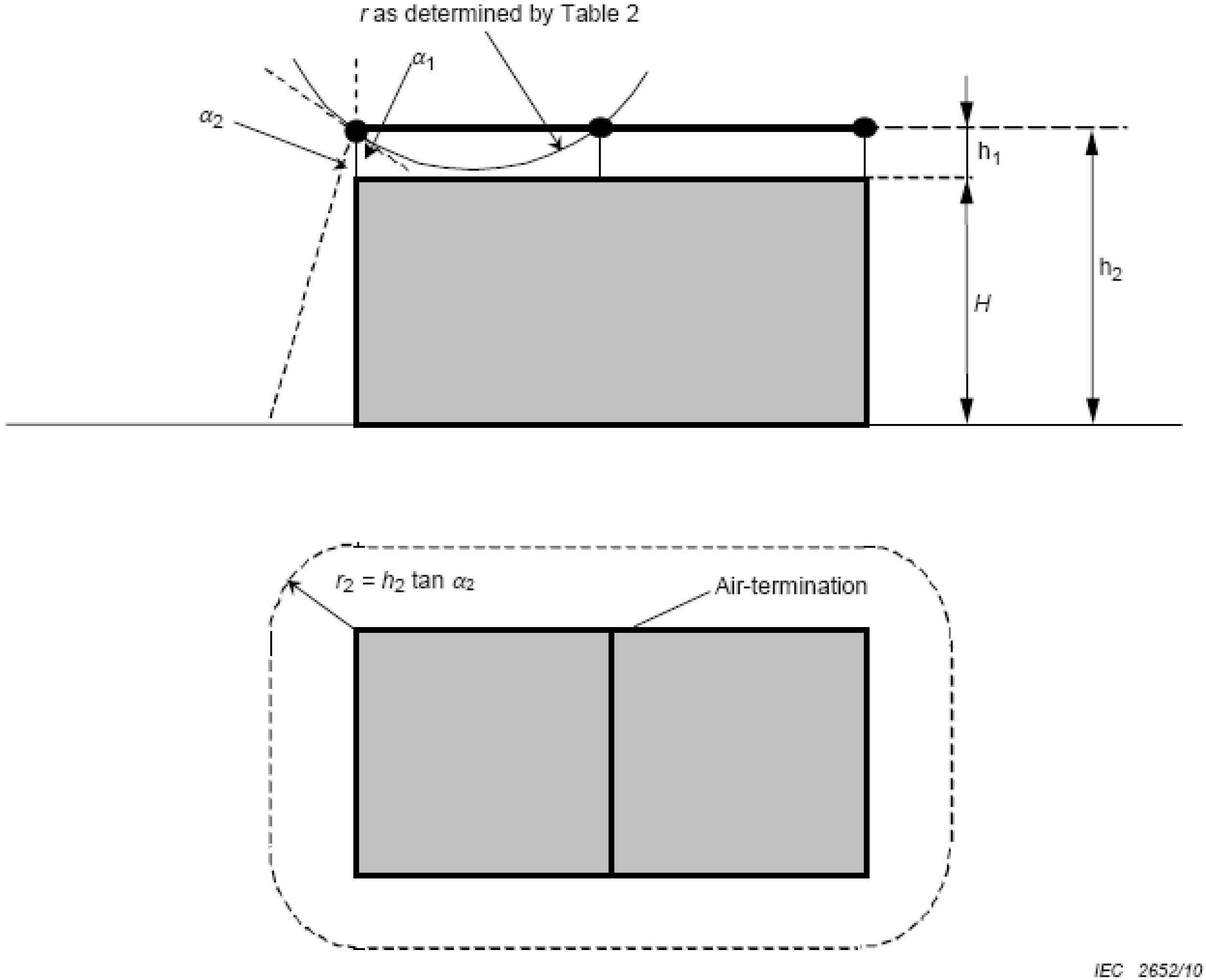


Figure A.4 – Volume protected by isolated wires combined in a mesh according to the protection angle method and rolling sphere method

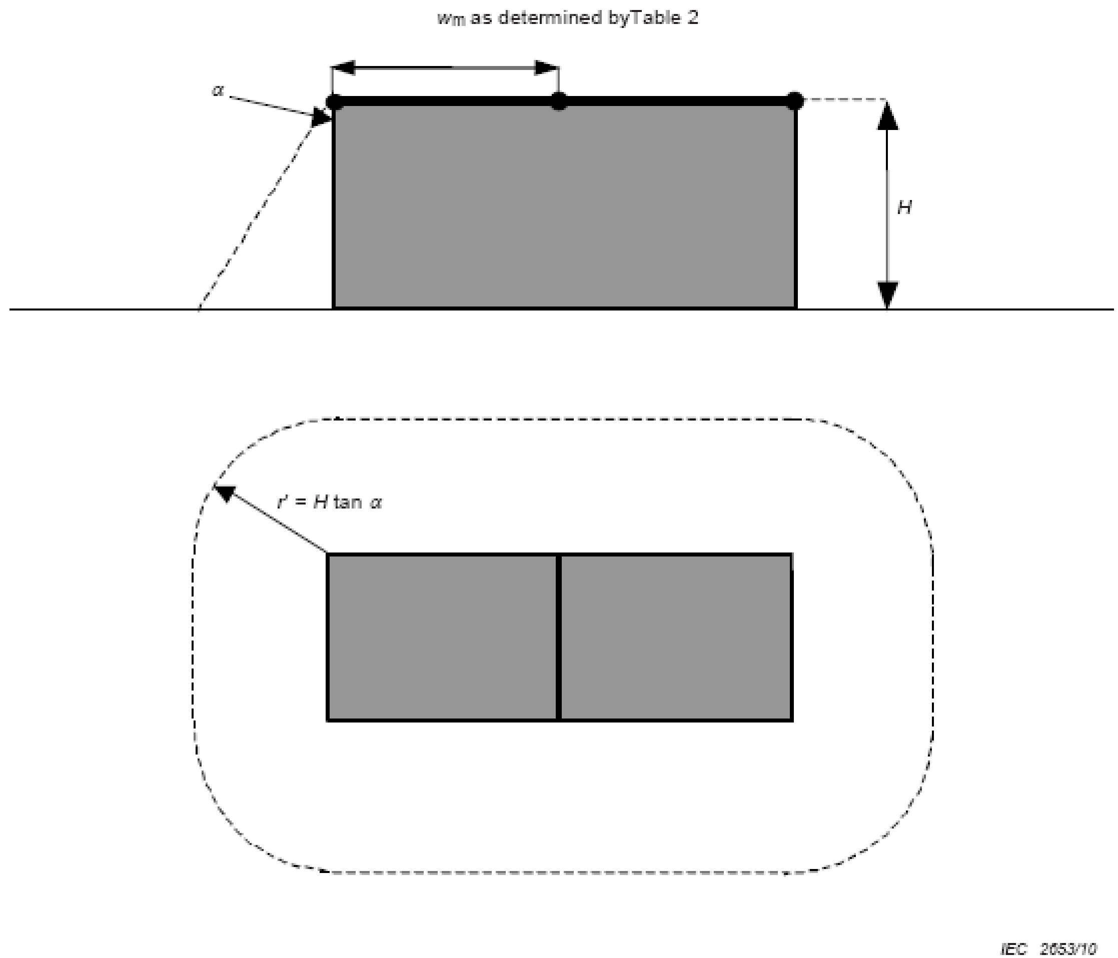
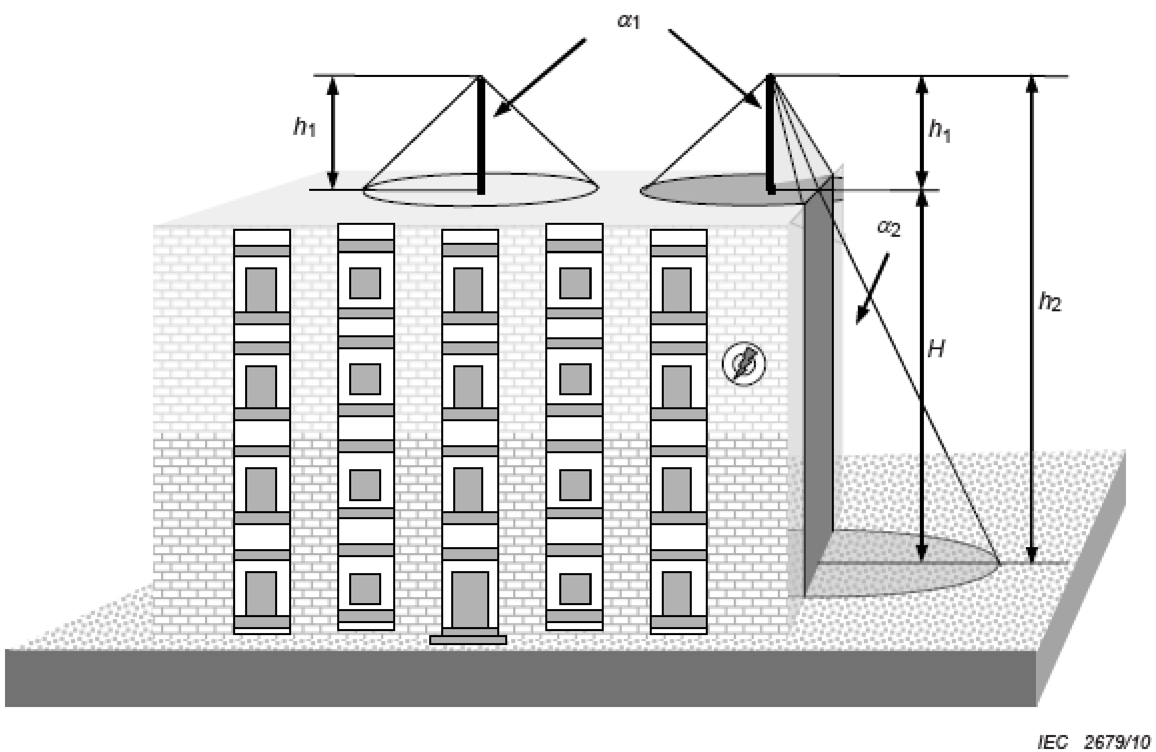


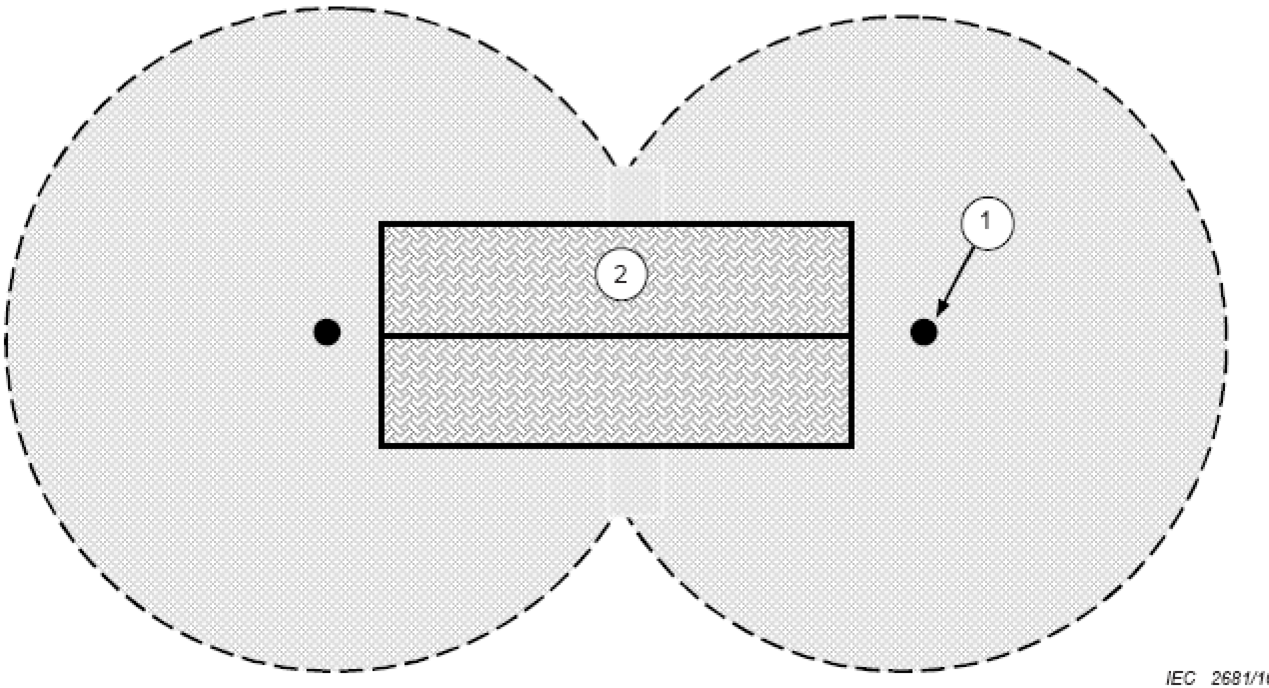
Figure A.5 – Volume protected by non-isolated wires combined in a mesh according to the mesh method and the protection angle method



Key

H	height of the building over the ground reference plane
h_1	physical height of an air-termination rod
h_2	$h_1 + H$, being the height of the air-termination rod over the ground
α_1	the protection angle corresponding to the air-termination height $h = h_1$, being the height above the roof surface to be measured (reference plane)
α_2	the protection angle corresponds to the height h_2

Figure E.12 – Protection angle method air-termination design for different heights according to Table 2



NOTE The two circles denote the protected area on the ground as the reference plane.

Figure E.13b – Projection on the horizontal reference plane

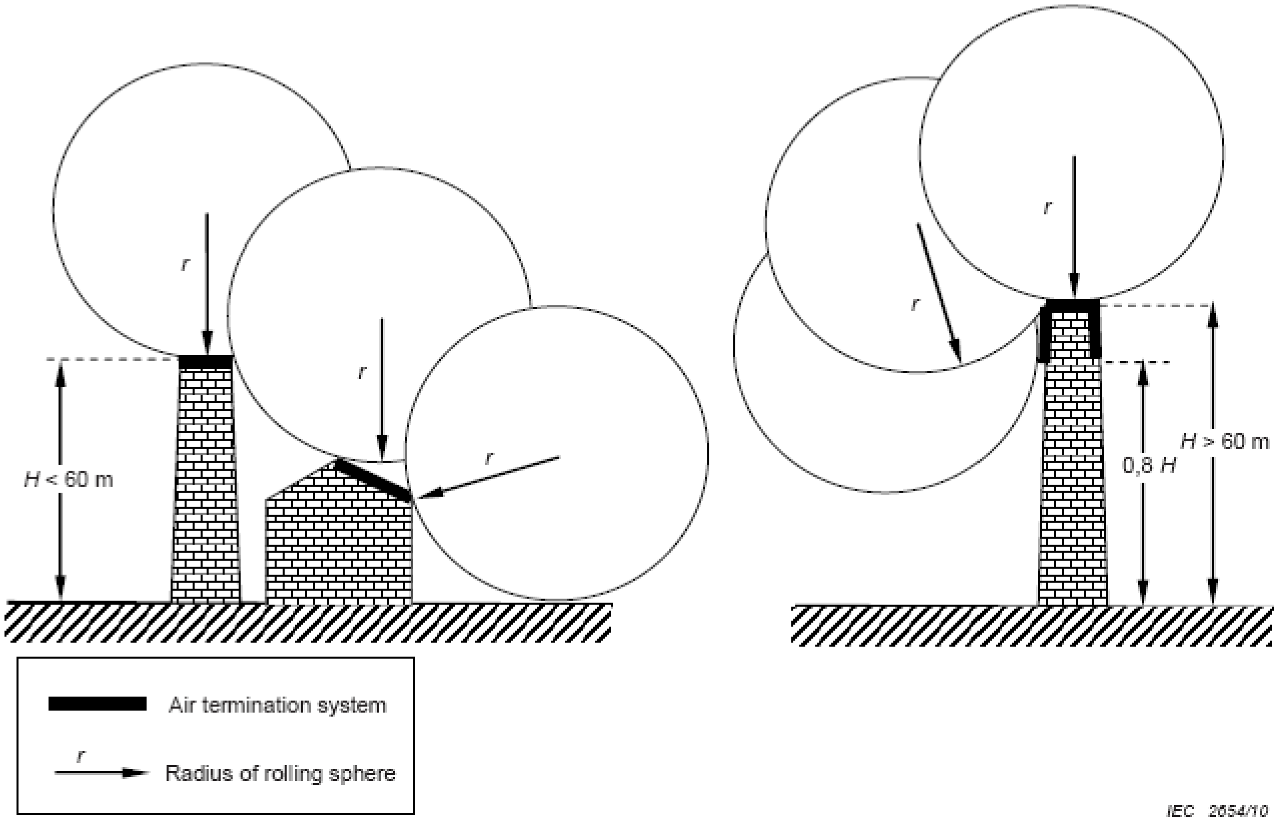
Figure E.13 – Isolated external LPS using two isolated air-termination masts designed according to the protection angle air-termination design method

The rolling sphere method

- Applying this method, the positioning of the air-termination system is adequate if **no point of the structure to be protected** comes into contact with **a sphere with radius, r,** depending on the class of LPS, **rolling around and on top of the structure in all possible directions**.
- In this way, the sphere only touches the air-termination system

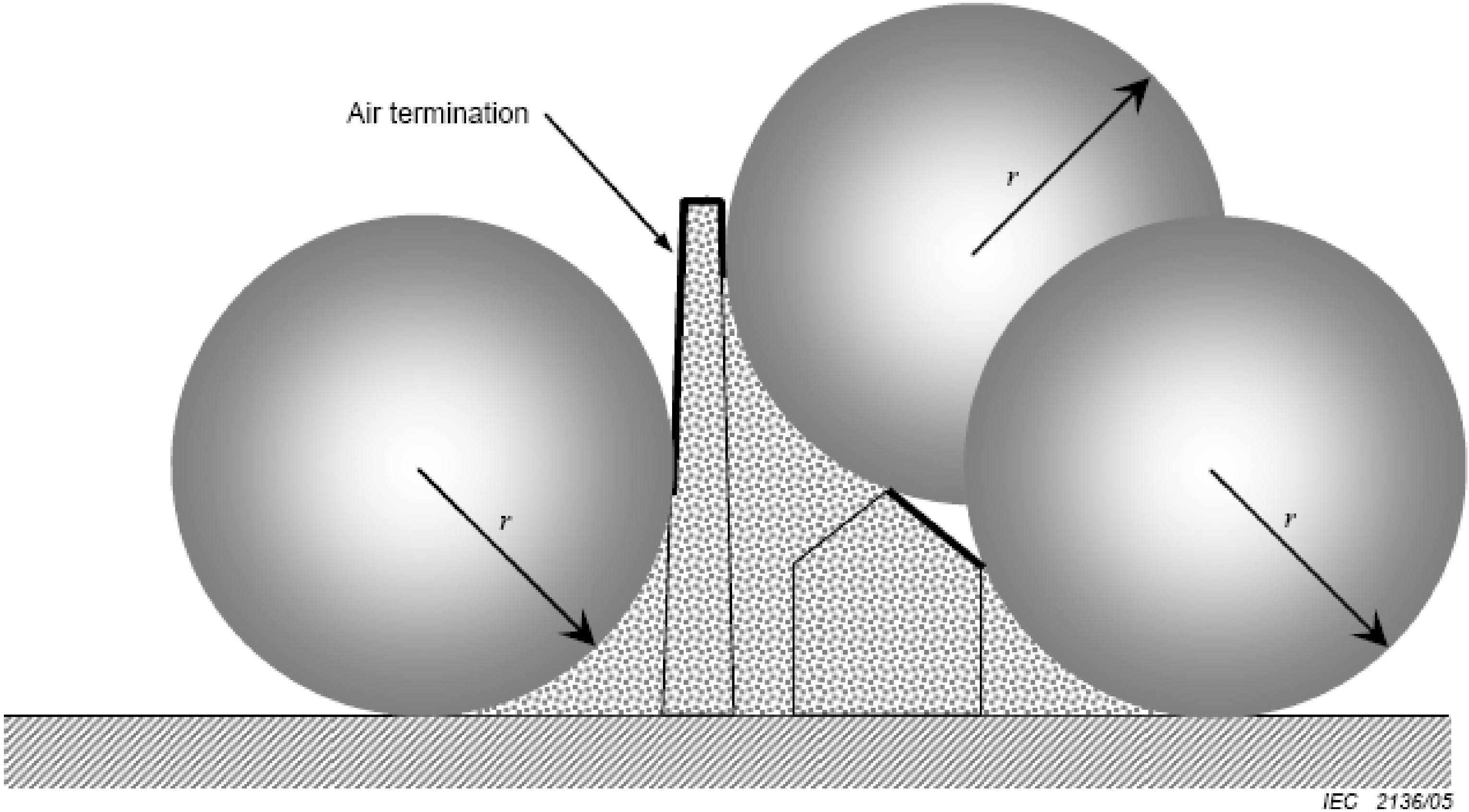
- On all structures **higher** than the rolling sphere radius r, flashes to the side of structure may occur.
- Each lateral point of the structure touched by the rolling sphere is a possible point of strike.
- However, the **probability for flashes to the sides** is generally **negligible** **for structures lower than 60 m.**

- The sphere of radius r is **rolled around and over all the structure** until it meets the ground plane or any permanent structure or object in contact with the ground plane which is capable of acting as a conductor of lightning.
- A striking point could occur where the **rolling sphere touches the structure** and at such points protection by an air-termination conductor is required.



NOTE The rolling sphere radius, r, should comply with the selected class of LPS (see Table 2).

Figure A.6 – Design of an air-termination system according to the rolling sphere method



r Radius of the rolling sphere according to Table 2.

NOTE Air-termination LPS conductors are installed on all points and segments which are in contact with the rolling sphere, whose radius complies with the selected protection level except for the lower part of the structure in accordance with 5.2.3.

Figure E.18a – Design of an LPS air-termination according to the rolling sphere method

- For taller structures, the **major part** of all flashes will hit the top, horizontal leading edges and corners of the structure.
- Only a **few per cent** of all flashes will be to the side of the structure.
- Moreover, observation data show that the probability of flashes to the sides **decreases rapidly as the height** of the point of strike on tall structures when measured from the ground.
- Therefore consideration should be given to install a lateral air-termination system on the upper part of tall structures (**typically the top 20% of the height of the structure**).
- In this case the **rolling sphere method will be applied only to the positioning of the air-termination system of the upper part of the structure.**

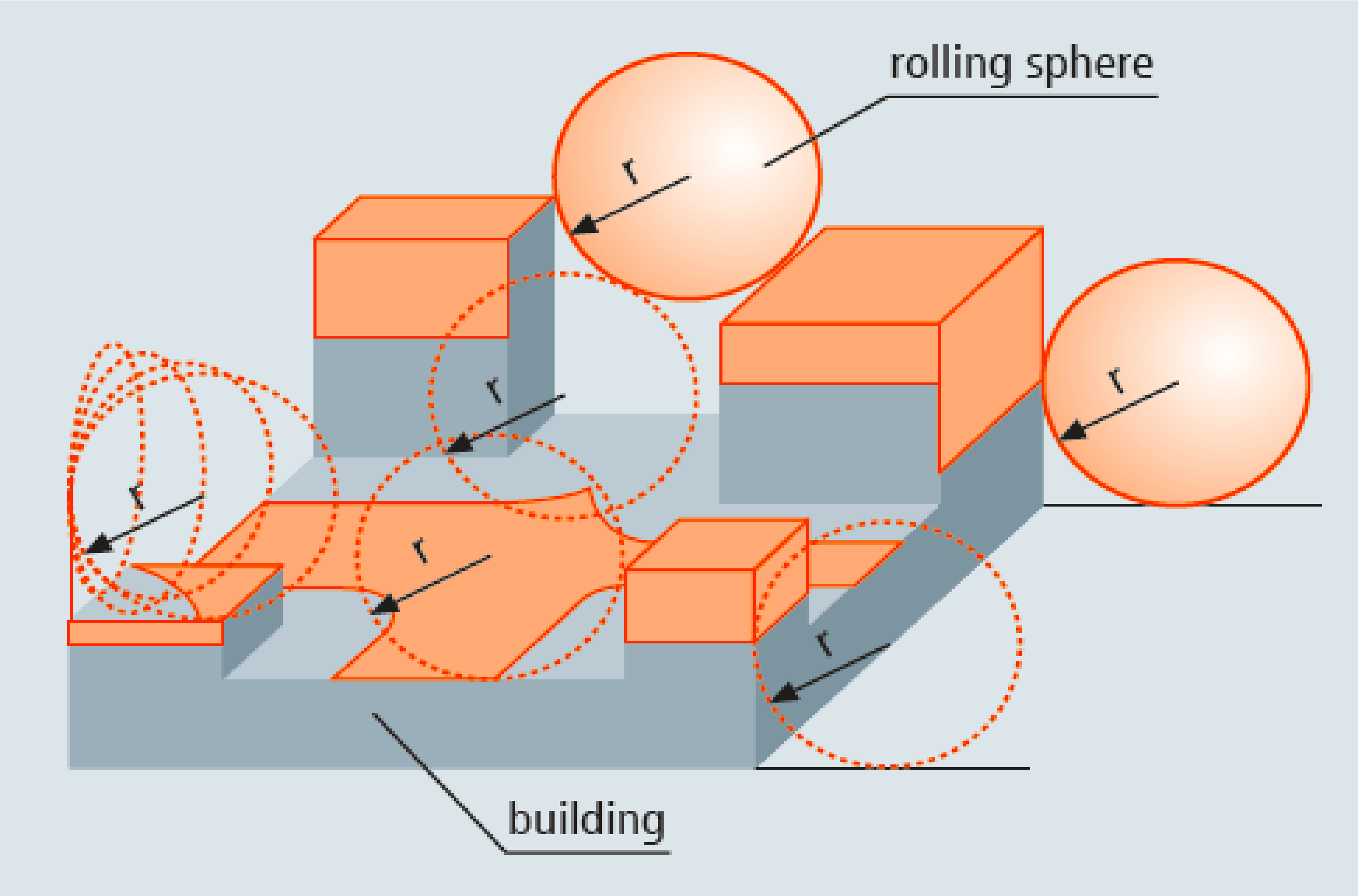
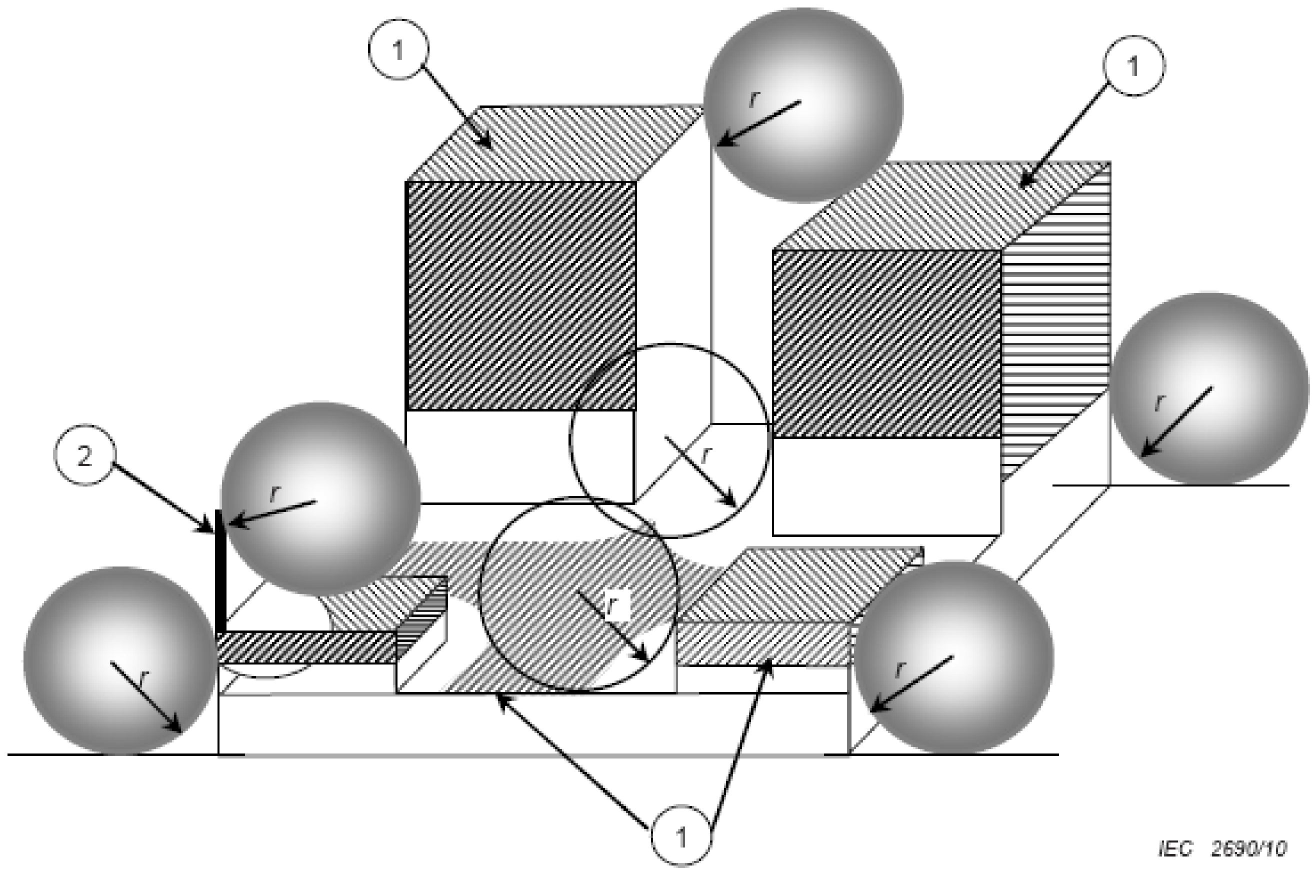


Figure 5.1.1.3 Schematic application of the rolling sphere method at a building with very irregular surface

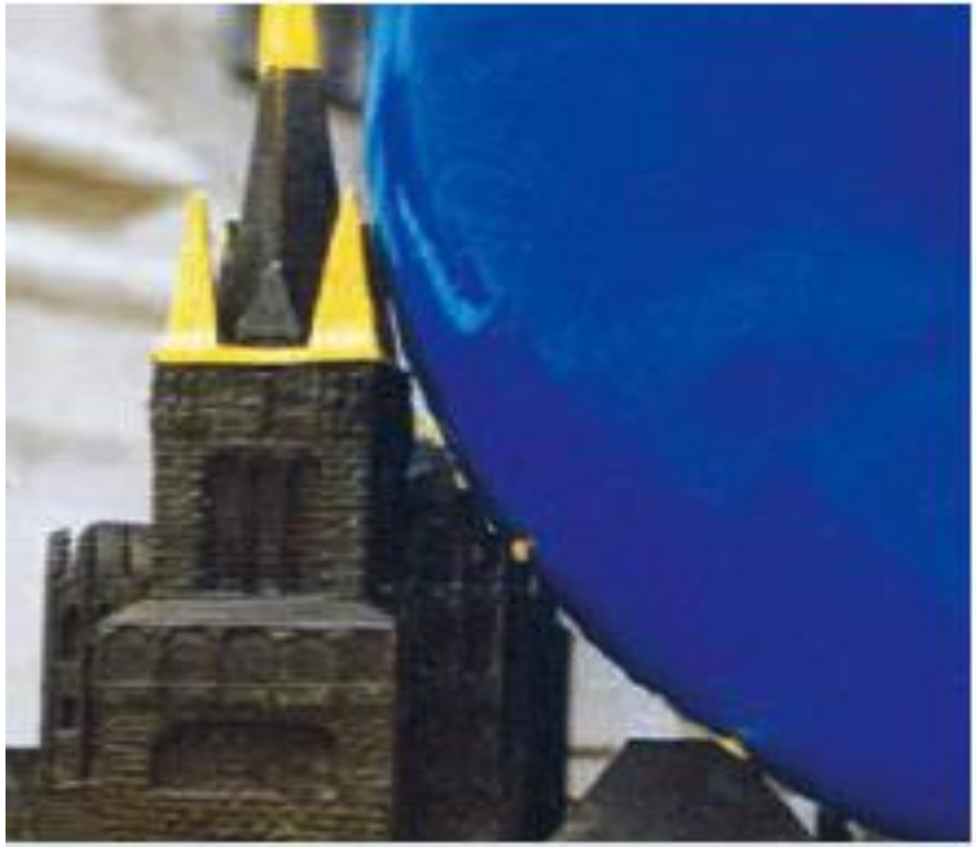


Key

1 shaded areas are exposed to lightning interception and need protection according Table 2
2 mast on the structure
r radius of rolling sphere according to Table 2

NOTE Protection against side flashes is required according to 5.2.3 and A.2.

Figure E.18 – Design of an LPS air-termination conductor network on a structure with complicated shape



A rolling sphere cannot only touch the steeple, but also the nave of the church at multiple points, as this model experiment shows. All these points are potential points of strike.

Figure 5.1.1.2 Model of a rolling sphere; source: Prof. Dr. A. Kern, Aachen

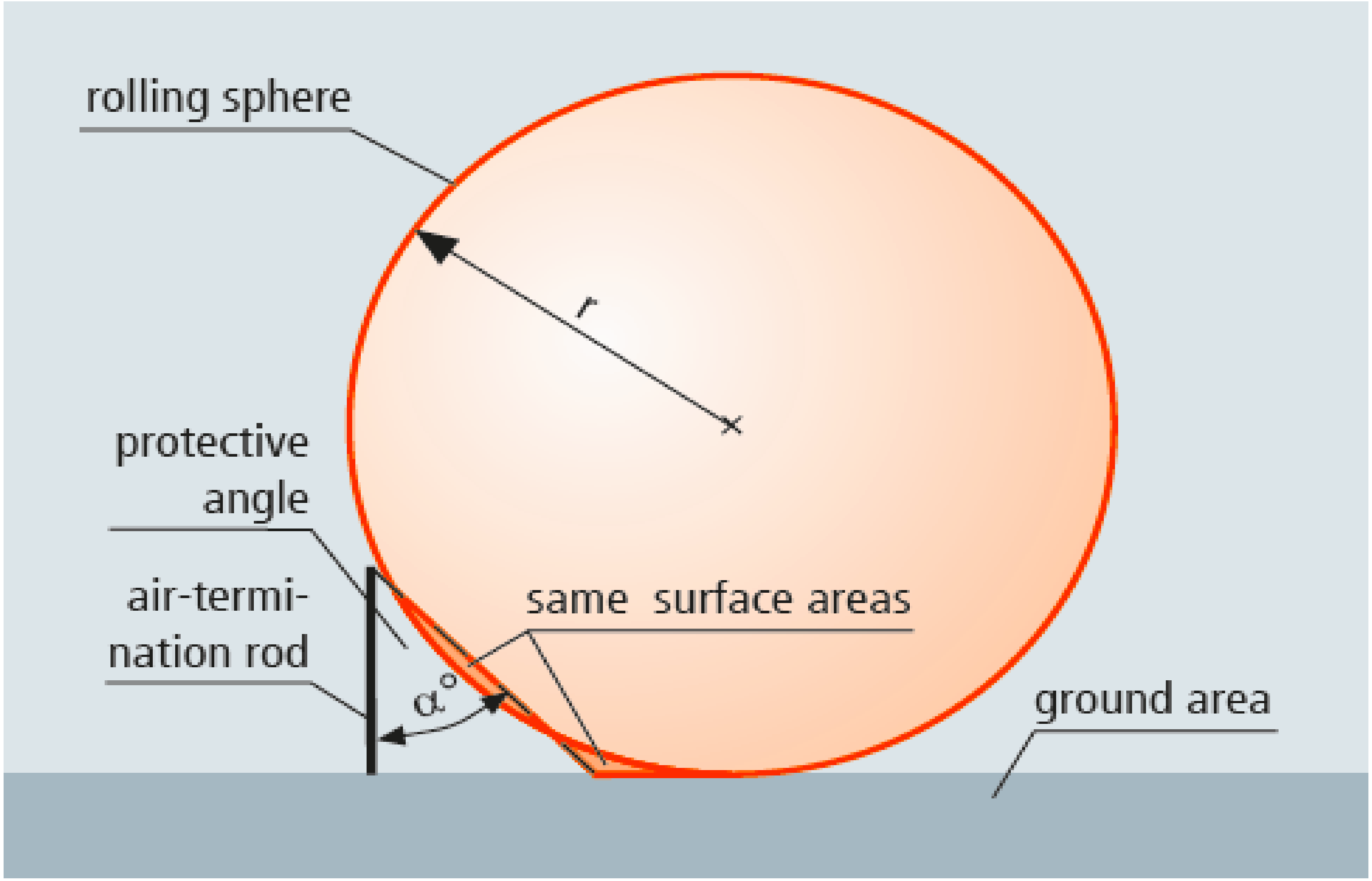


Figure 5.1.1.11 Protective angle and comparable radius of the rolling sphere

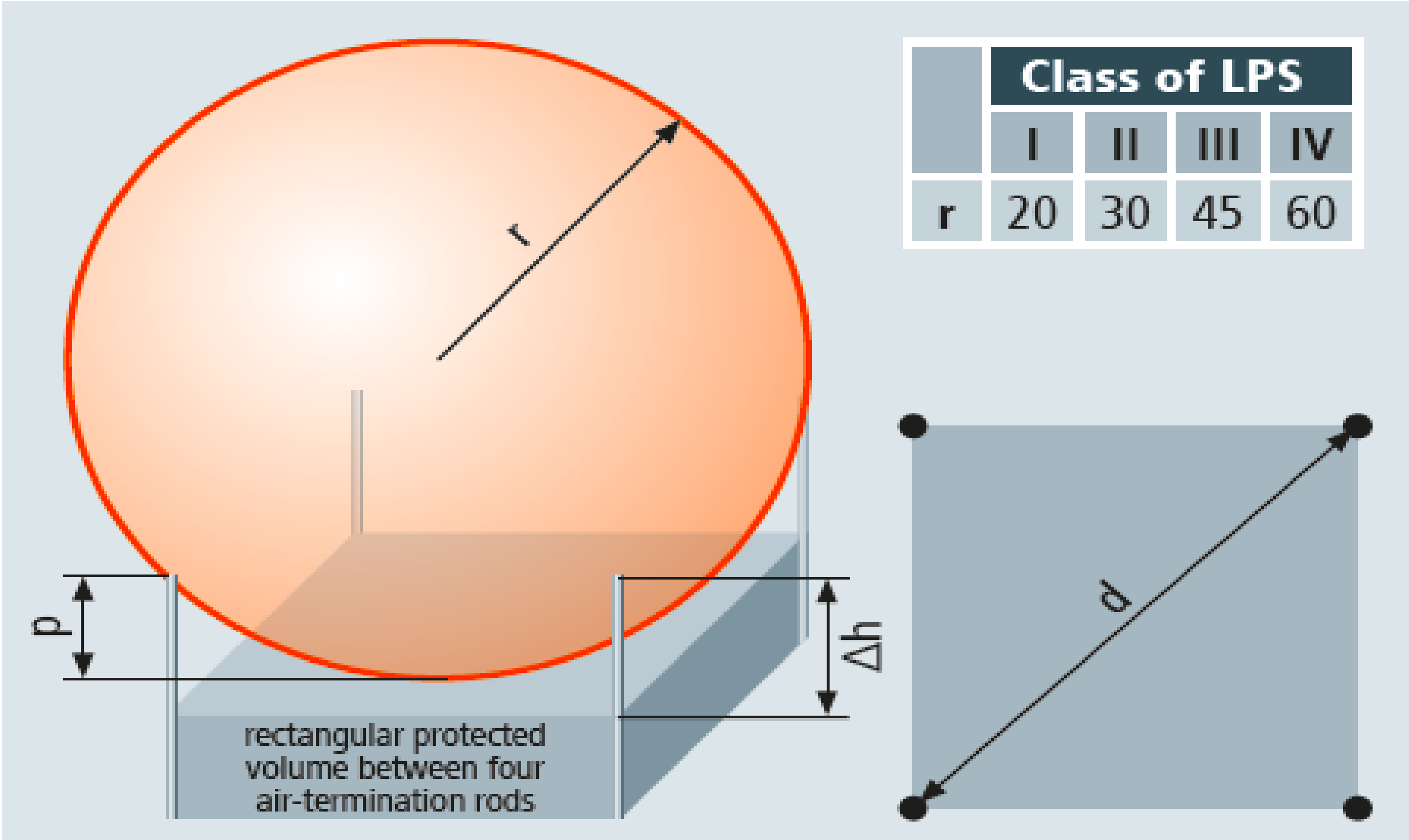


Figure 5.1.1.8 Air-termination system for roof-mounted structures and their protected volume

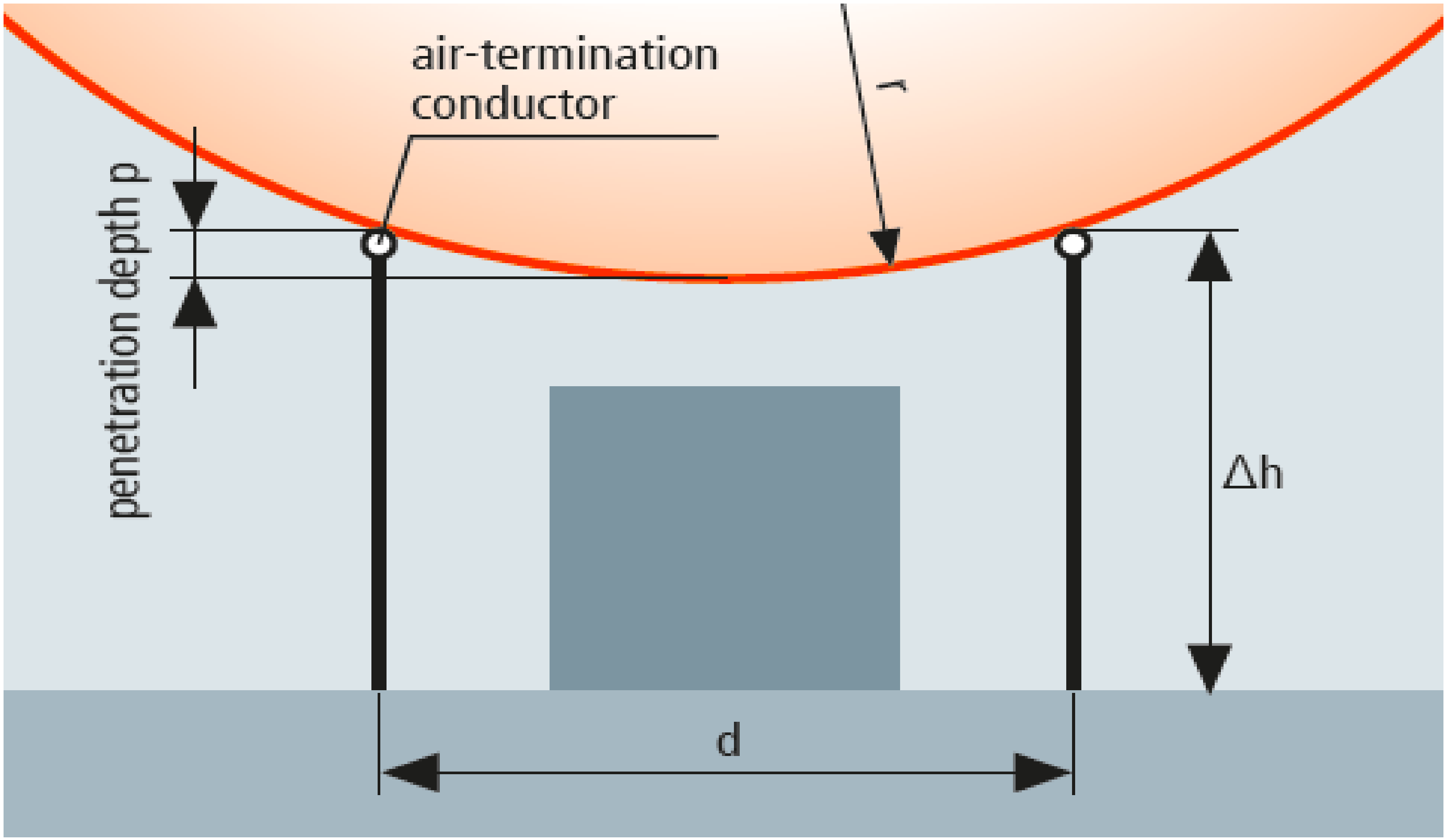


Figure 5.1.1.7 Penetration depth p of the rolling sphere

- When the rolling sphere method is applied to drawings of the structure, the **structure should be considered from all directions** to ensure that no part protrudes into an unprotected zone – a point which might be overlooked if only front, side and plan views on drawings are considered.

- The **protected space** generated by an LPS conductor is the **volume not penetrated by the rolling sphere** when it is in contact with the conductor and applied to the structure.

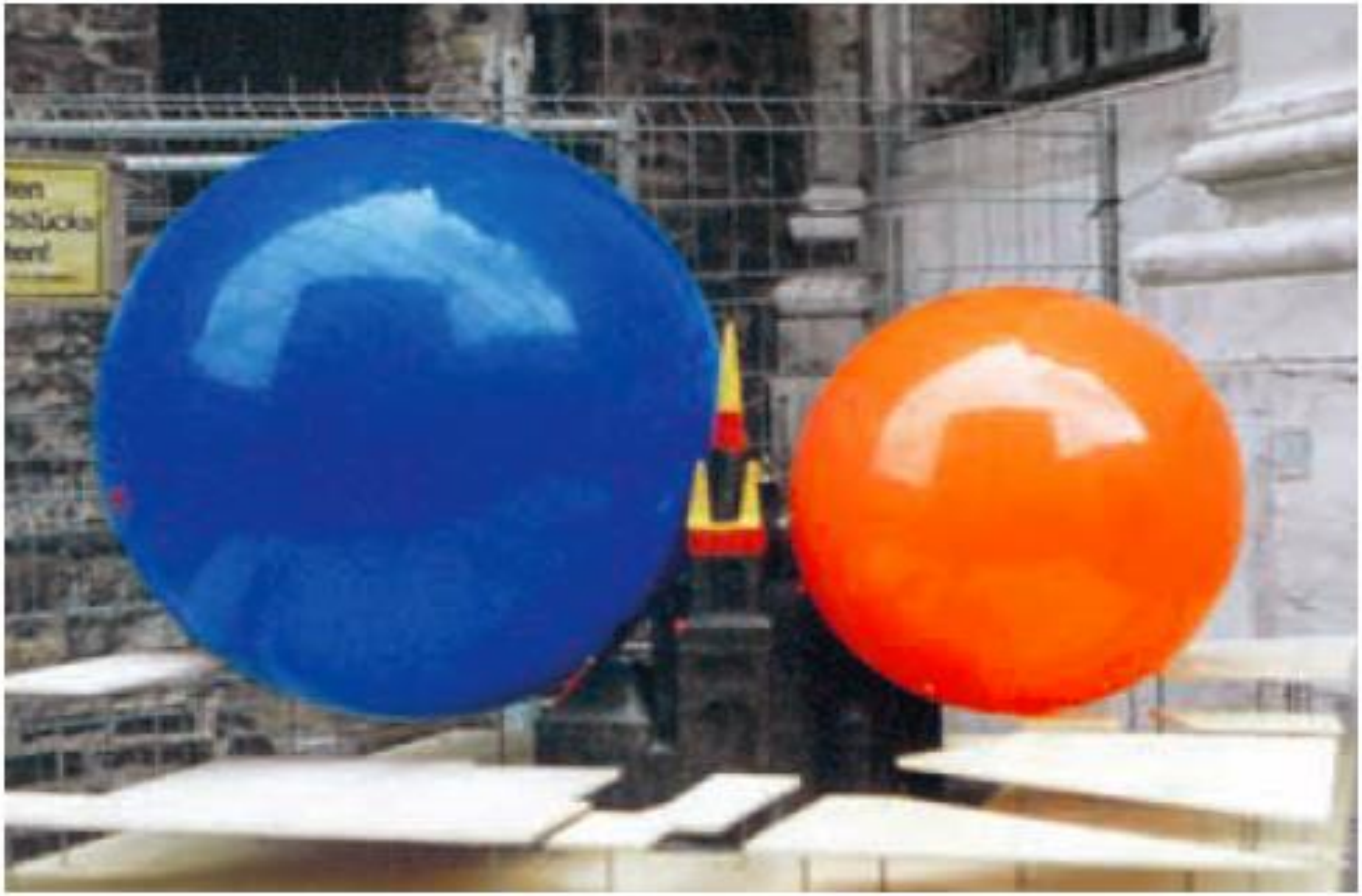


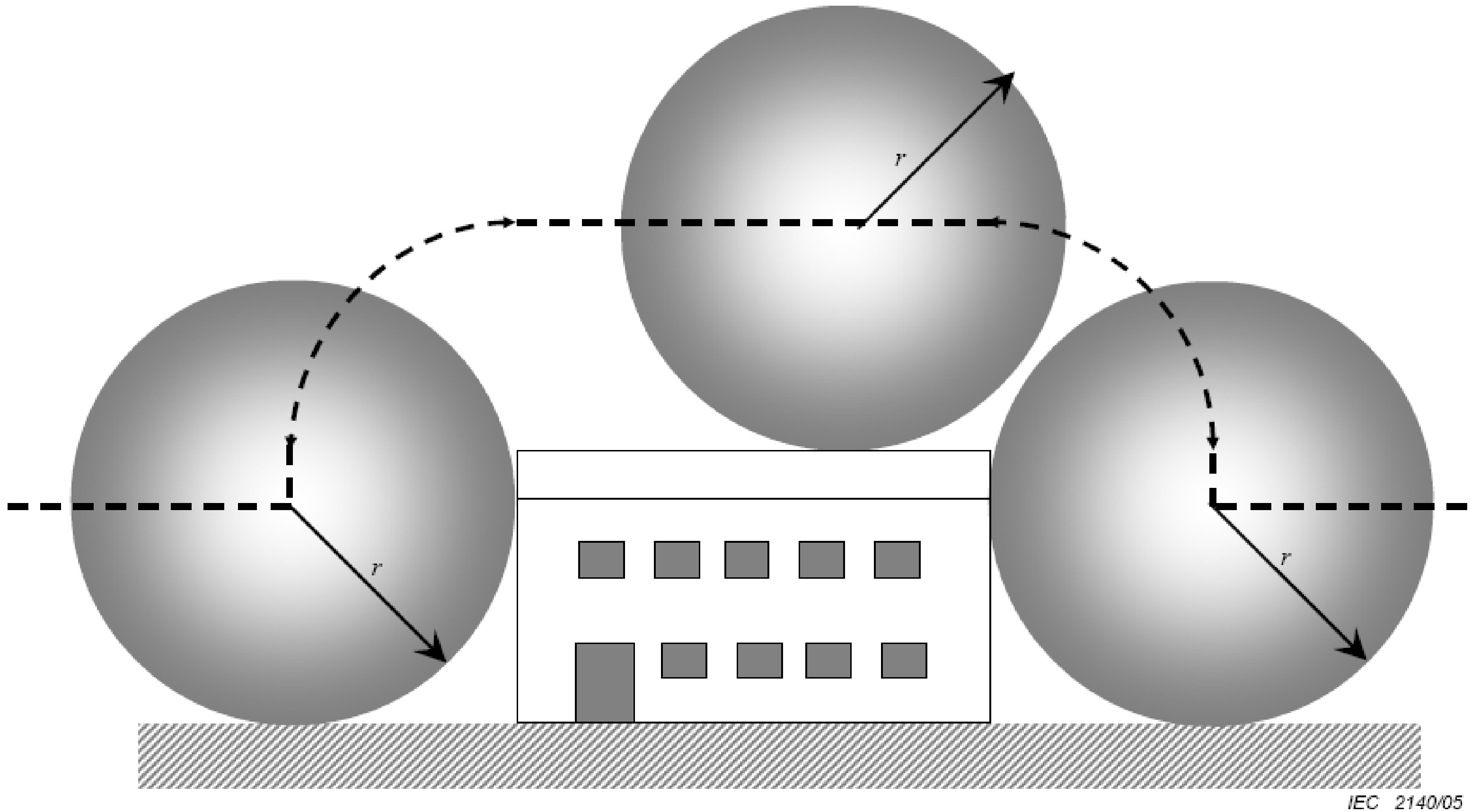
Figure 5.1.1.6 Aachen Cathedral: Model with surroundings and rolling spheres of classes of LPS II and III; source: Prof. Dr. A. Kern. Aachen

Figure 5.1.1.4 New administration building: Model with rolling sphere according to class of LPS I; source: WBG Wiesinger

Figure 5.1.1.5 New DAS administration building: Areas threatened by lightning strikes for class of LPS I, top view (excerpt); source: WBG Wiesinger

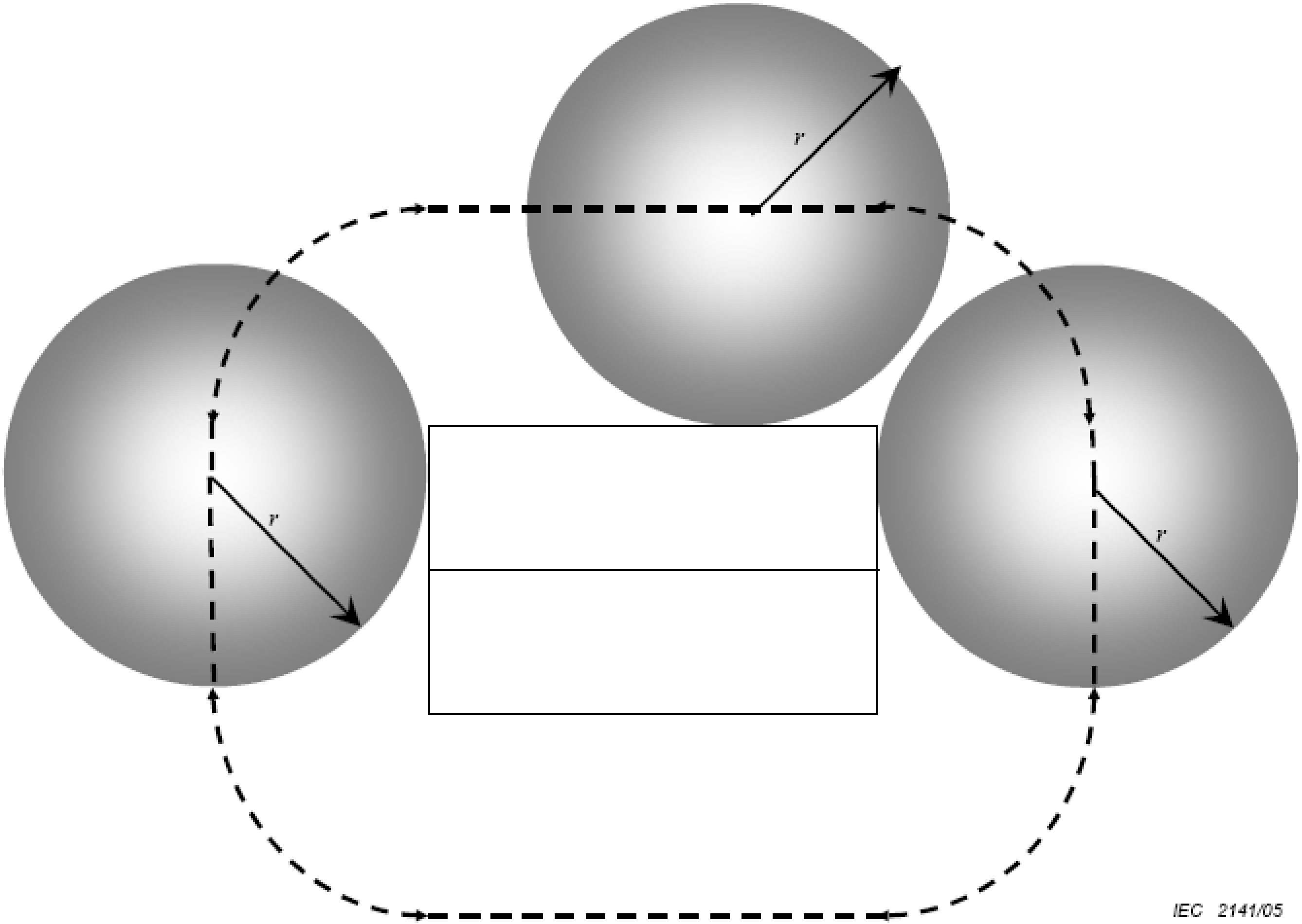
Rolling sphere method

- All those lightning flashes with **tips lying on the path of the centre** of the rolling sphere will **discharge to the nearest point of the building**.
- Around the **edges of the roof** there is a **quarter circular path** with **possible positions of the tip of the downward leader** which will **discharge to the edge of the building**.
- This **shows that a considerable portion of the strikes will occur at the edge of the roof**, some at the walls and some at the roof surface.
- In order to make a prediction about the overall possibility of a strike to the **wall**, the **plan view** must also be considered (see Figure E.21b).



r Radius of the rolling sphere according to Table 2

Figure E.21a – Side view



r Radius of the rolling sphere according to Table 2

Figure E.21b – Plan view

Figure E.21 – Points at which lightning will strike a building

The mesh method

- For the purpose of protecting **flat surfaces**, a mesh is considered to protect the whole surface if the following conditions are fulfilled.

  a) **air-termination conductors** are positioned on

  – **roof edge lines**,

  – **roof overhangs**,

  – **roof ridge lines**, if the roof slope exceeds 1/10,

  – **the lateral (side) surfaces of the structure higher than 60 m** at levels **higher than 80 %** of the height of the structure;

  b) the **mesh dimensions** of the air-termination network are **not greater** than the values given in Table 2;

c) the network of the air-termination system is accomplished in such a way that the lightning current will always encounter **at least two distinct metallic routes to the earth** and no metal installation protrudes outside the volume protected by air-termination systems;

A larger number of down-conductors results in reduction of the separation distance and reduces the electromagnetic field within the building

d) the air-termination conductors follow as far as possible **short and direct routes**.

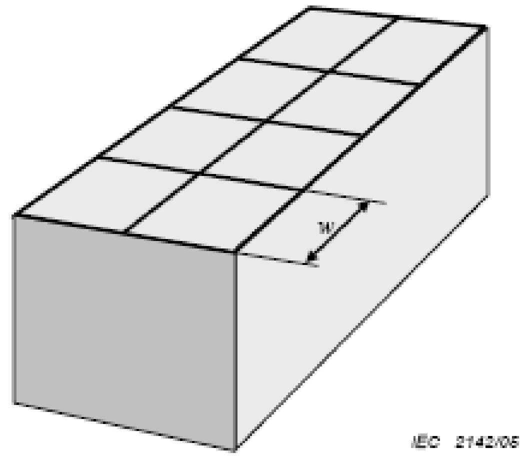
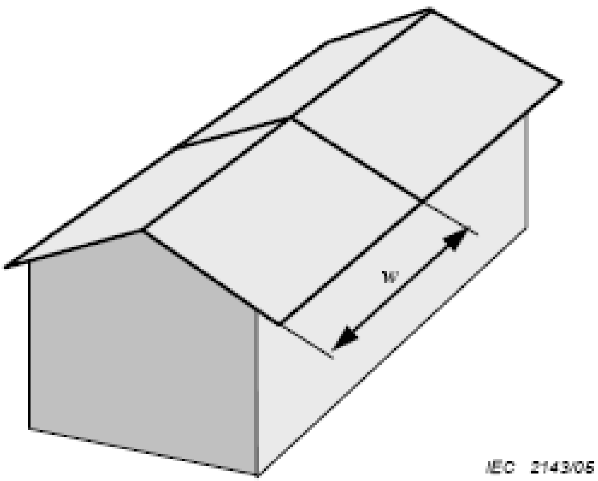


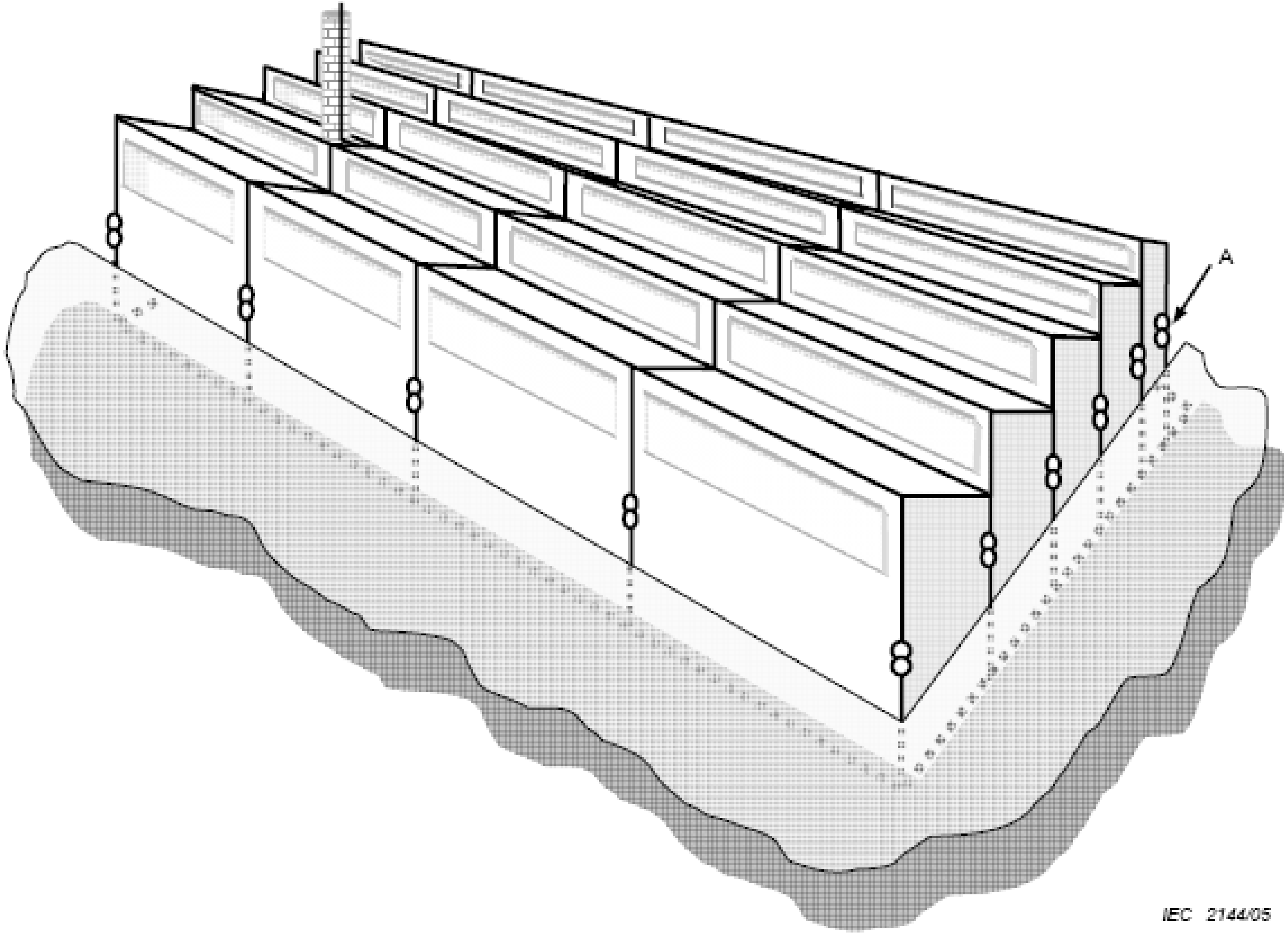
Figure E.22a – LPS air-termination on a flat-roof structure



Key
w Mesh size

NOTE The mesh size should comply with Table 2.

Figure E.22b – LPS air-termination on a sloped-roof structure



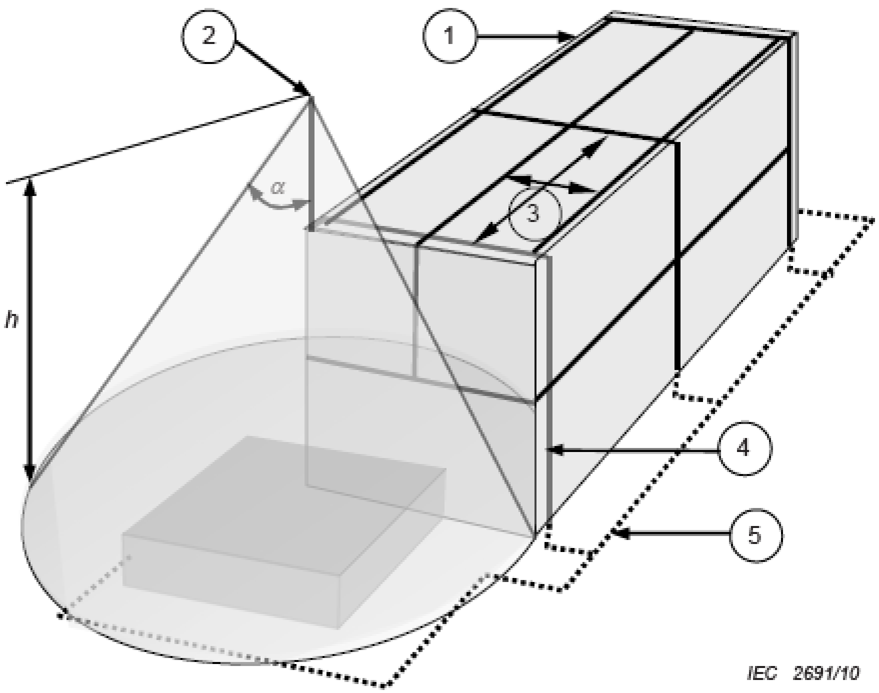
Key
A Test joint

NOTE All dimensions should comply with the selected protection level according to Tables 1 and 2.

Figure E.22c – An example of LPS on a shed roof structure

- For the design of the air-termination system, the three methods should be used, independent or in any combination, providing that the zones of protection afforded by different parts of the air-termination overlap and ensure that the structure is entirely protected.
- All three methods may be used for the design of an LPS.
- The choice of the method depends on a practical evaluation of its suitability and the vulnerability of the structure to be protected.
- Notes:
  - ➢ The protection angle method is suitable for **simple structures** or for small parts of bigger structures.
  - ➢ This method is **not suitable** for structures higher than the selected radius of the rolling sphere
  - ➢ The **rolling sphere method** is suitable for **complex shaped** structure
  - ➢ The **mesh method** is for general purposes and it is particularly **suitable for the protection of plane surfaces**.

- Figure E.19 shows the protection afforded by an LPS air-termination system according to the mesh method, **rolling sphere method** and protection angle method with a general arrangement of air-termination elements.



Key

1	air-termination conductor
2	air-termination rod
3	mesh size
4	down-conductor
5	earthing system with ring conductor
h	height of the air-terminal above ground level
α	protection angle

Figure E.19 – Design of an LPS air-termination according to the protection angle method, mesh method and general arrangement of air-termination elements

- **Structures 60 m in height or more**
  - **An air-termination system** shall be installed to protect the **upper part of tall structures** (i.e. typically the topmost **20%** of the height of the structure as far as this part exceeds 60 m in height) **and the equipment installed on it.**
  - The rules for positioning the air-termination systems on these upper parts of a structure shall meet **at least the requirements** of **LPL IV** with **emphasis on the location of air-termination devices on corners**, **edges**, and **significant protrusions** (such as balconies, viewing platforms, etc.)
  - The air-termination requirement for the side of a tall structure may be satisfied by the **presence of external metallic materials such as metal cladding or metallic curtain walls.** May also include external down-conductors when not provided by natural external metallic conductors.

- In structures higher than **120 m**, the topmost **20 % of lateral surfaces should be equipped with air-termination systems**.

- If sensitive parts (e.g. electronic equipment) are present on the outside of the wall in the upper part of the building, they should be protected by special air-termination measures, such as horizontal **finials**, mesh conductors or equivalent.

3. Down-Conductor Systems

- In order to reduce the probability of damage due to lightning current flowing in the LPS, the down-conductors shall be arranged in such a way that from the point of strike to earth
  - a) **Several parallel current paths ex**ist
  - b) The **length of the current paths is kept to a minimum**
  - c) **Equipotential bonding to conducting parts of the structure is performed** accordingly
- Lateral connection of down-conductors is considered to be good practice
- The installation of as many down-conductors as possible, at equal spacing around the perimeter interconnected by ring conductors, **reduces the probability of dangerous sparking and facilitates the protection of internal installation**s.
- Typical values of the preferred distance between down-conductors are given in Table 4.

Table 4 – Typical preferred values of the distance between down-conductors according to the class of LPS

Class of LPS	Typical distances m
I	10
II	10
III	15
IV	20

- **Positioning for an isolated LPS**

a) If the air-termination consists of rods on separate masts (or one mast) not made of metal or interconnected reinforcing steel, **at least one down-conductor is needed for each mast**. **No additional down-conductors are required for masts made of metal or interconnected reinforcing steel**.

In several countries, the use of reinforced concrete as a part of the LPS is not allowed.

b) If the air-termination consists of **catenary wires** (or one wire), **at least one down-conductor is needed at each supporting structure**.

c) If the air-termination forms a **network of conductors**, **one down-conductor is needed at least at each supporting wire end**.

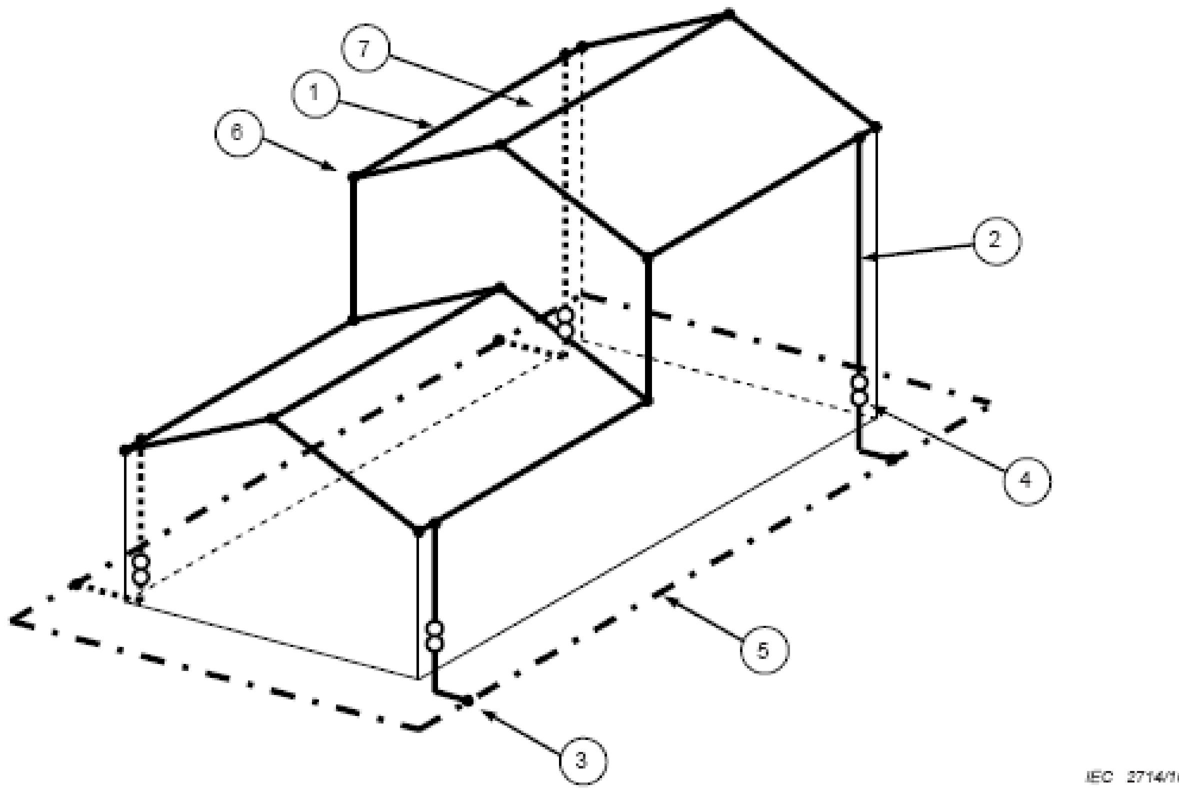
- **Positioning for a non-isolated LPS**

  For **each** non-isolated LPS the **number of down-conductors shall be not less than two** and should be distributed around the perimeter of the structure to be protected, subject to architectural and practical constraints.

- **A down-conductor should be installed at each exposed corner of the structure**, where this is possible.

- The **choice of number and position** of down-conductors should take into account the fact that, if the lightning current is shared in several down-conductors, **the risk of side flash and electromagnetic disturbances inside the structure is reduced**.
- It follows that, as far as possible, the down-conductors should be **uniformly placed** along the perimeter of the structure and **with a symmetrical configuration**.
- The **current sharing** is **improved** not only by increasing the **number** of down-conductors but also by **equipotential interconnecting rings**.
- Down-conductors should be placed **as far as possible away from internal circuits** and **metallic parts** in order to avoid the need for equipotential bonding with the LPS.

- A **variation** in spacing of the down-conductors of **±20 %** is acceptable as long as the mean spacing conforms to Table 4.
- In **closed courtyards** with more than **30 m perimeter**, down-conductors have to be installed.
- **External down-conductors** should be installed between the air-termination system and the earth-termination system.
- Wherever natural components are available they can be used as down-conductor.
- If the **separation distance** between down-conductors and the internal installations is **too large**, the **number of down-conductors should be increased** to meet the required separation distance.
- Air-termination systems, down-conductor systems and earth-termination systems should be **harmonized** to produce the **shortest possible path** for the lightning current.
- Down-conductors should preferably be **connected** to **junctions of the air-termination system** network and routed vertically to the junctions of the earth-termination system network.

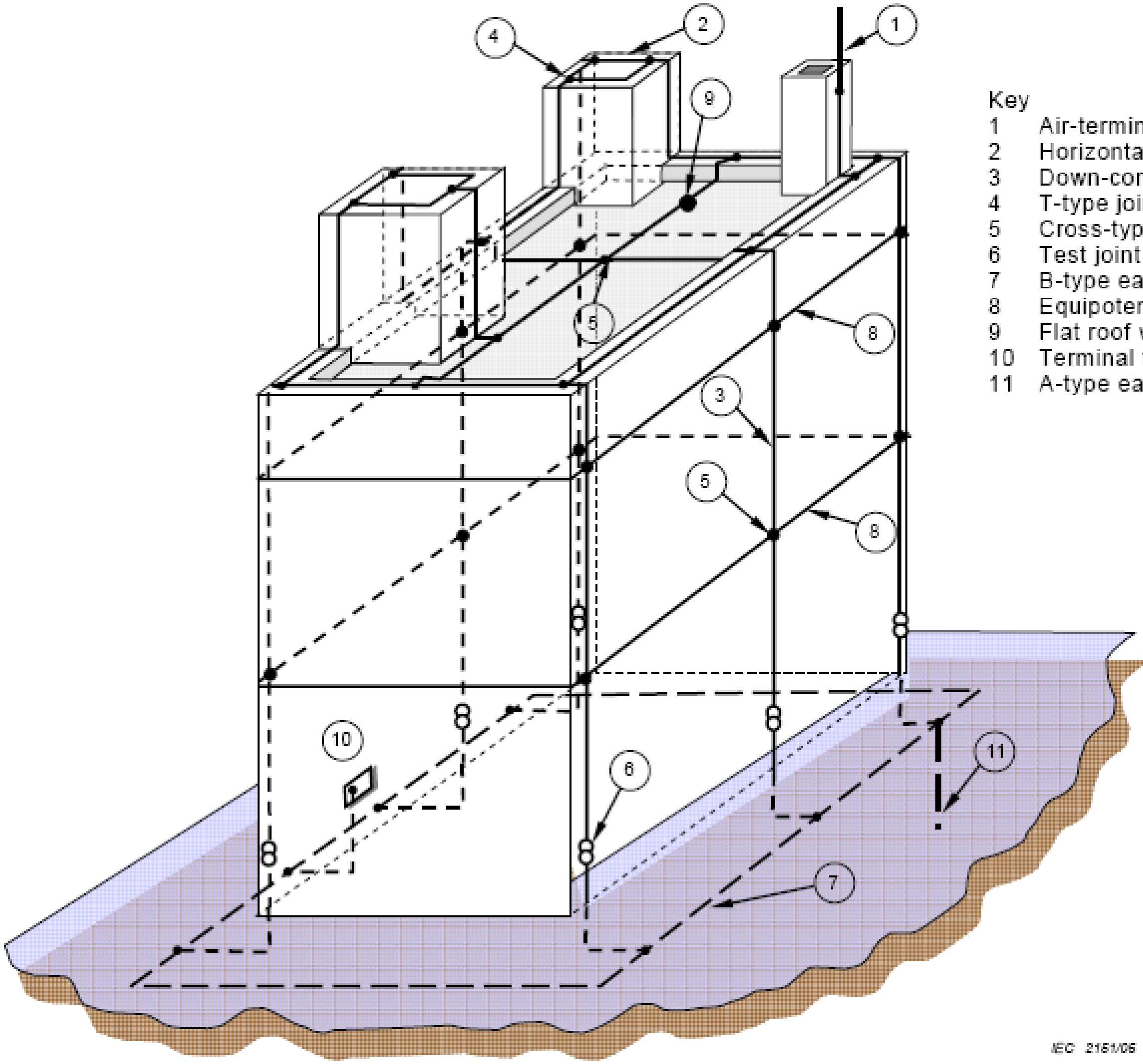


Key

1 horizontal air-termination conductor
2 down-conductor
3 T-type joint – corrosion resistant
4 test joint
5 type B earthing arrangement, ring earth electrode
6 T-type joint on the ridge of the roof
7 mesh size

NOTE The distance between the down-conductors should comply with 5.2, 5.3 and Table 4.

Figure E.36 – Installation of external LPS on a structure of insulating material with different roof levels



Key
1 Air-termination rod
2 Horizontal air-termination conductor
3 Down-conductor
4 T-type joint
5 Cross-type joint
6 Test joint
7 B-type earthing arrangement, ring earth electrode
8 Equipotentialization ring conductor
9 Flat roof with roof fixture
10 Terminal for connecting the equipotentialization bar of the internal LPS
11 A-type earthing arrangement

NOTE An equipotentialization ring is applied. The distance between the down-conductors complies with the requirements in Table 4.

Figure E.25 – Positioning of the external LPS on a structure made of insulating material e.g. wood or bricks with a height up to 60 m with flat roof and with roof fixtures

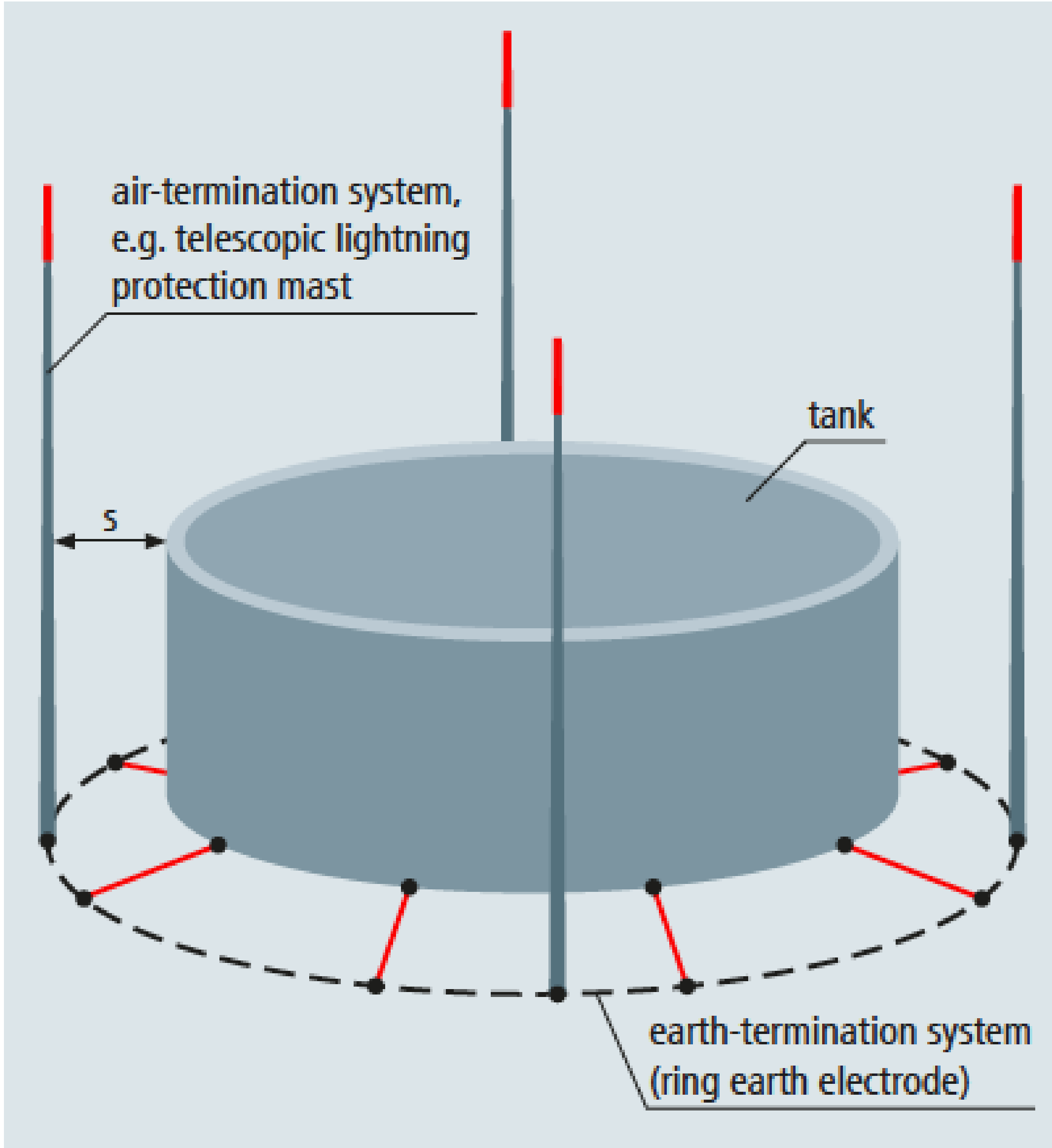


Figure 9.32.2 Air-termination system for a tank with air-termination rods and air-termination cables

4. Earth-Termination Systems

For earth-termination systems, electrodes can be laid vertically or horizontally. Depending on either horizontal or vertical positioning, the minimum length of electrode for each protection class is specified (see Fig. 3 below).

In terms of connection between electrodes, two basic types of earth electrode arrangements apply.

Type A arrangement (NON CLOSED LOOP)

Type B arrangement (CLOSED LOOP)

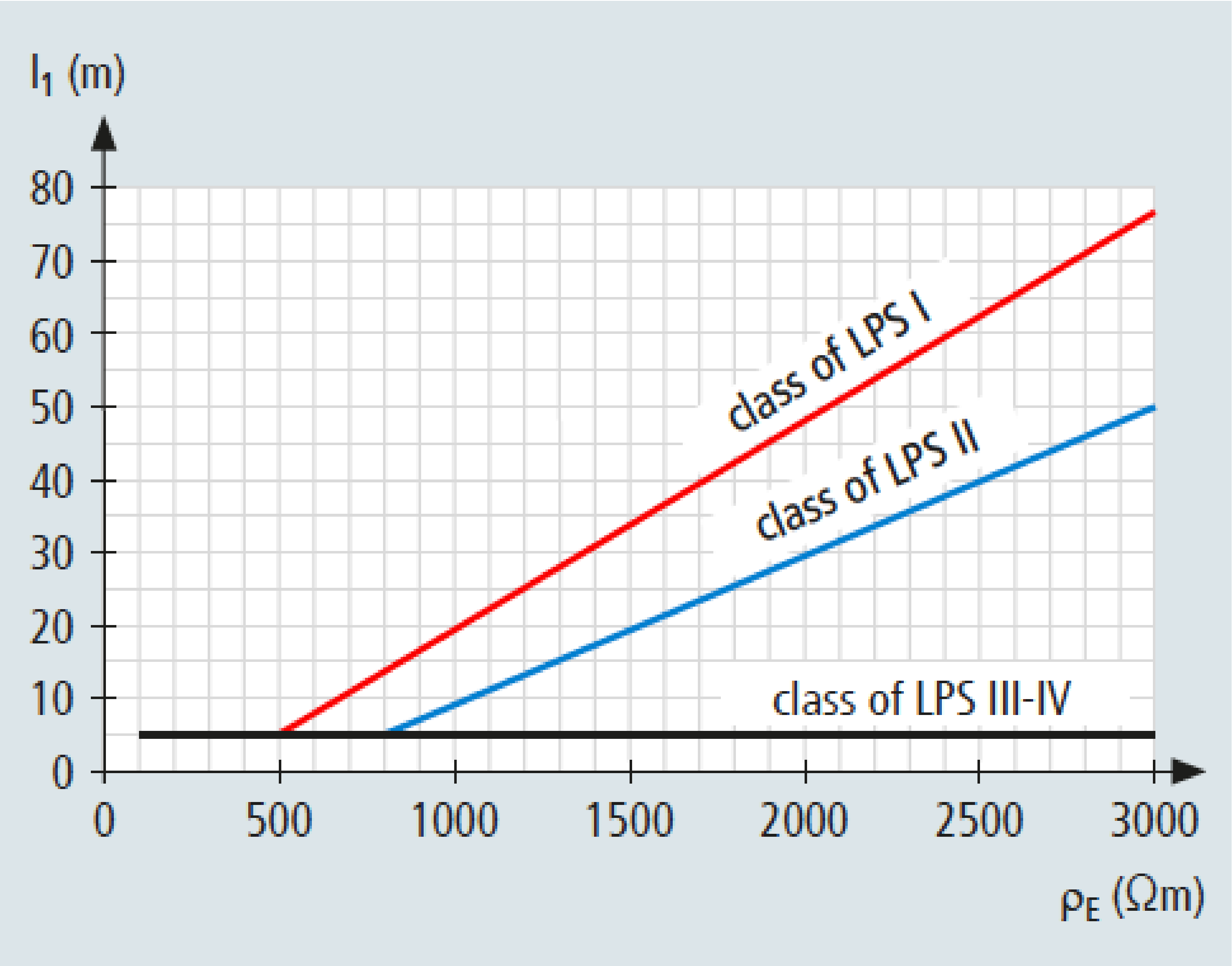


Figure 5.5.1.1 Minimum lengths of earth electrodes

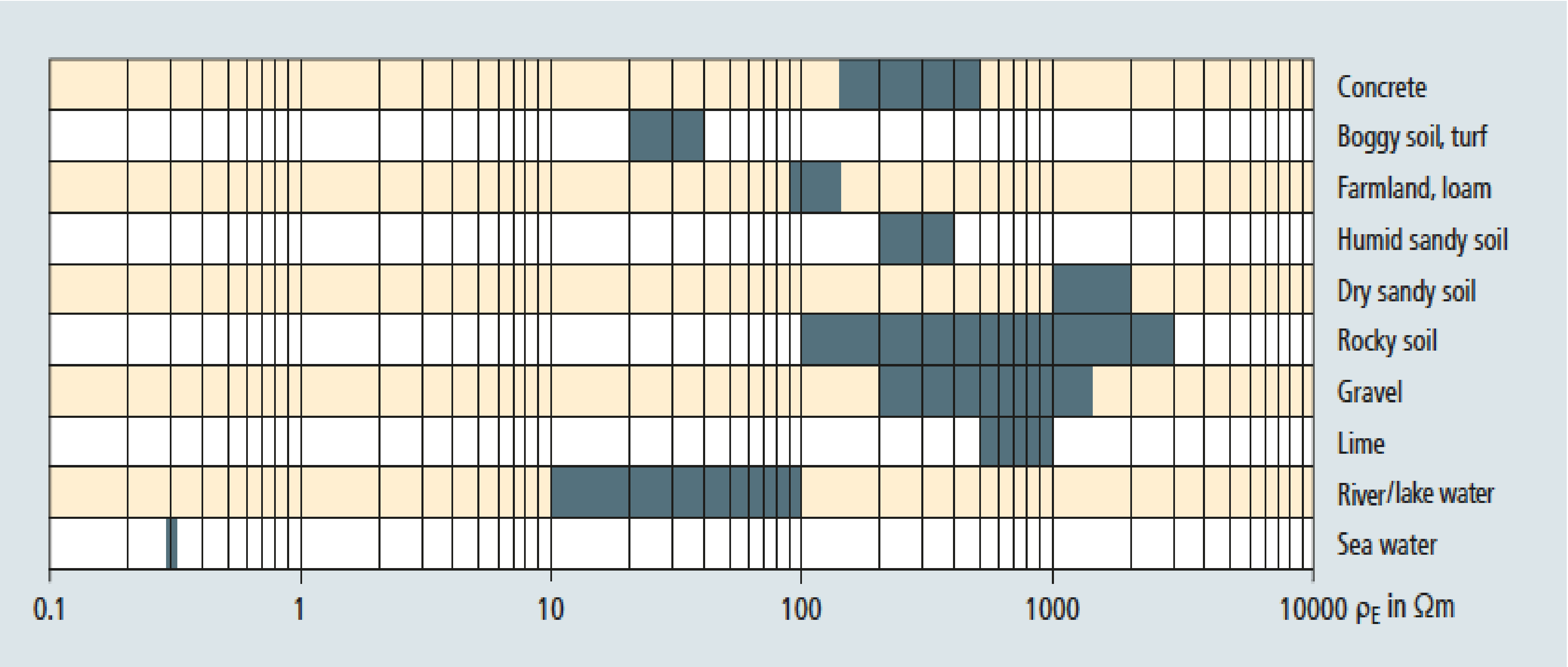


Figure 5.5.4 Earth resistivity ρ_E in case of different types of soil

Earth electrode	Approximate formula	Auxiliary
Surface earth electrode (radial earth electrode)	$R_A = \frac{2 \cdot \rho_E}{l}$	–
Earth rod	$R_A = \frac{\rho_E}{l}$	–
Ring earth electrode	$R_A = \frac{2 \cdot \rho_E}{3 \cdot d}$	$d = 1.13 \cdot \sqrt[2]{A}$
Meshed earth electrode	$R_A = \frac{\rho_E}{2 \cdot d}$	$d = 1.13 \cdot \sqrt[2]{A}$
Earth plate	$R_A = \frac{\rho_E}{4.5 \cdot a}$	–
Hemispherical / foundation earth electrode	$R_A = \frac{\rho_E}{\pi \cdot d}$	$d = 1.57 \cdot \sqrt[3]{V}$

R_A Earth resistance (Ω)
ρ_E Earth resistivity (Ωm)
l Length of the earth electrode (m)
d Diameter of a ring earth electrode, the area of the equivalent circuit or a hemispherical earth electrode
A Area (m^2) of the enclosed area of a ring or meshed earth electrode
a Edge length (m) of a square earth plate. In case of rectangular plates: a is substituted by $\sqrt{b \cdot c}$, where b and c are the two sides of the rectangle
V Volume of a single foundation earth electrode

Table 5.5.1 Formulas for calculating the earth resistance R_A for different earth electrodes

Type A arrangement

- This type of arrangement comprises **horizontal or vertical earth electrodes** installed outside the structure to be protected **connected to each down-conductor** or **foundation earth electrodes** **not forming a closed loop.**
- The type A earth-termination system is suitable for **low structures** (for example family houses), **existing structures** or an **LPS with rods or stretched wires or for an isolated LPS**.
- This type of arrangement comprises **horizontal** or **vertical** **earth electrodes** **connected to each down-conductor**.
- Where there is a **ring** conductor, which interconnects the down-conductors, **in contact with the soil** the earth electrode arrangement is still classified as type A if the ring conductor is in contact with the soil **for less than 80 % of its length**.
- In a type A arrangement the **minimum number of earth electrodes** should be **one for each down-conductor** and **at least two for the whole LPS.**

- The **minimum length** of each earth electrode at the base of each down-conductor is

  – l_1 for **horizontal** electrodes, or
  – 0.5 l_1 for **vertical** (or inclined) electrodes,

  where l_1 is the minimum length of horizontal electrodes shown in the relevant part of Figure 3.

- The earth electrodes (type A arrangement) shall be installed at a depth of upper end at least 0.5 m and distributed as uniformly as possible to minimize electrical coupling effects in the earth.

Type B arrangement

- This type of arrangement comprises either **a ring conductor** external to the structure to be protected, **in contact with the soil for at least 80 % of its total length**, or **a foundation earth electrode forming a closed loop**. Such earth electrodes may also be meshed.

- The type B earth-termination system is **preferred for meshed air-termination systems** and for **LPS with several down-conductors**.

- It is recommended that the number of electrodes shall be not less than the number of the down-conductors, with a minimum of two.
- The additional electrodes should be connected to the ring earth electrode at points where the down-conductors are connected and, for as many as possible, equidistantly.

- For the **<u>ring</u>** earth electrode (or foundation earth electrode), the **mean radius r_e** of the **area enclosed by the ring** earth electrode (or foundation earth electrode) shall be **not less than** the value l_1:

  $$re >= l_1$$

  where l_1 is represented in Figure 3 according to LPS class I, II, III and IV.

- The ring earth electrode (type B arrangement) should preferably be buried at a depth of at least 0.5 m and at a distance of about 1 m away from the external walls.

- Earth electrodes shall be installed in such a way as to allow inspection during construction.
- The embedded depth and the type of earth electrodes shall be such as to minimize the effects of corrosion, soil drying and freezing and thereby stabilize the conventional earth resistance.
- It is recommended that the upper part of a vertical earth electrode equal to the depth of freezing soil should not be regarded as being effective under frost conditions.
- For **bare solid rock**, only the type B earthing arrangement is recommended.
- For structures with extensive electronic systems or with high risk of fire, type B earthing arrangement is preferable.

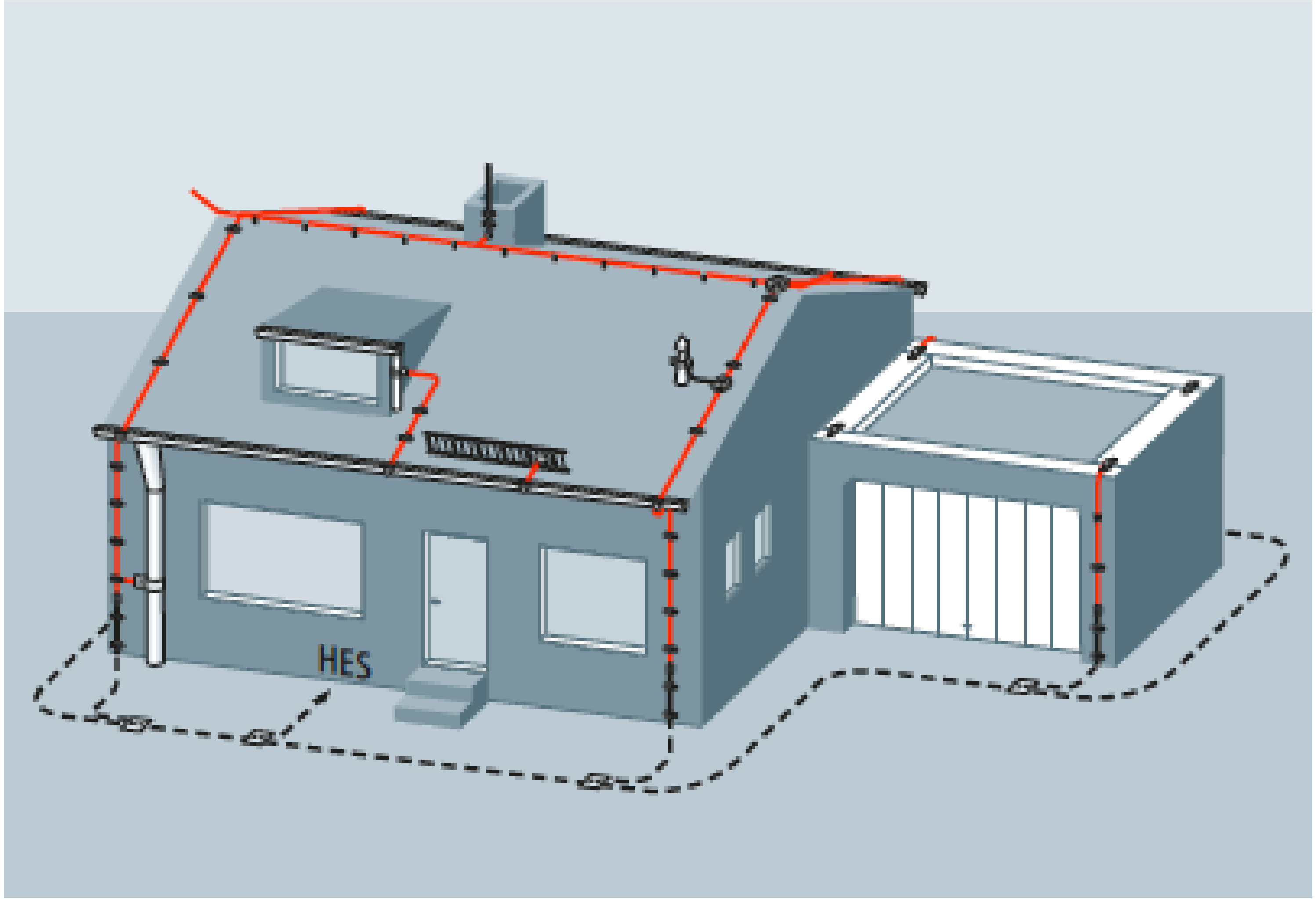


Figure 5.5.3.1 Ring earth electrode around a residential building

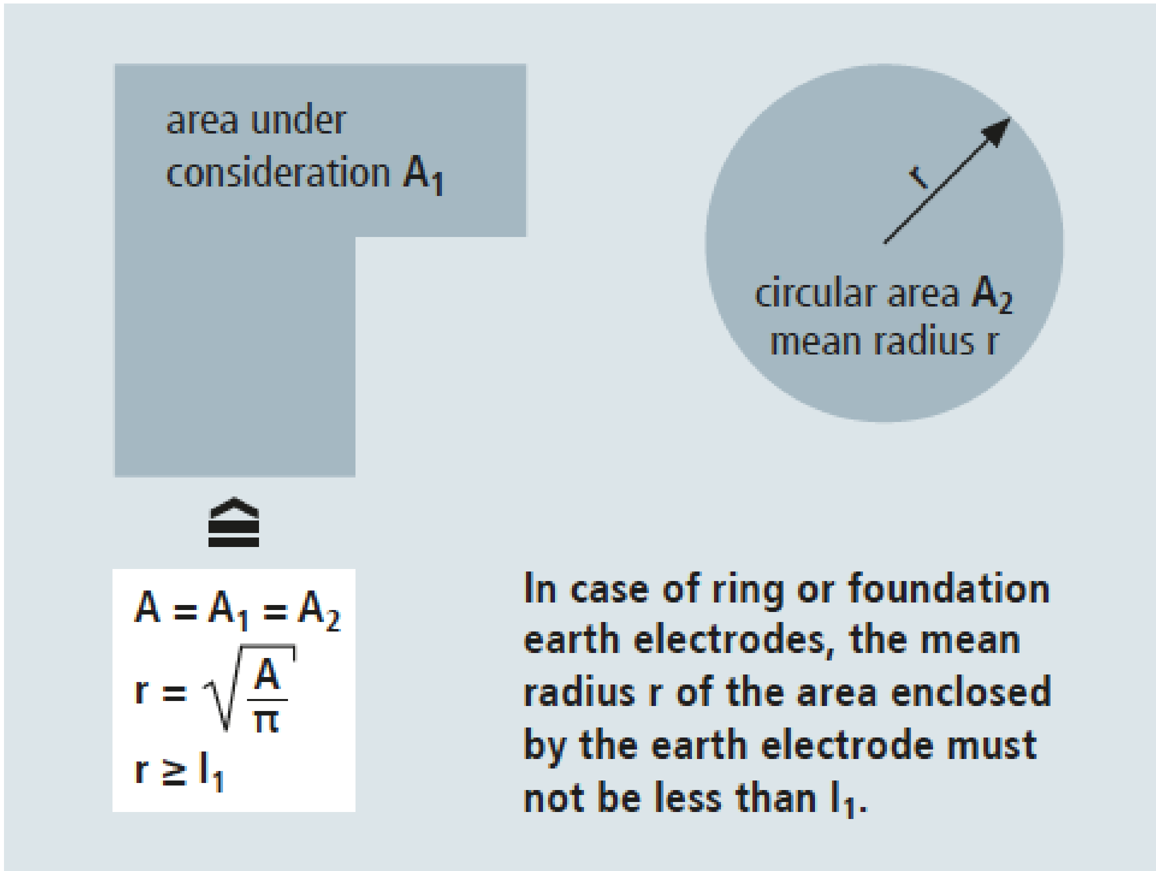


Figure 5.5.1.2 Type B earth electrode – Determination of the mean radius – Sample calculation

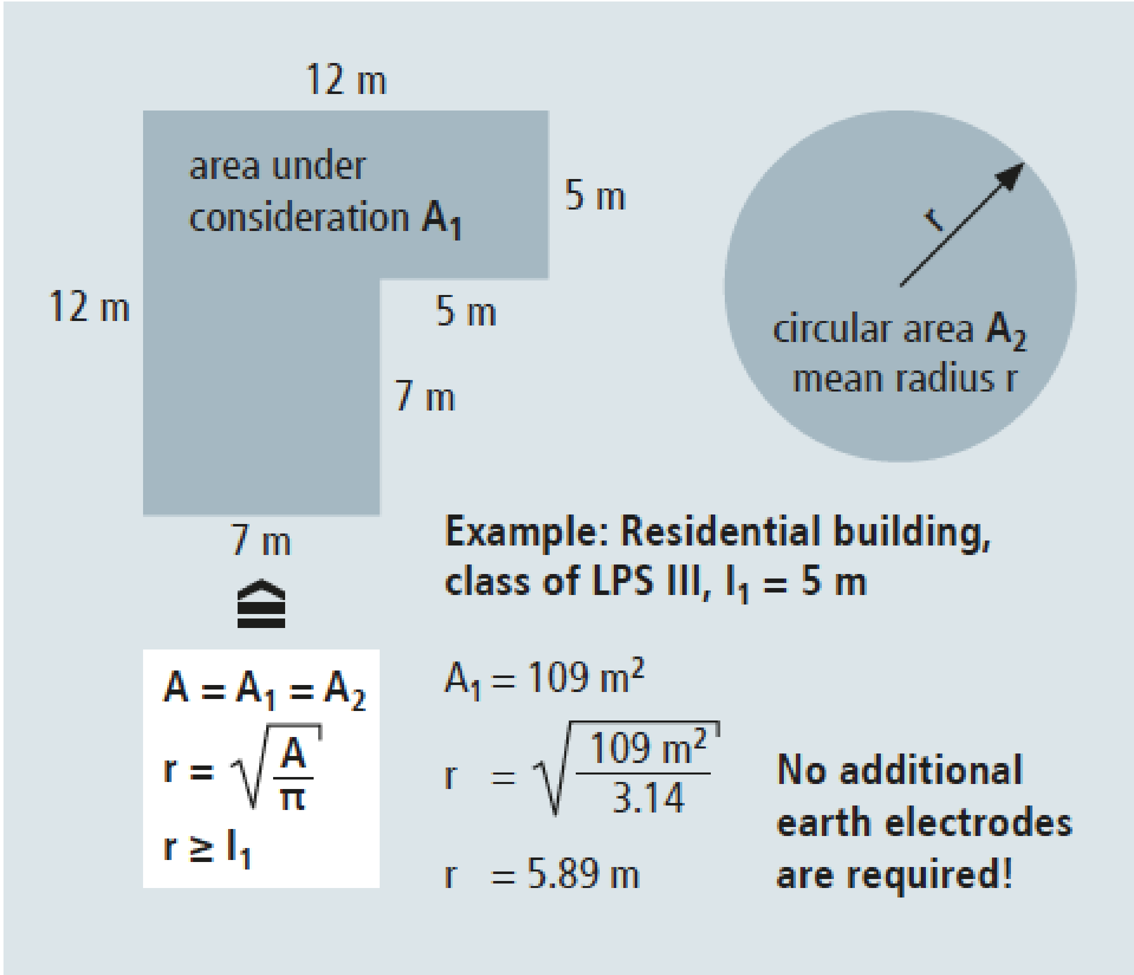


Figure 5.5.1.3 Type B earth electrode – Determination of the mean radius – Sample calculation

Protection measures against touch voltages

In certain conditions, the vicinity of the down-conductors of an LPS, may be hazardous to life even if the LPS has been designed and constructed according to the above-mentioned requirements.

The hazard Is reduced to a tolerable level if one of the following conditions is fulfilled:

a) under normal operation conditions there are no persons within 3 m from the downconductors;

b) a system of at least 10 down-conductors is employed;

c) the contact resistance of the surface layer of the soil, within 3 m of the down-conductor, is not less than 100 kΩ.

If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to touch voltages as follows:

– **insulation** of the exposed down-conductor is provided, e.g. at least 3 mm cross-linked polyethylene;

– **physical restrictions** and/or warning notices to minimize the probability of down-conductors being touched.

Protection measures against step voltages

In certain conditions, the vicinity of the down-conductors may be hazardous to life.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

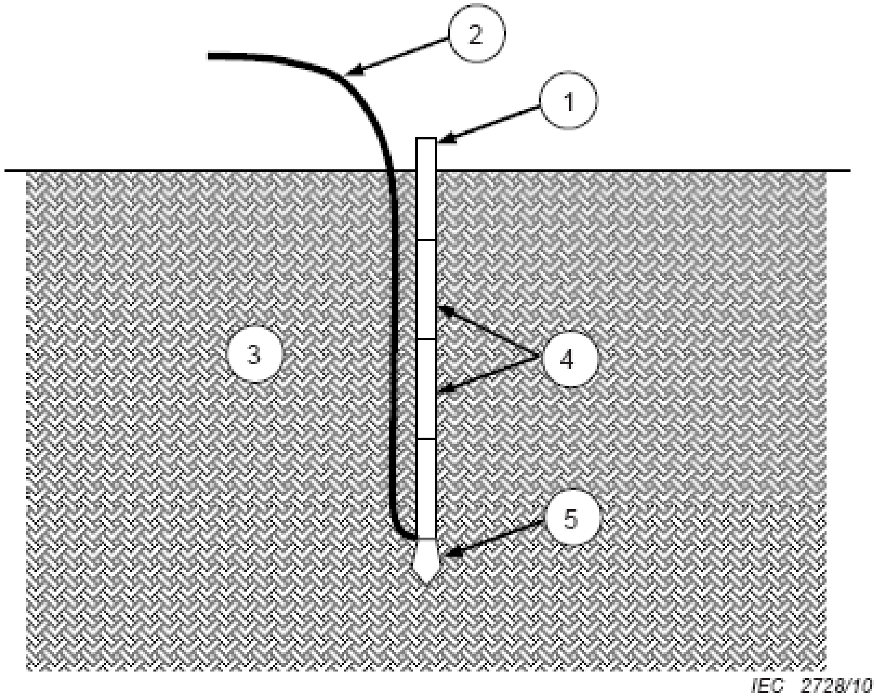
a) under normal operation conditions there are no persons within 3 m from the downconductors;

b) a system of at least 10 down-conductors is employed;

c) the contact resistance of the surface layer of the soil, within 3 m of the down-conductor, is not less than 100 kΩ.

If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to step voltages as follows:

- **equipotentialization** by means of a **meshed earth-termination system**;
- **physical restrictions** and/or warning notices to minimize the probability of access to the dangerous area, within 3 m of the down-conductor.



Key

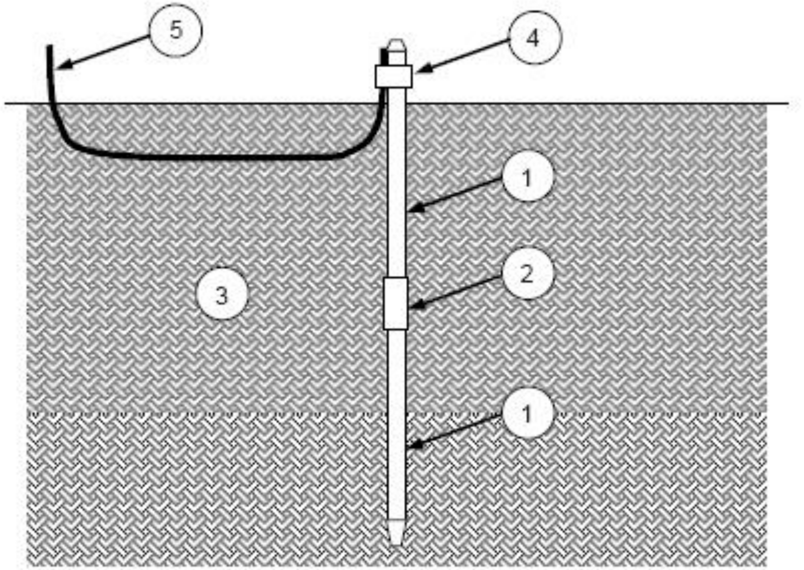
1 short upper-most driving rod
2 earthing conductor
3 soil
4 short driving rods
5 driving steel dart

NOTE 1 A continuous wire conductor is driven into the soil by means of short driving rods. The electrical continuity of the earth electrode conductor is of great advantage; using this technique, no joints are introduced into the earth electrode conductor. Short driving rod segments are also easy to handle.

NOTE 2 The short upper-most driving rod may be removed.

NOTE 3 The uppermost part of the earthing conductor may have an insulating jacket.

Figure E.41a – Example of a type A earthing arrangement with a vertical conductor type electrode



Key

1 extensible earth rod
2 rod coupling
3 soil
4 conductor to rod clamp
5 earthing conductor

Figure E.41b – Example of a type A earthing arrangement with a vertical rod type electrode

Figure E.41 – Two examples of vertical electrodes in type A earthing arrangement

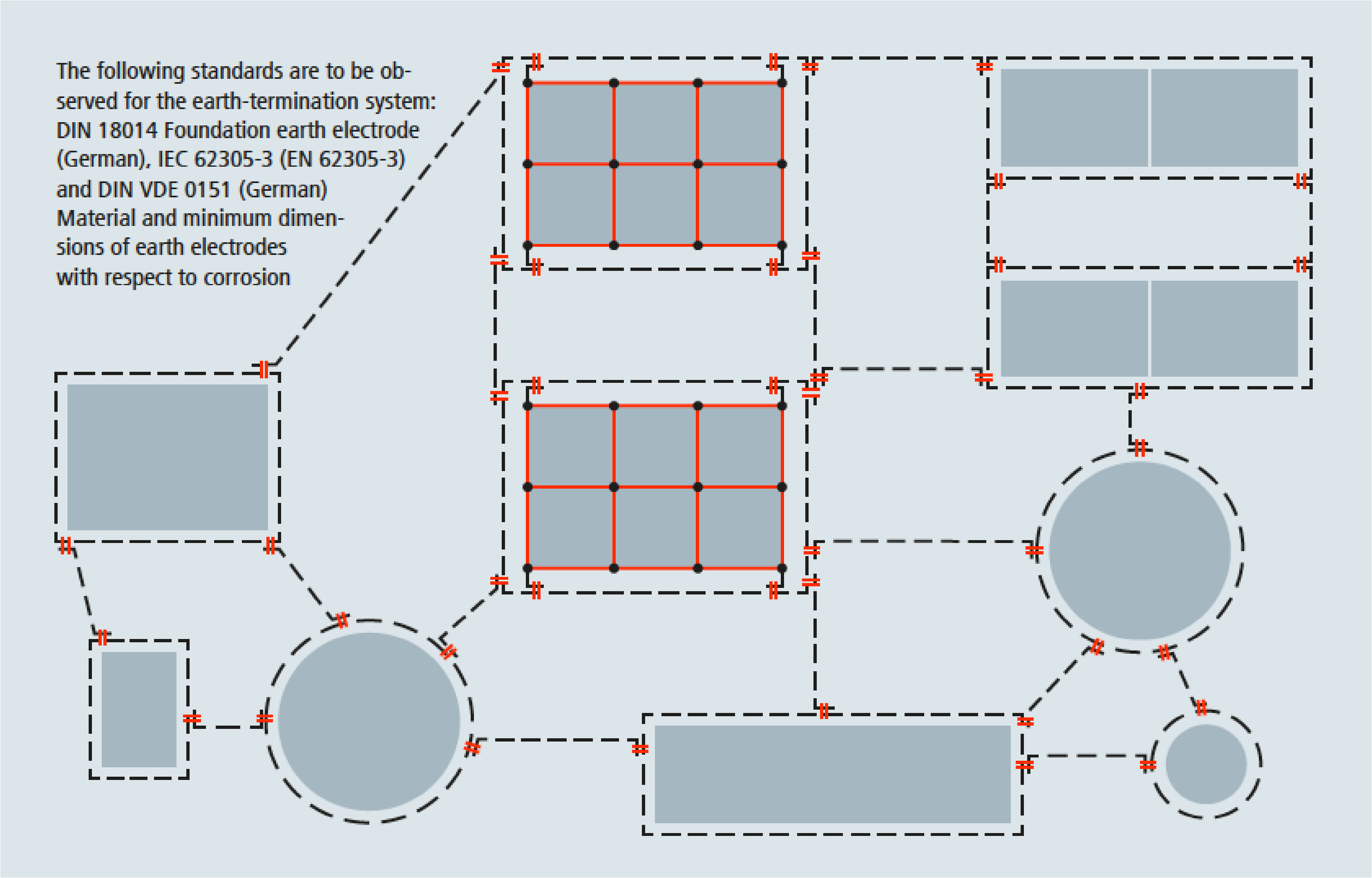


Figure 9.32.6 Example of an intermeshed earth-termination system

5. Internal Lightning Protection System

- The **internal LPS** shall prevent the occurrence of **dangerous sparking within the structure** to be protected due to lightning current flowing in the external LPS or in other conductive parts of the structure.

- Dangerous sparking may occur between the **external LPS** and **other components** such as:
  – metal installations;
  – internal systems;
  – external conductive parts and lines connected to the structure.

- Dangerous sparking between different parts can be avoided by means of
  – equipotential bonding, or
  – **electrical insulation** between the parts.

Lightning equipotential bonding

- Equipotentialization is achieved by interconnecting the LPS with
  - metal installations,
  - internal systems,
  - external conductive parts and lines connected to the structure.

- When lightning equipotential bonding is established to internal systems, part of the lightning current may flow into such systems and this effect shall be taken into account.

- Interconnecting means can be
  - bonding conductors, where the electrical continuity is not provided by natural bonding,
  - surge protective devices (SPDs), where direct connections with bonding conductors are not feasible.
  - isolating spark gaps (ISGs), where direct connections with bonding conductors are not allowed.

Lightning equipotential bonding

- The manner in which lightning equipotential bonding is achieved is important and shall be discussed with the operator of the telecommunication network, the electric power, gas pipes operator, and other operators or authorities concerned, as there may be conflicting requirements.

- SPDs shall be installed in such a way that they can be inspected.

Lightning equipotential bonding for metal installations

- In the case of **an isolated** external LPS, lightning equipotential bonding shall be established at ground level only.

- For an external LPS which is **not isolated**, lightning equipotential bonding shall be installed at the following locations:

a) in the basement or approximately at ground level. Bonding conductors shall be connected to a bonding bar constructed and installed in such a way that it allows easy access for inspection. The bonding bar shall be connected to the earth-termination system. For large structures (typically more than 20 m in length), a ring bonding bar may be used or more than one bonding bar can be installed, provided that they are interconnected;

b) where insulation requirements are not fulfilled.

Lightning equipotential bonding for metal installations

- Lightning equipotential bonding connections shall be made as direct and straight as possible.
- The minimum values of the cross-section of the bonding conductors connecting different bonding bars and of the conductors connecting the bars to the earth-termination system are listed in Table 8.
- The minimum values of the cross-section of the bonding conductors connecting internal metal installations to the bonding bars are listed in Table 9.
- If insulating pieces are inserted into gas lines or water pipes, inside the structure to be protected they shall, with the agreement of the water and gas supplier, be bridged by isolating spark gaps (ISGs) designed for such an operation.

Table 8 – Minimum dimensions of conductors connecting different bonding bars or connecting bonding bars to the earth-termination system

Class of LPS	Material	Cross-section mm^2
I to IV	Copper	16
	Aluminium	25
	Steel	50

Table 9 – Minimum dimensions of conductors connecting internal metal installations to the bonding bar

Class of LPS	Material	Cross-section mm^2
I to IV	Copper	6
	Aluminium	10
	Steel	16

Lightning equipotential bonding for external conductive parts

- For external conductive parts, lightning equipotential bonding shall be established as near as possible to the point of entry into the structure to be protected.
- If direct bonding is not acceptable, suitable **ISGs** may be used.

Lightning equipotential bonding for internal systems

- If cables of internal systems are screened or located in metal conduits, it may be sufficient to bond only these screens and conduits
- If cables of internal systems are neither screened nor located in metal conduits, they shall be bonded via SPDs. In TN systems, PE and PEN conductors shall be bonded to the LPS directly or with an SPD.
- If protection of internal systems against surges is required, a coordinated SPD system may be used. SPDs shall comply with IEC 61643-1 and IEC 61643-21

Lightning equipotential bonding for lines connected to the structure to be Protected

- All the conductors of each line should be bonded directly or with an SPD. Live conductors shall only be bonded to the bonding bar via an SPD. In TN systems, PE or PEN conductors shall be bonded directly or via an SPD to the bonding bar.

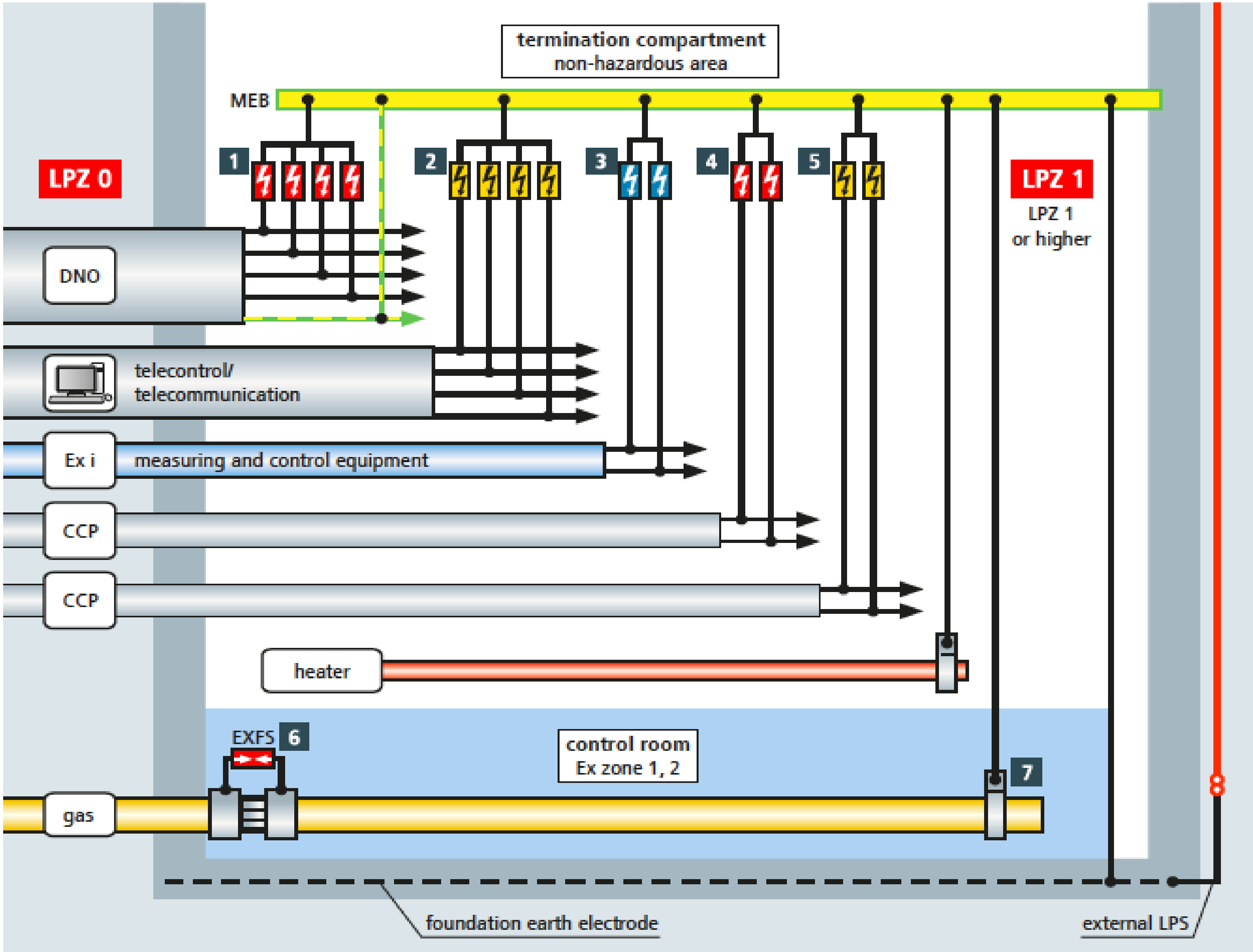


Figure 9.33.6 Lightning equipotential bonding for incoming lines

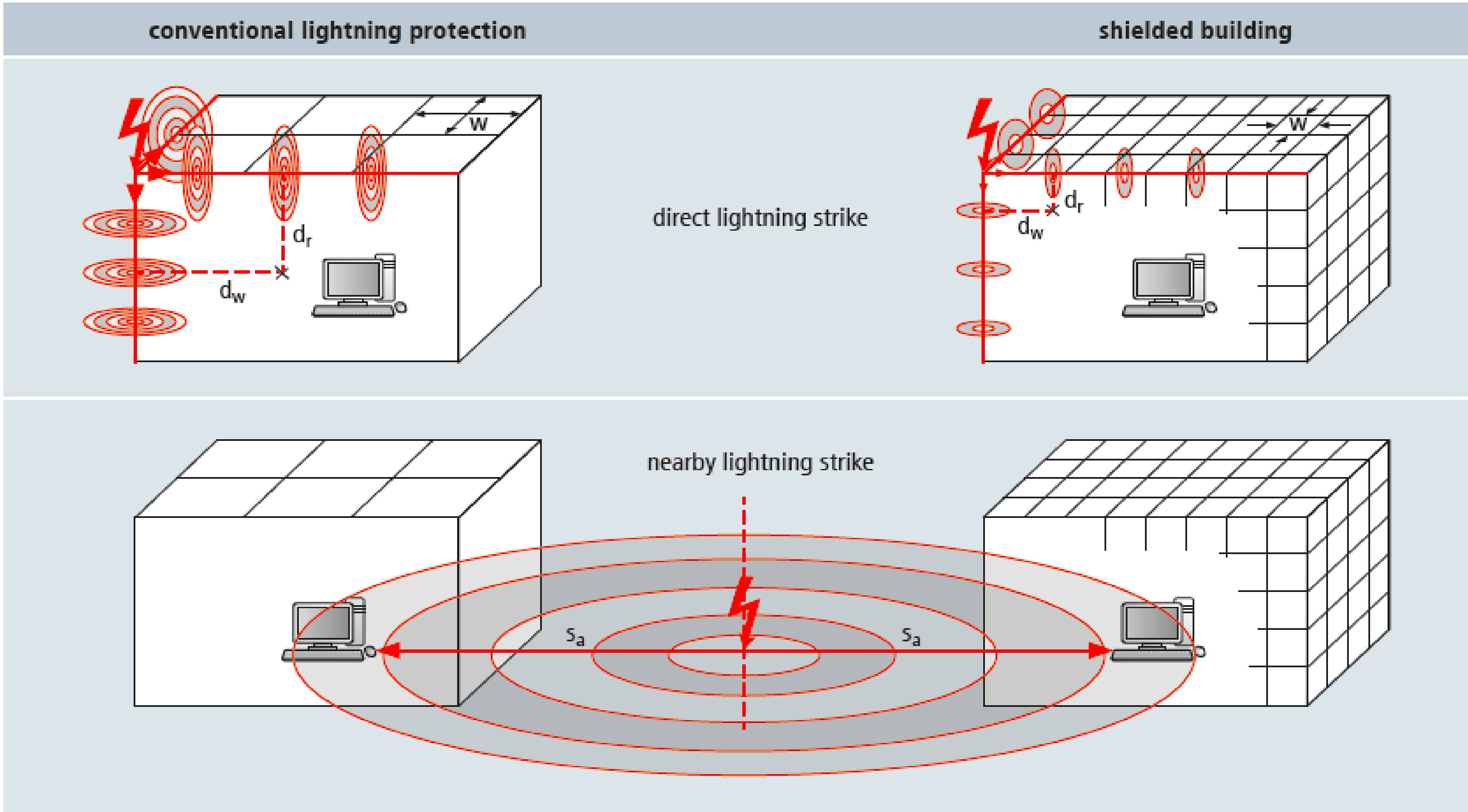


Figure 9.32.3 Shielding of structures by using natural components of the building

Electrical insulation of the external LPS

- Electrical insulation between the air-termination or the down-conductor and the structural metal parts, the metal installations and the internal systems can be achieved by providing a separation distance, s, between the parts.
- The general equation for the calculation of s is given by:

$$S = k_i / k_m \times k_c \times l \quad (m)$$

where

k_i depends on the selected class of LPS (see Table 10)

k_m depends on the electrical insulation material (see Table 11)

k_c depends on the (partial) lightning current flowing on the air-termination and the downconductor(see Table 12 and Annex C);

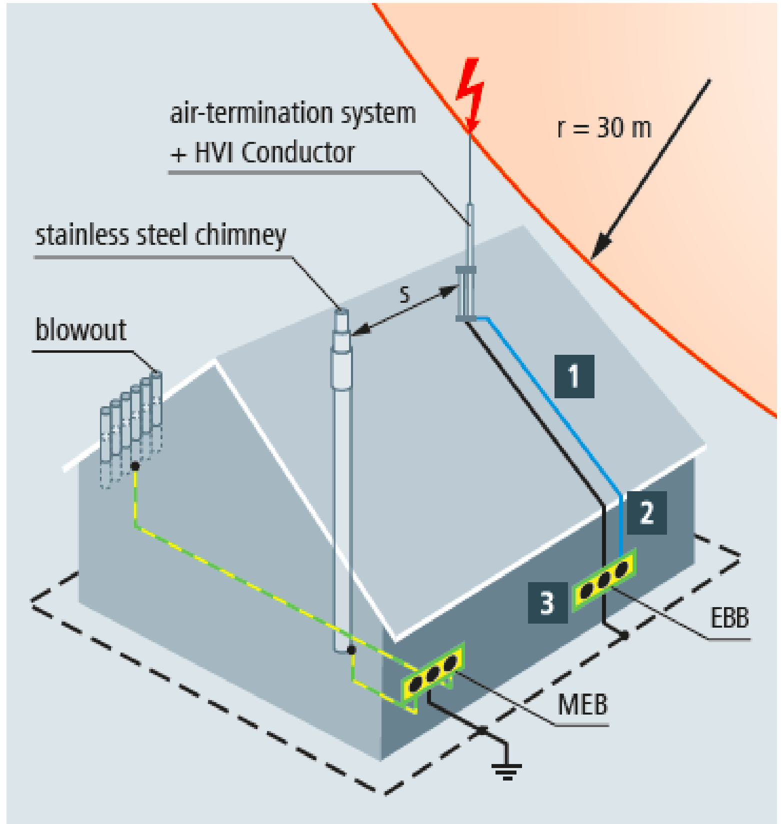
l is the length, in metres, along the air-termination and the down-conductor from the point, where the separation distance is to be considered, to the nearest equipotential bonding point or the earth termination

Table 10 – Isolation of external LPS – Values of coefficient k_i

Class of LPS	k_i
I	0,08
II	0,06
III and IV	0,04

Table 11 – Isolation of external LPS – Values of coefficient k_m

Material	k_m
Air	1
Concrete, bricks, wood	0,5
NOTE 1 When there are several insulating materials in series, it is a good practice to use the lower value for k_m. NOTE 2 In using other insulating materials, construction guidance and the value of k_m should be provided by the manufacturer.	



	Components	Part No.
1	Roof conductor holder with angled brace for HVI Conductor	202 830
2	Wall-mounted conductor holder for HVI Conductor	275 229
3	Earthing busbar (2 x 2 terminals)	472 109

Figure 9.33.1 Isolated external lightning protection system for a gable roof

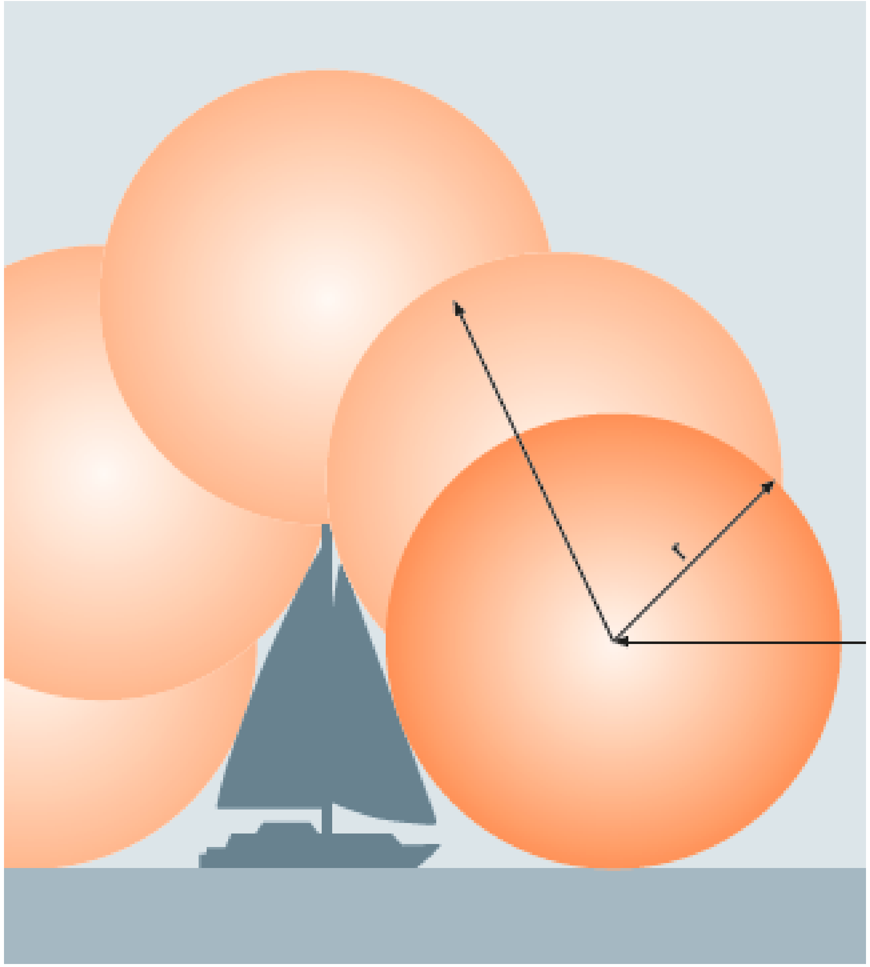


Figure 9.34.1 Determination of the lightning risk for a yacht using the rolling sphere method in case of class of LPS III

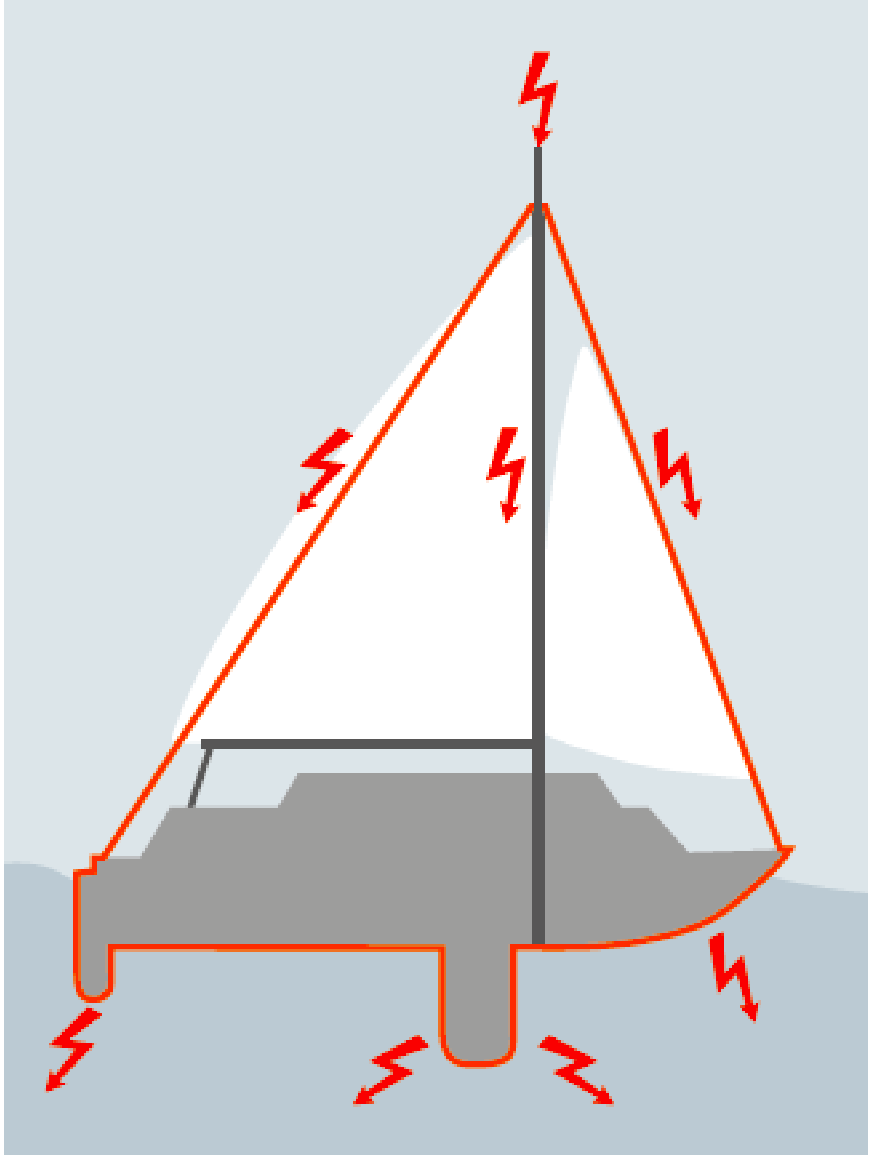
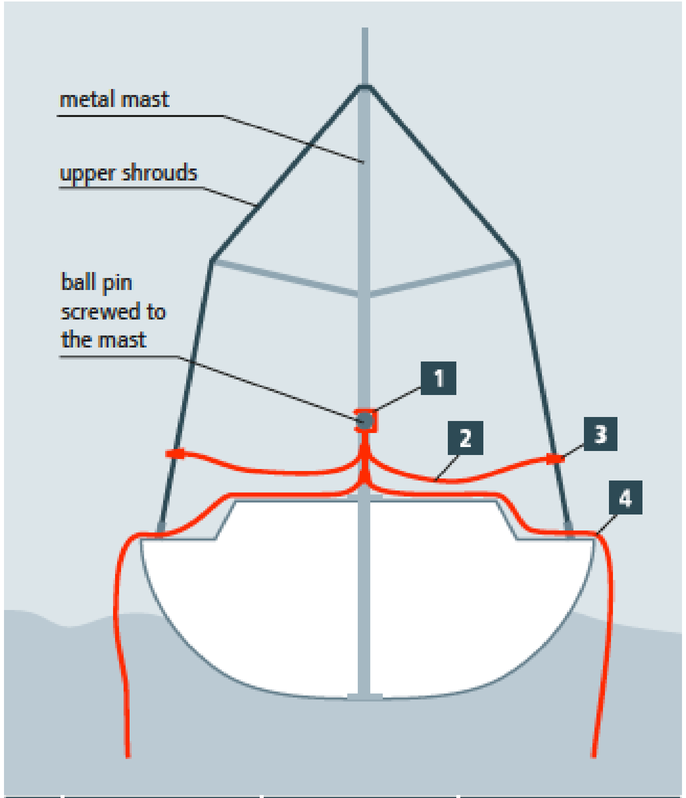
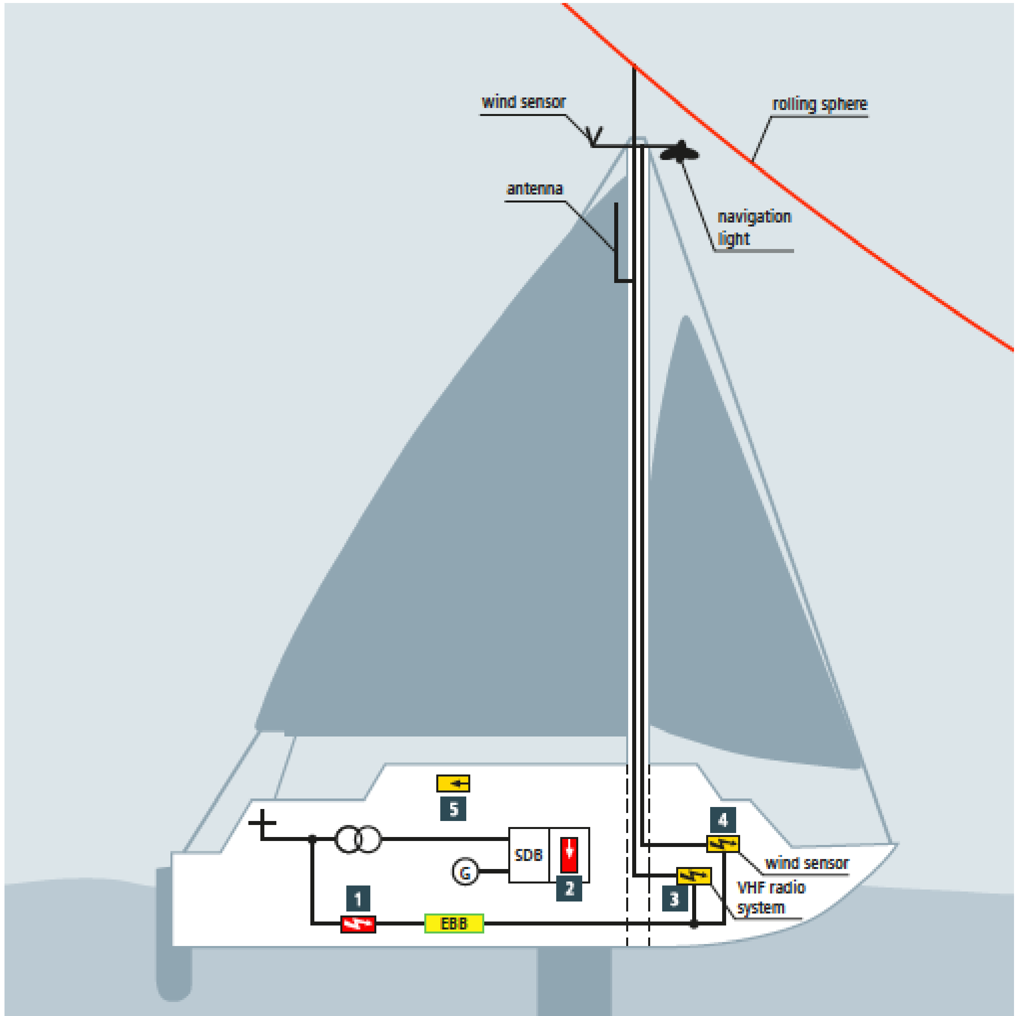


Figure 9.34.2 Lightning current distribution on a yacht following a lightning strike to the mast



	Component	Type/material	Part No.
1	Universal earth-ing clamp	UEK 25 HG	774 234
2	Multipole earthing cable	e.g. V6TZ3N8	Can be configured via the DEHN earthing and short-circuiting configurator
3	Earthing tongs	Stainless steel	546 001
4	Braided copper strip	Copper	377 007

Figure 9.34.3 Mobile lightning protection for a yacht with a metal mast



	Surge protective device	Protection for	Part No.
1	DEHNventil DV M TN 255 DEHNgap DGP M 255	Power supply system	951 200 961 101
2	DEHNguard DG M TT 2P 275	Sub-distribution board	952 110
3	DEHNgate DGA AG N	VHF radio system	929 045
4	BLITZDUCTOR BXT ML4 BE 24 + BXT BAS base part	Wind sensor for the navigation system	920 324 + 920 300
5	BLITZDUCTOR BXT ML4 BE 36 + BXT BAS base part	Power supply system of the navigation system	920 336 + 920 300

Figure 9.34.5 Basic surge protection for a yacht (observe the technical data of the manufacturer of the surge protective devices)

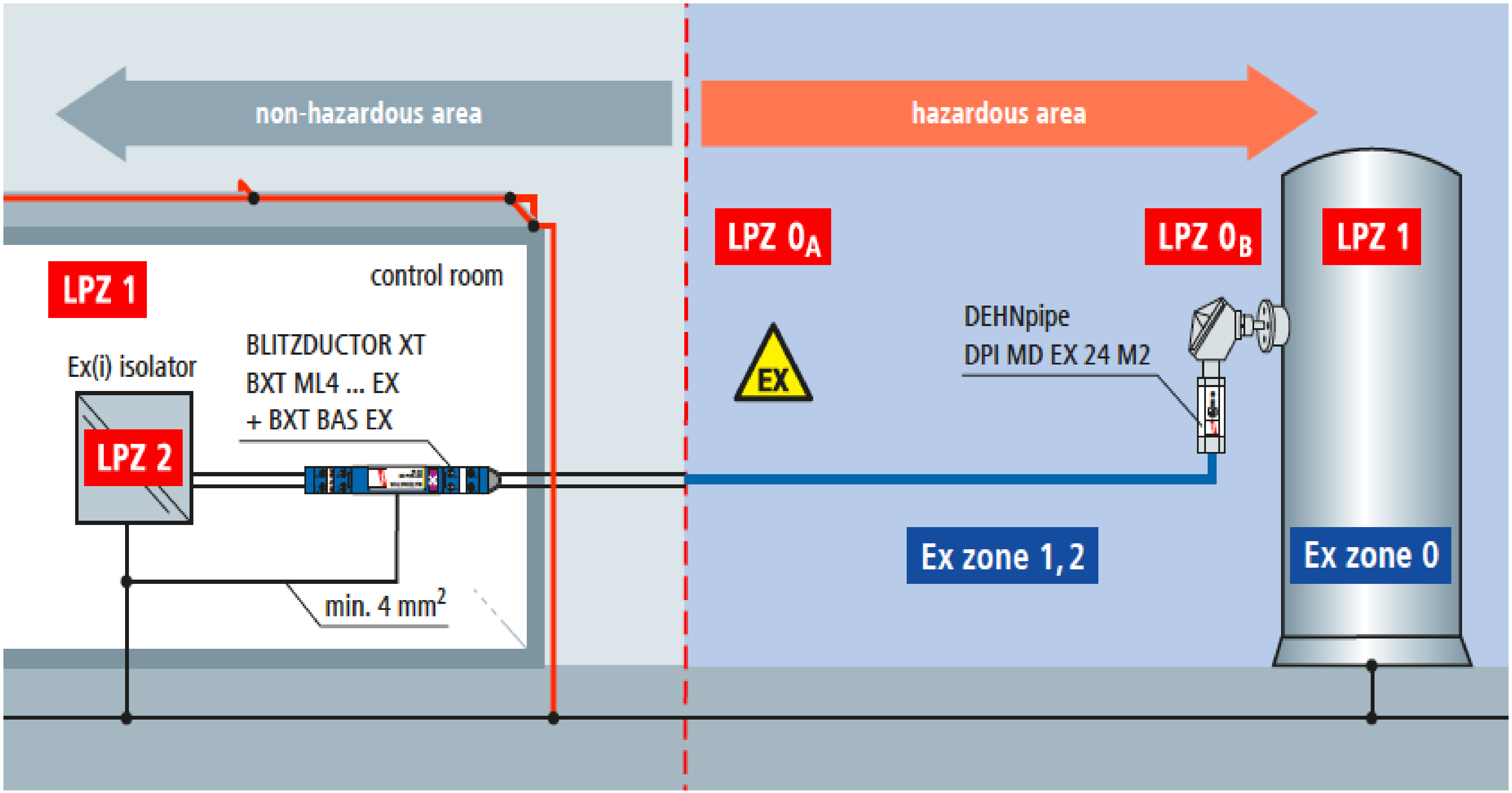


Figure 9.32.4 Surge protective devices in an intrinsically safe measuring circuit

Technical data	Transmitter TH02	Surge protective device BXT ML4 BD Ex 24
Place of installation	zone 1	zone 1
Degree of protection	ib	ia
Voltage	U_i max. = 29.4 V d.c.	U_c = 33 V d.c.
Current	I_i max. = 130 mA	I_N = 500 mA
Frequency	f_{HART} = 2200 Hz, frequency modulated	f_G = 7.7 MHz
Immunity level	according to NE 21, e.g. 0.5 kV core / core	discharge capacity of 20 kA (8/20 µs), voltage protection level ≤ 52 V core / core
Tested to	ATEX, CE	ATEX, CE, IEC 6143-21, IECEX
Unearthed 500 V	yes	yes
Internal capacitance C_i	C_i =15 nF	negligibly small
Internal capacitance L_i	L_i = 220 µH	negligibly small

Table 9.32.2 Example of a temperature transmitter

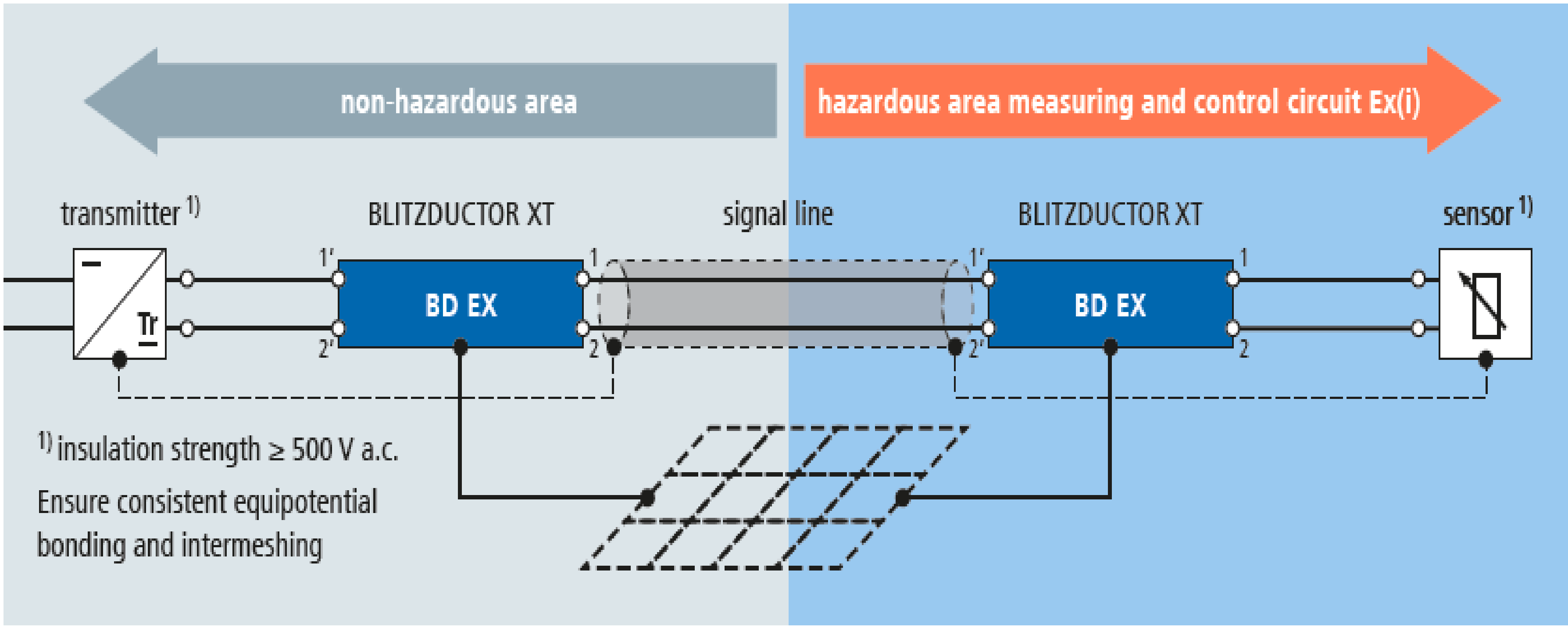
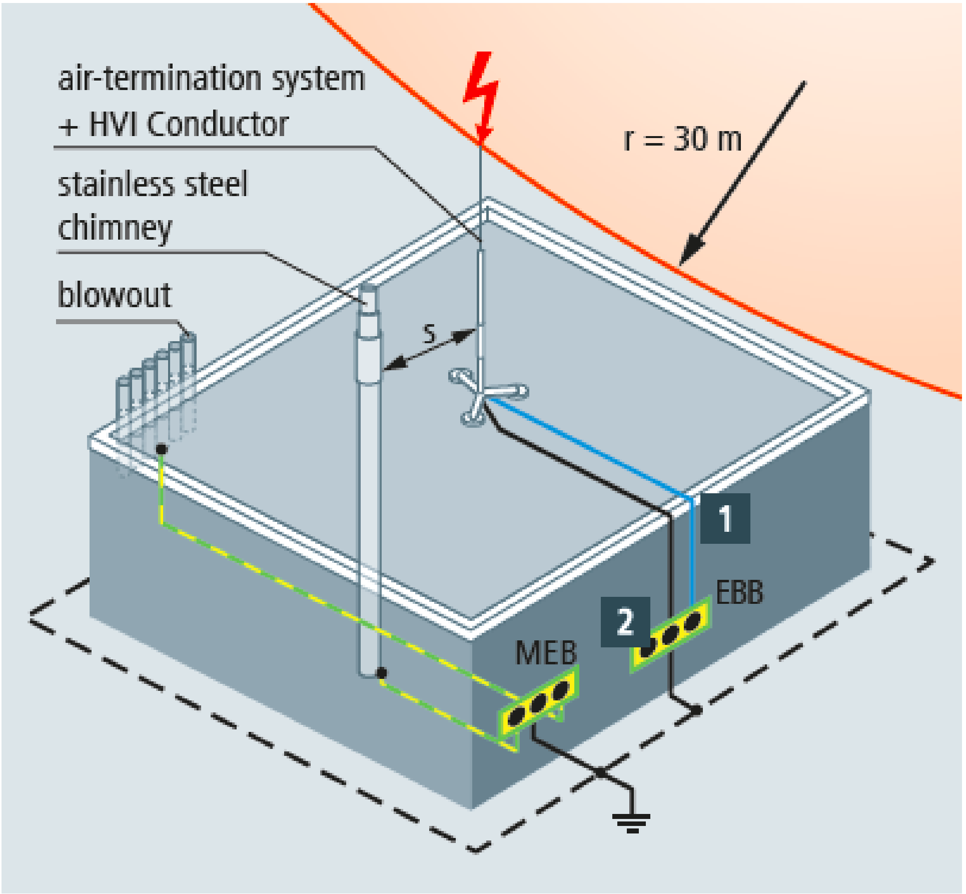


Figure 9.32.7 Example of the shield treatment of intrinsically safe cables



	Components	Part No.
1	HVI Ex W70 holder	275 440
	HVI Ex W200 holder	275 441
	HVI Ex busbar 500	275 498
2	Earthing busbar (2x2 terminals)	472 109

Figure 9.33.4 Isolated external lightning protection system for a flat roof