Protection Engineering Group 2016, Monroe, LA

By Richard Chadwick, DEHN Inc.

Richard.Chadwick@dehn-usa.com

Title: Comparison of Lightning Protection Systems (LPS) in accordance with NFPA 780 and IEC 62305-3.

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UL will grant their Master Label to a LPS that is designed compliant with UL 96A (based on NFPA 780) if installed by a UL certified installer, using UL listed components and passing a inspection by a UL LPS inspector.

UL will also provide their Master Label for a LPS designed compliant with IEC 62305 if installed by a UL certified installer and passing a UL inspection by a UL LPS inspector.

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Abstract

- This talk present the basic theory and philosophy for IEC 62305-X LPS as compared and contrasted to NFPA 780.
- We will present two reports for the LPS design of the same structure prepared by industry experts from the IEC 62305 and NFPA 780 schools of thought.
- Caveat: IEC 62305 is a very complex multi-part document, and this talk will only scratch the surface at a high level. For more detailed information see DEHN's Lightning Protection Guide, 3rd Edition, ISBN 978-9813770-1-9, free pdf download available from www.dehn-international.com

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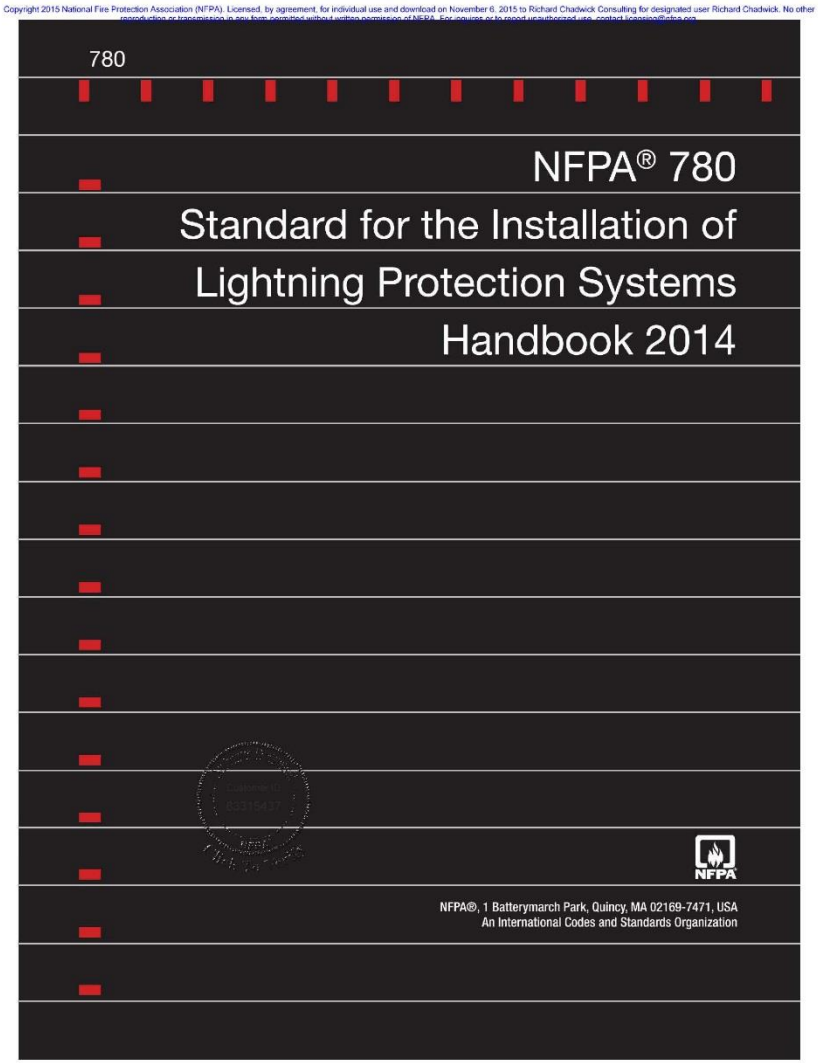
Lightning Protection Standard NFPA 780 - 2014

As of the date of this report, the NFPA 780 standard is currently published under the 2014 edition, with public input for consideration of the Technical Committee consideration for the next 2017 edition.



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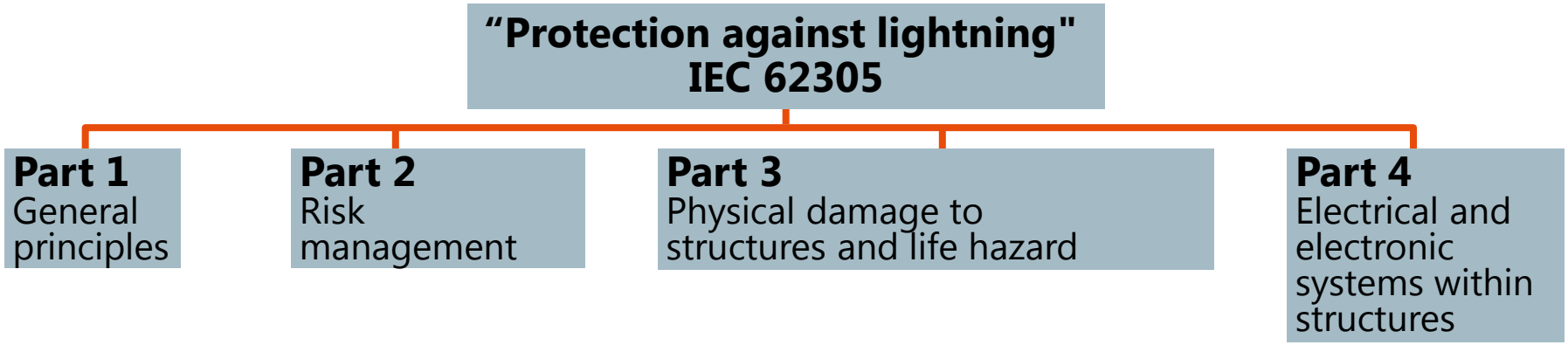
Lightning protection standard
IEC 62305:2010



The IEC 62305 standard is currently published as Edition 2: 2010 and is updated by committee TC81 under the regular maintenance process with new versions expected in 2017 and 2018

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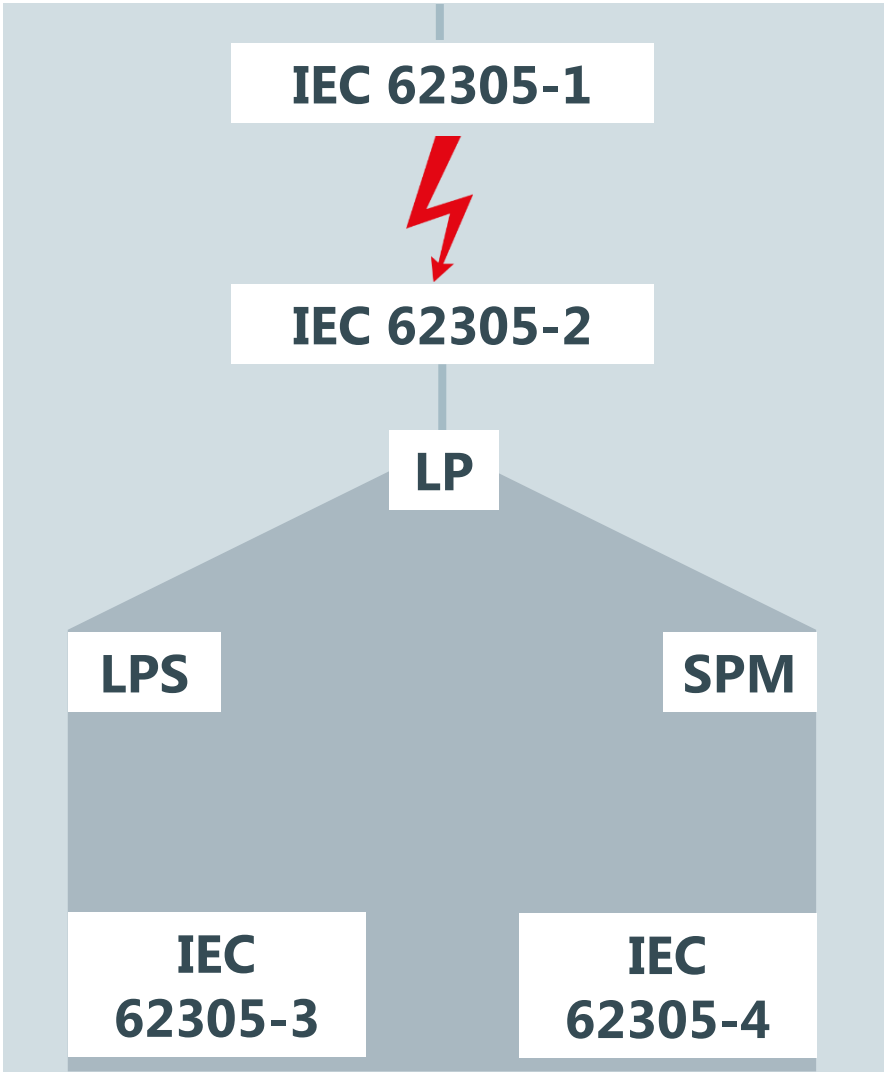
Connection between the various parts of IEC 62305



Lightning threat

Lightning risk

LP: Lightning Protection

LPS: Lightning Protection System
SPM: Surge Protection Measures

Protection measures

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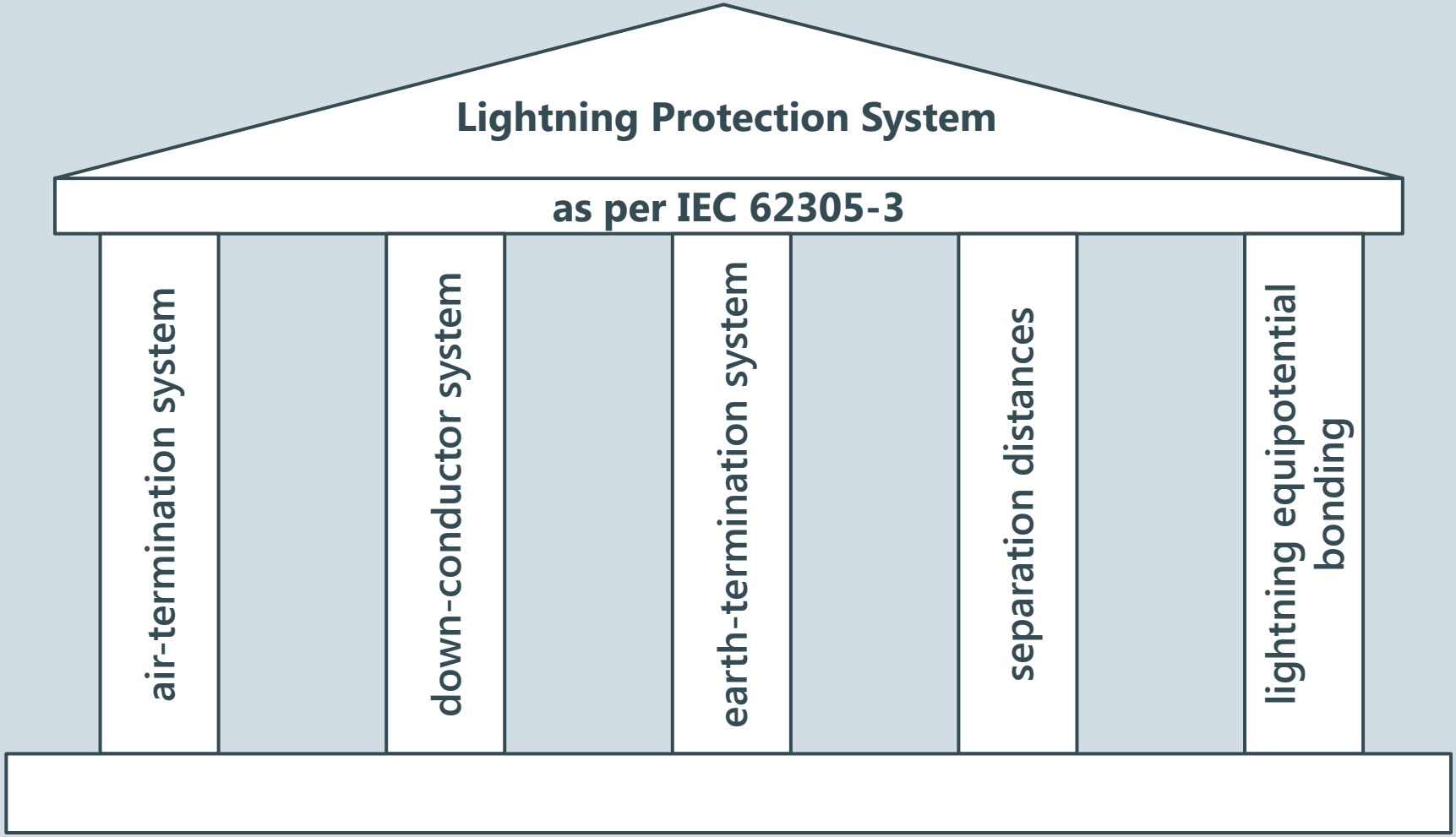
Elements of a Lightning Protection System (LPS)



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AGENDA

- Example building for comparison of IC and NFPA LPS
- Risk Analysis
- Lightning Protection Levels
- Air termination system
- Down conductors
- Earth termination system

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Example Building

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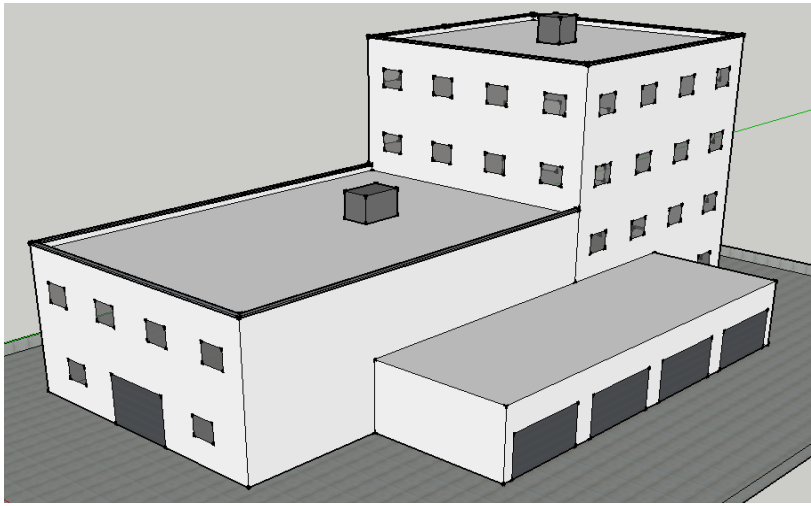
Description of the Structure

- Located in Houston Texas area, with a cloud-to-ground strike flash density of 10-14 flashes /sq.km/year.
- Building houses offices in the taller structure and manufacturing in the lower structure.
- Terrain is flat with no taller structures nearby.
- Outer structure is re-enforced masonry, with two levels, rooftop chillers and parking overhang.
- The structure is illustrated here, approximately 20 m height x 30 m wide x 50 m long



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IEC 62305 and NFPA LPS Design Reports

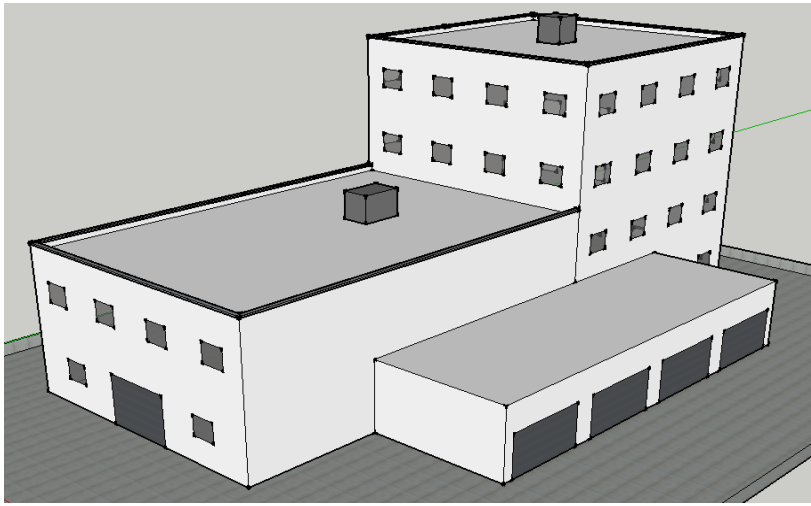
Reports were commissioned by DEHN for IEC 62305 and NFPA 780 lightning protection systems meeting requirements for UL Master Label certification:

IEC 62305 Concept Description

Project: Proposed Building Structure

Class of LPS: III

Subject Matter Expert, DEHN Germany



NFPA 780 Based Lightning Protection System Design for Fictitious Building Structure

Subject Matter Expert, Engineering Consultant

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IEC62305 Design Theory and Philosophy

- This example IEC LPS design criteria is based on a structure with LPS IEC Class III requirements which are typical commercial buildings
- Class III implies a protection system capable of intercepting lightning strikes with currents as low as 10 kA and as high as 100 kA 10/350 us.
- The rolling sphere method has been employed to develop a safety canopy constructed with a geometry of a 45 m radius and down conductors system capable of handling 100 kA currents. .
- The earthing ring around the building serves in place of individual, dedicated earthing rods.
- This design achieves full protection with eight total rods and allows flexible use of the space for future changes or equipment installation.

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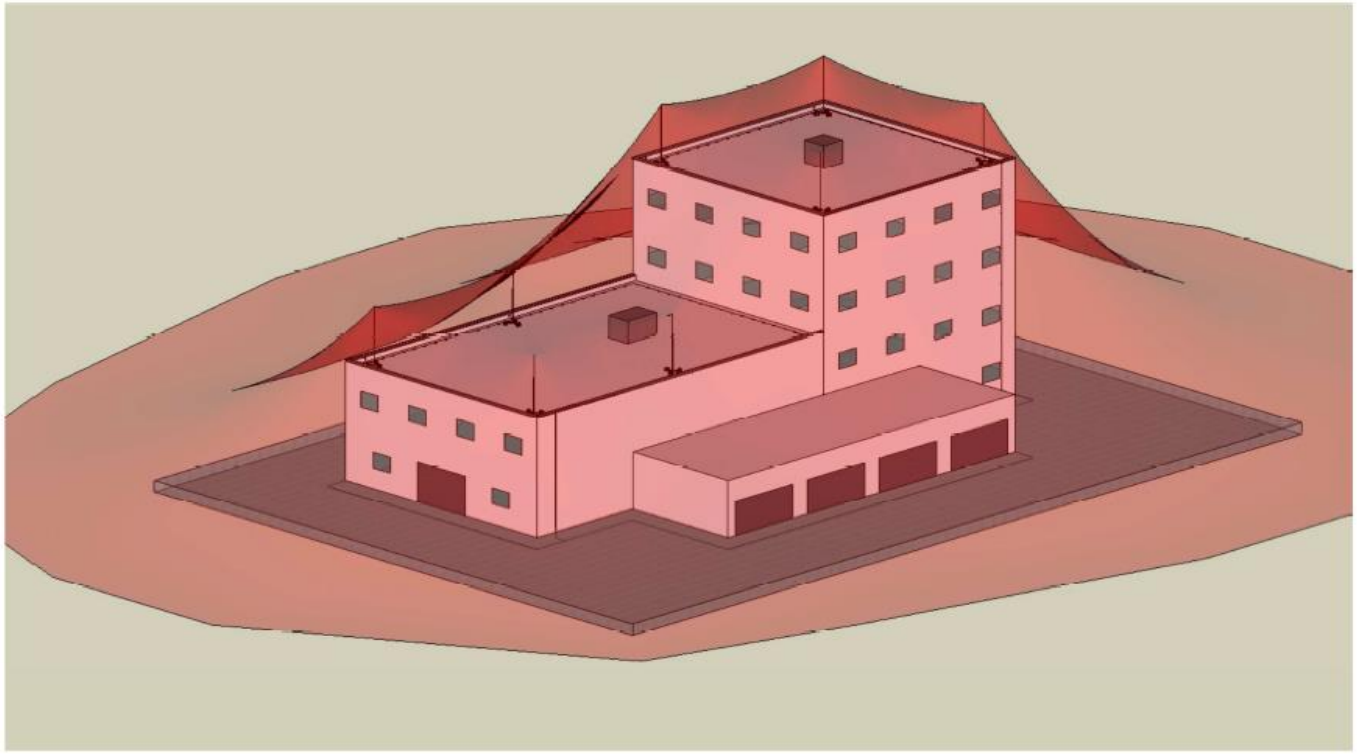
IEC62305 Design Layout

Here is an image of the IEC Lightning Protection System for this example structure.

Note the rolling sphere blanket of coverage



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NFPA 780 Design Theory and Philosophy

- The NFPA LPS design is based on the standard NFPA Class I lightning protection system for lower height ordinary building not more than 75ft tall.
- For this class of structure there is no requirement for a rolling sphere, so the basic air termination placement, down conductor cross section design and earthing rod matching system are employed per relevant NFPA 780 clauses.
- To meet the standard, each air termination rod height is selected at 24in tall, with interconnection along the roof and down conductors terminating into a dedicated earthing rod. Additional 18 in rods were added for the roof mounted air handling units, and along the loading dock structure.

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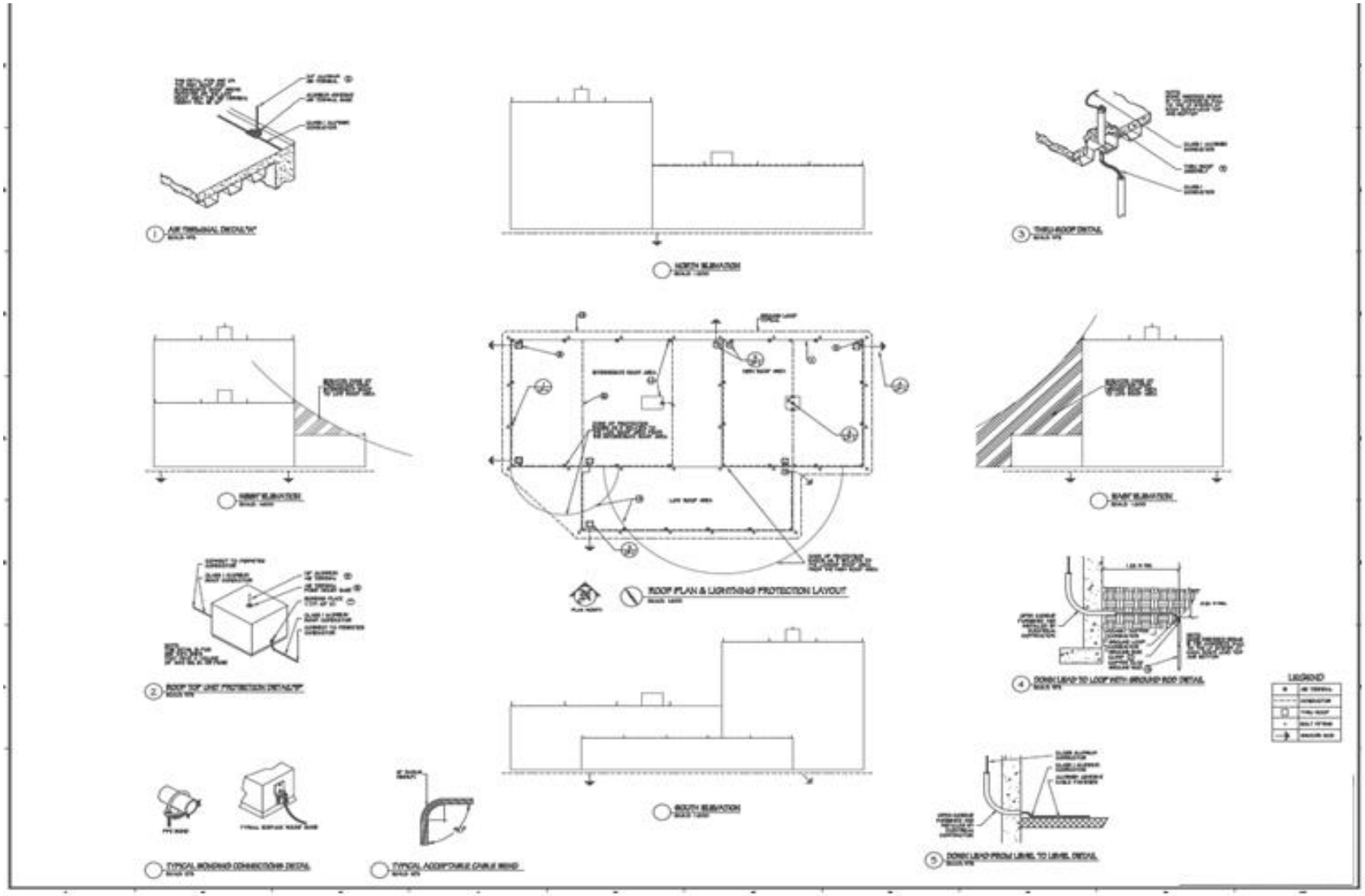
NFPA 780 Design Layout



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Comparison of Key Aspects

The results are summarized here and a brief discussion of material so designers can make a first order evaluation of the different approaches

Functional Hardware	IEC 62305 Design Element	NFPA 780 Design Element
Air Terminal	8 Rods, 4m Height DEHN type self supporting, mounted along upper perimeter	22 Rods, 24" Height along upper perimeter with 6 additional 18" Rods along edge of lower deck
Down Conductor	4 Conductors - total 200ft length	9 Conductors - total 550 feet length
Ground Rod	Ring earthing system	9 Ground Rods, 9ft long

Estimated installed costs of the two systems are comparable

Description	estimated cost of material	estimated cost installation	total
IEC 62305 prescribed LPS	$ 7,500	$ 2,400	$ 9,900
NFPA 780 prescribed LPS	$ 5,000	$ 3,600	$ 8,600

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Risk Analysis

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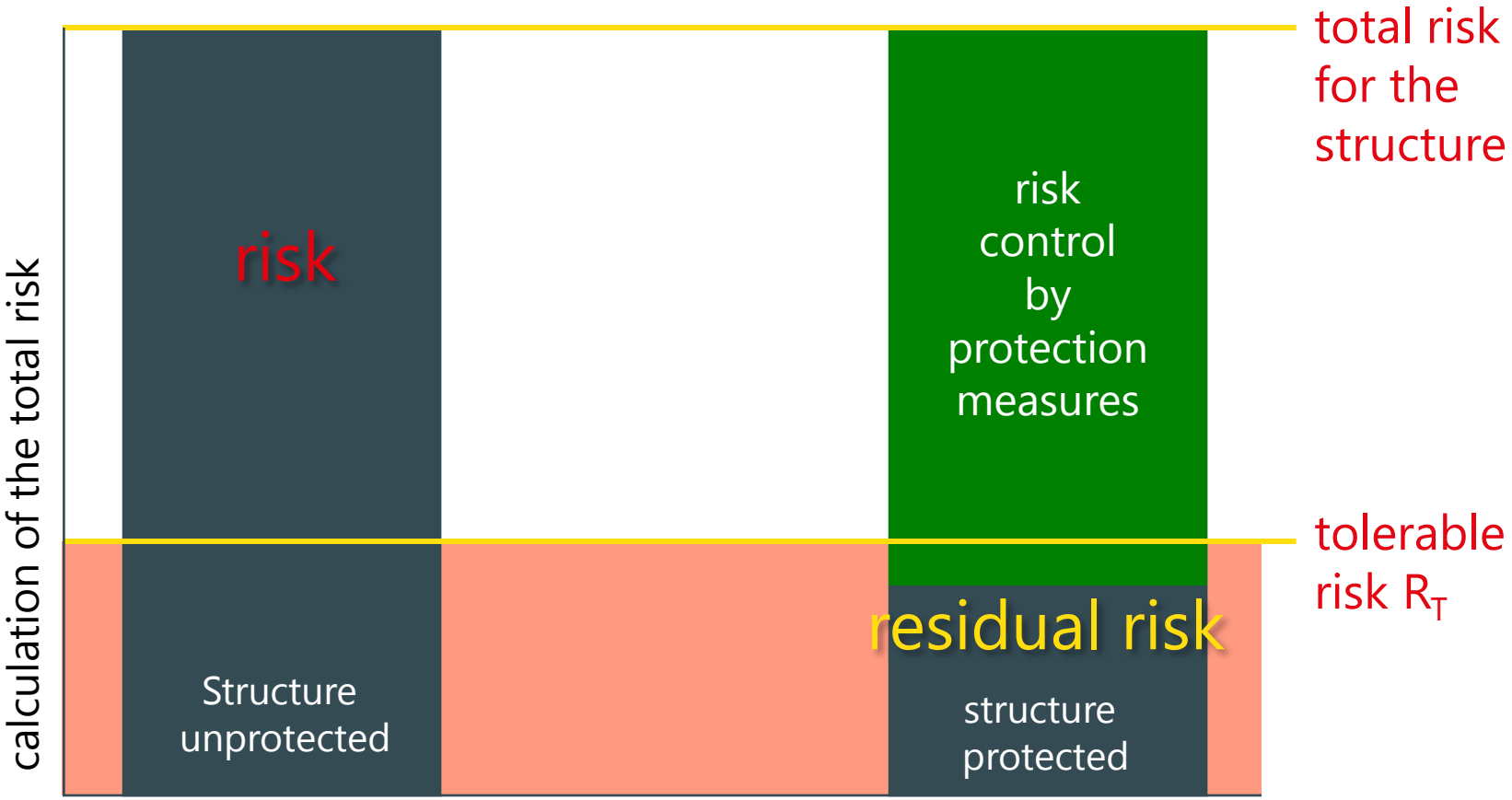
Risk assessment



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Sources of damage

Source of damage

RISK

The lightning current is the primary source of damage.
The following sources are distinguished by the point of strike:

S1: Flashes to a structure;

S2: Flashes near a structure;

S3: Flashes to a line;

S4: Flashes near a line.

Ref.: IEC 62305-2 :2010

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Types of damage

Types of damage which can appear as the consequence of lightning flashes:

D1: Injury to living beings due to touch and step voltages

D2: Physical damage (fire, explosion, mechanical destruction, release of chemicals) due to lightning current effects including sparking

D3: Failure of internal systems due to LEMP

Ref.: IEC 62305-2 :2006

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Types of loss

Each type of damage, alone or in combination with others, may produce a different consequential loss in the object to be protected. The type of loss that may appear depends on the characteristics of the object itself and its content.

The following types of loss shall be taken into account:

L1: loss of human life;

L2: loss of service to the public;

L3: loss of cultural heritage;

L4: loss of economic value (structure and its content, service and loss of activity)

Types of loss L1, L2 and L3 can be regarded as loss of social values, type of loss L4 can be regarded as economic loss.

Ref.: IEC 62305-2 :2006

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Risk Assessment

NFPA 780 has a 12 page INFORMATIONAL annex on risk assessment, including a sample worksheet

IEC 62305-2 is an 84 page NORMATIVE standard dedicated to risk assessment. IEC 62305-2 risk assessment software programs are available.

NEC Article 708.4 on Critical Operations Power Systems REQURIES a meteorological risk assessment SHALL be preformed and a migration plan designed and implemented. NEC 708.4 refers to NFPA 1600 for further guidance.

NFPA 1600 *Standard on Disaster/Emergency Management and Business Continuity Programs* is recognized by the US Department of Homeland Security as our National Preparadness Specification.

NFPA 1600 states that a meterological risk assessment SHOULD include lightning.

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Lightning strike to a building

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Lightning damage to a floating-roof tank
Orion Refinery, Norco, USA

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Lightning Protection Levels

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4. Lightning protection system (LPS)

4.1 Class of LPS

The characteristics of an LPS are determined by the characteristics of the structure to be protected and by the considered lightning protection level.

Four classes of LPS (I to IV), as shown in Table 1, are defined in this standard corresponding to lightning protection levels defined in IEC 62305-1.

LPL	Class of LPS
I	I
II	II
III	III
IV	IV

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4. Lightning protection system (LPS)

4.1 Class of LPS

Each class of LPS is characterized by the following:

a) Data dependent upon the class of LPS:

- **lightning parameters (see Tables 3 and 4 in IEC 62305-1:2010);**
- **rolling sphere radius, mesh size and protection angle (see 5.2.2);**
- **typical distances between down-conductors (see 5.3.3);**
- **separation distance against dangerous sparking (see 6.3);**
- **minimum length of earth electrodes (see 5.4.2).**

b) Data not dependent upon the class of LPS:

- **lightning equipotential bonding (see 6.2);**
- **minimum thickness of metal sheets or metal pipes in air-termination systems (see 5.2.5);**
- **LPS materials and conditions of use (see 5.5.1);**
- **material, configuration and minimum dimensions for air-terminations, down-conductors and earth-terminations (see 5.6);**
- **minimum dimensions of connecting conductors (see 6.2.2).**

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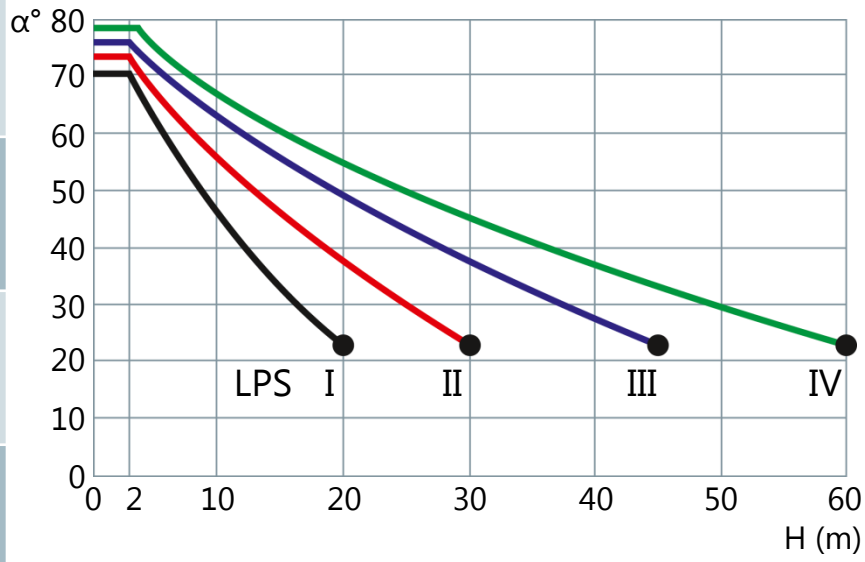
Rolling sphere radius, protection angle, mesh size and typical preferred distances between down conductors

Class of LPS	Protection method			Typical distances (m)
	Rolling sphere radius r (m)	Protection 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

Ref.: IEC 62305-3:2010, 5.2.2 + Table 2 + Figure 1, 5.3.3 + Table 4

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Formation of lightning discharge

Source: www.lightningtech.com/f_sets/facilities.html

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Formation of lightning discharge

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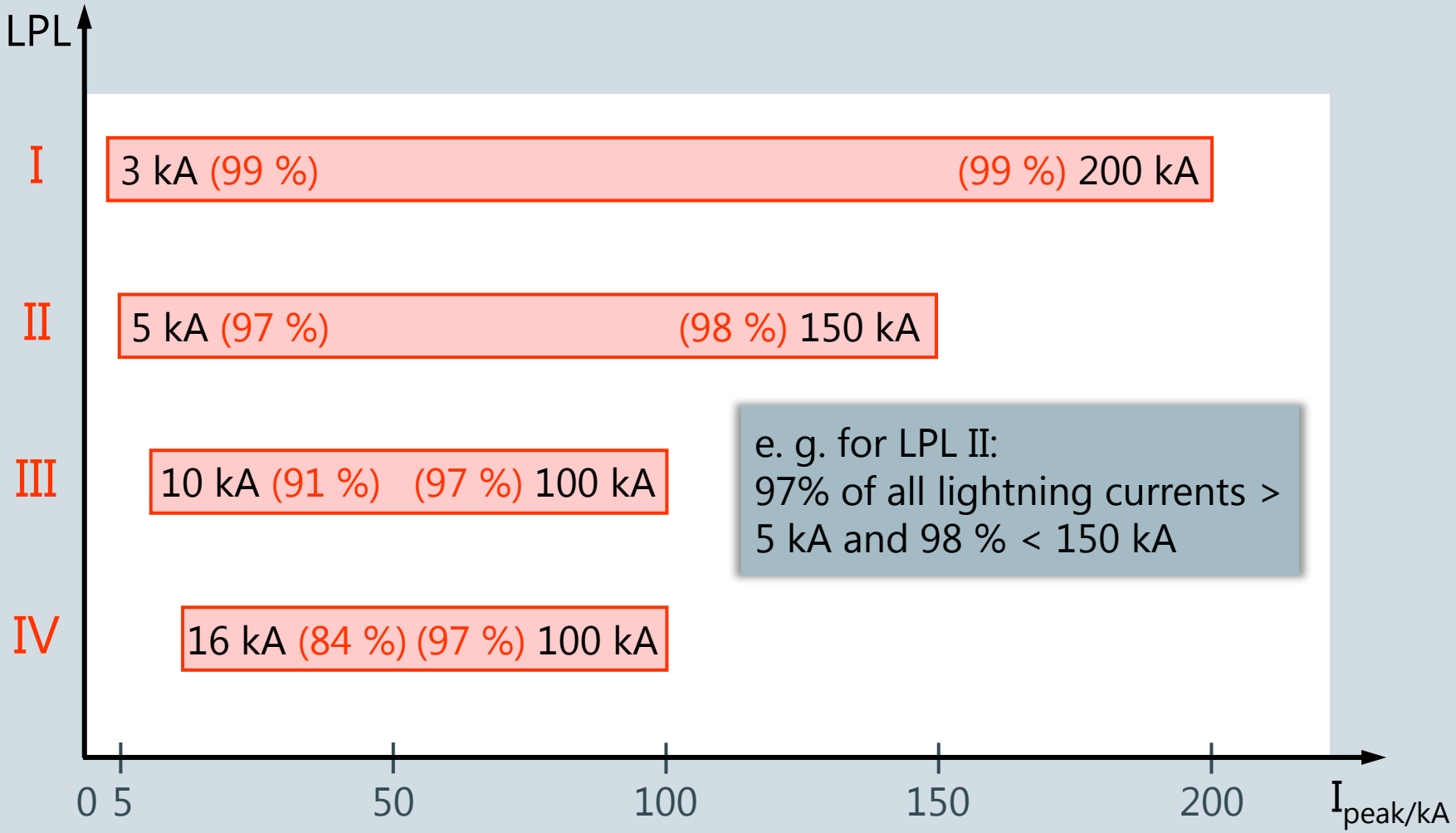
Probabilities of the limit values of the lightning current parameters



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Air Terminals

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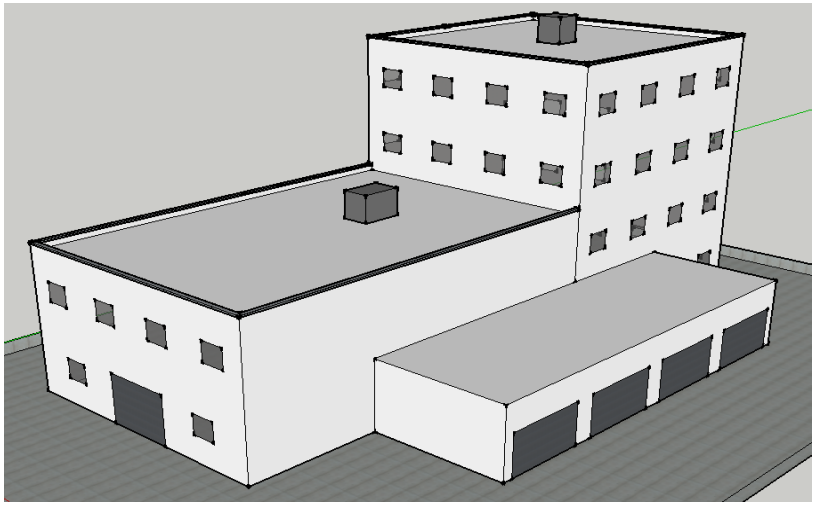
Example Building: Air Terminal Selection

In the IEC62305 design, A DEHN 4 m air termination rod type was selected to meet LPL III 45 m rolling sphere requirements. This length of rod reduces the total number of rods required.

To meet the NFPA 780 design requirements, 24-inch (0.6 m) aluminum air terminals were chosen for the office and manufacturing portions of the structure, and 18 inch air terminals were chosen for the garage section.



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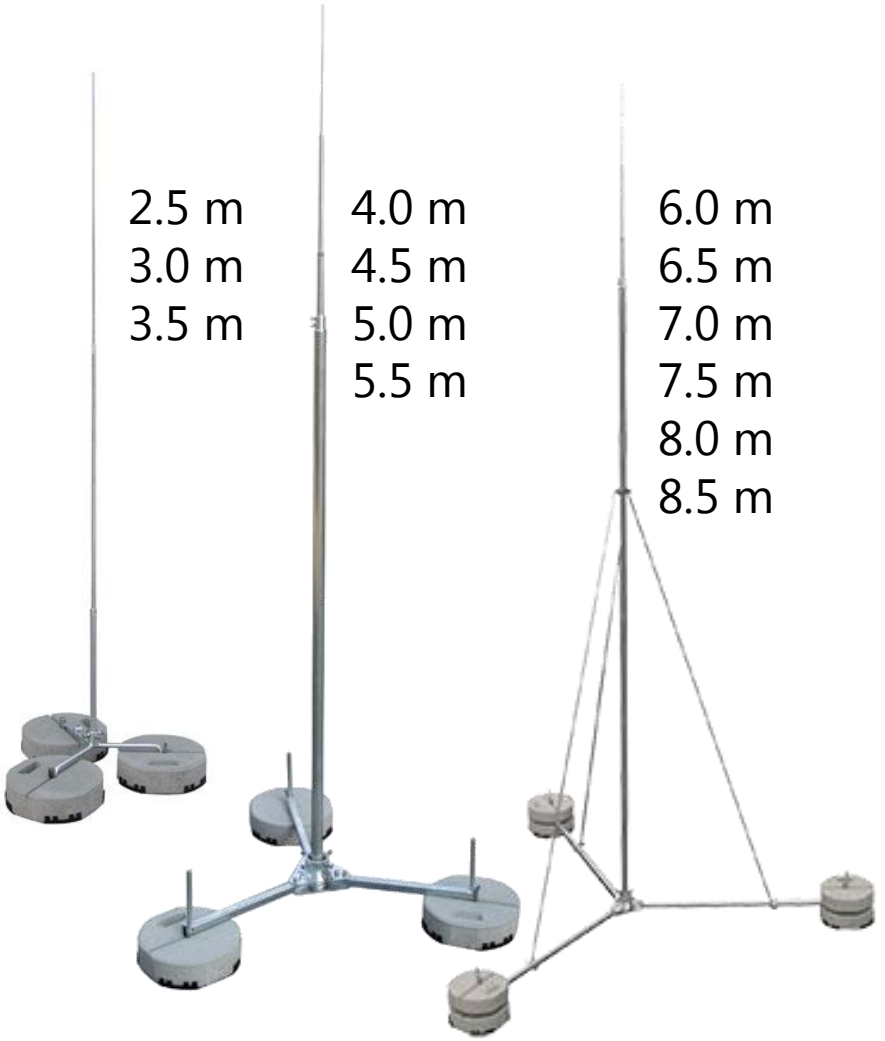
Self-supporting air-termination rods

Self-supporting air-termination rod

- Tripod for protecting roof-mounted structures
- Adaptation to the roof pitch up to max. 10°
- For wind load zone II + III
- Heights from 2.5 m to 14 m



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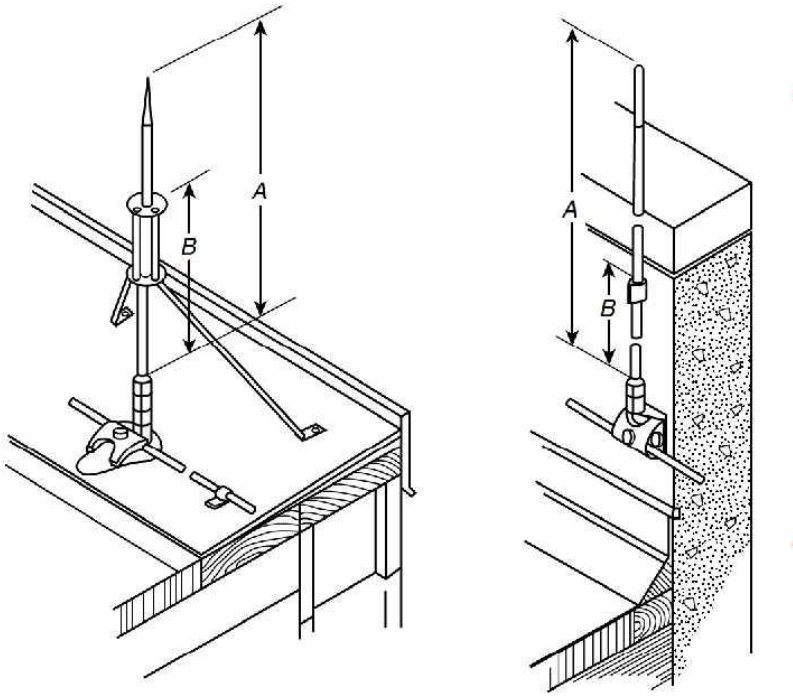
NFPA 780 Air Terminals

Air terminals must be permanently attached to structure.

For air terminals over 24 inches support must be added at not less than ½ height.

4 m (13 ft) air terminals in IEC design do not meet this NFPA requirement



A: Air terminals over 24 in. (600 mm) high are supported.
B: Air terminal supports are located at a point not less than one-half the height of the air terminal.
Note: Air terminal tip configurations can be sharp or blunt.

FIGURE 4.6.2.2.2 Air Terminal Support.

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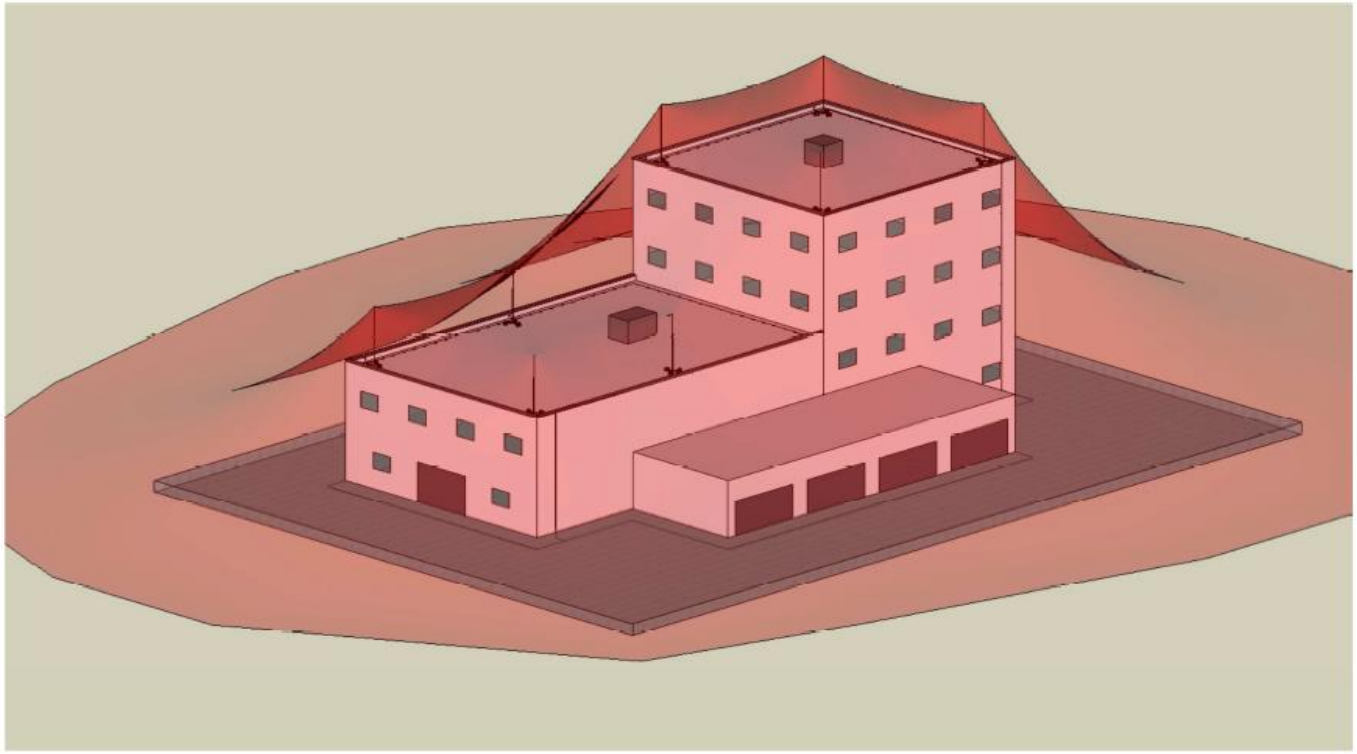
IEC62305 Design Layout

Here is an image of the IEC Lightning Protection System for this example structure.

Note the rolling sphere blanket of coverage



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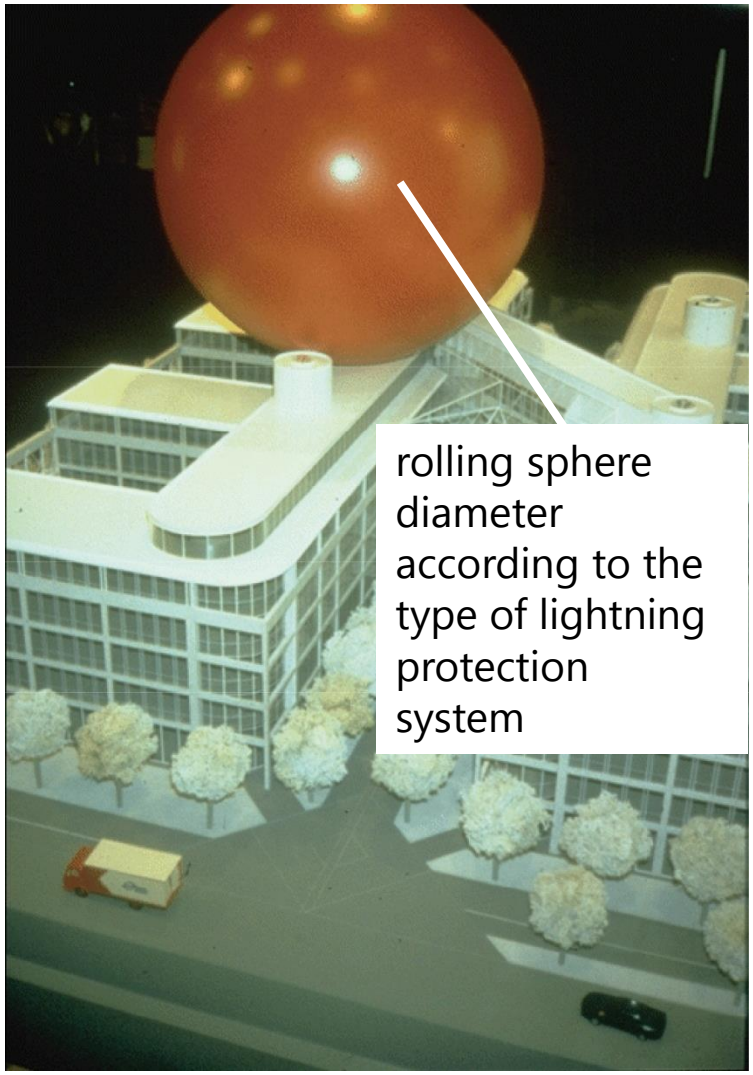
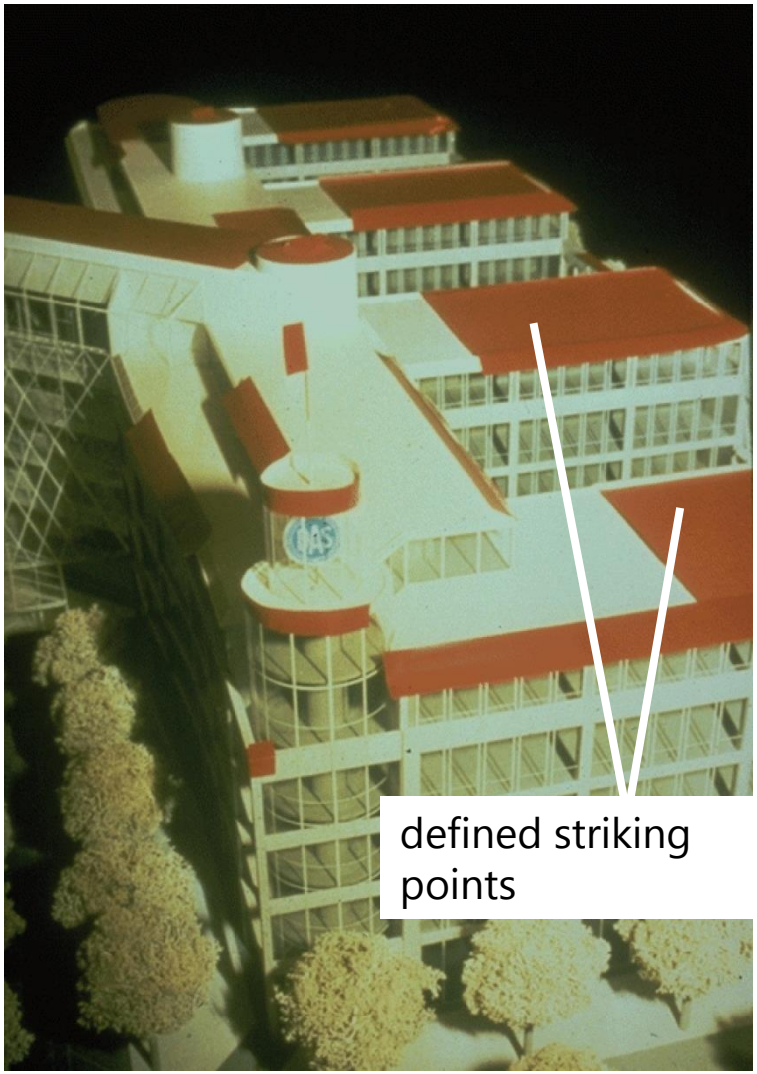
Application of the rolling sphere method at a model





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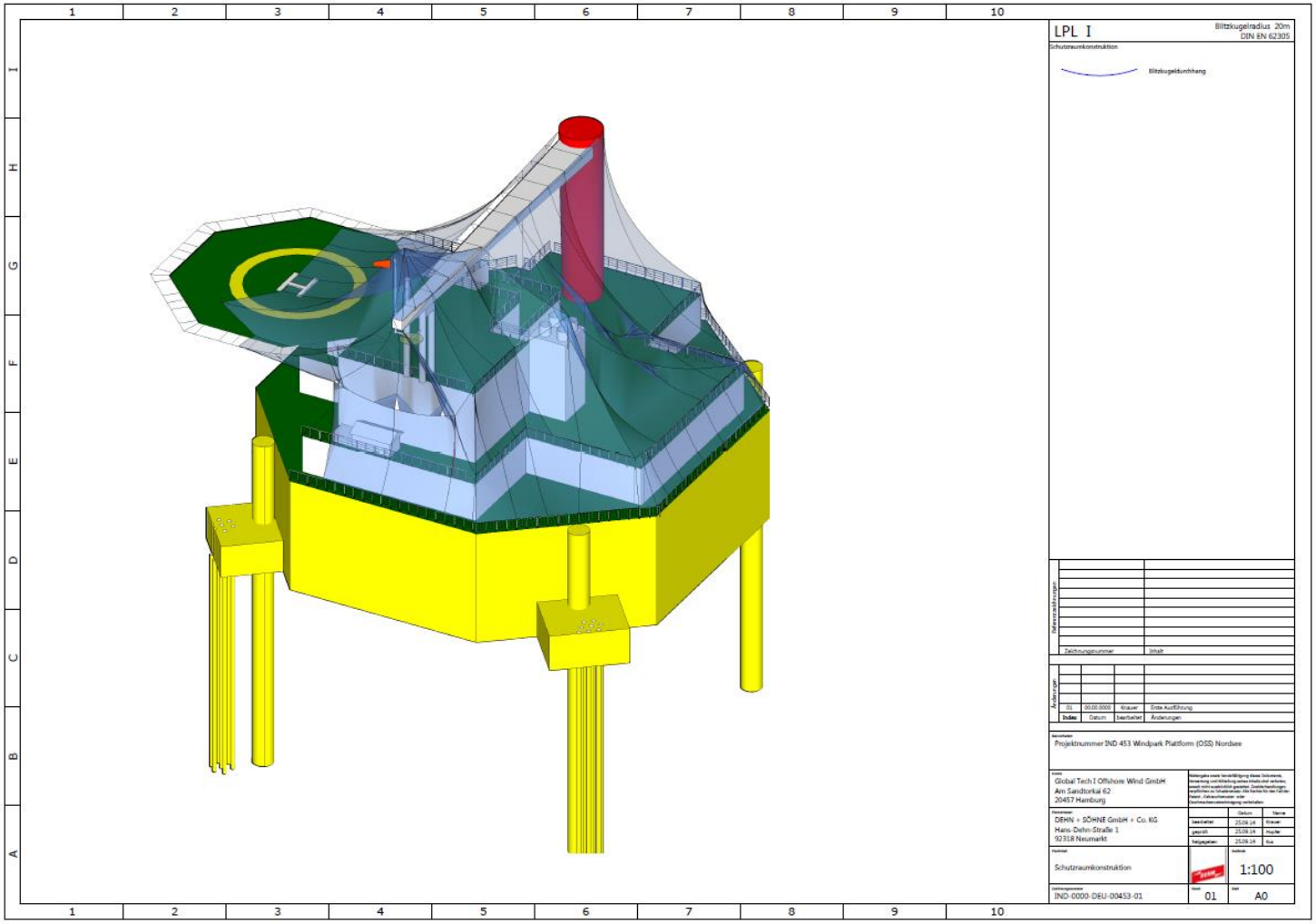
3D concept development
Example 2: HVDC platform (North Sea)



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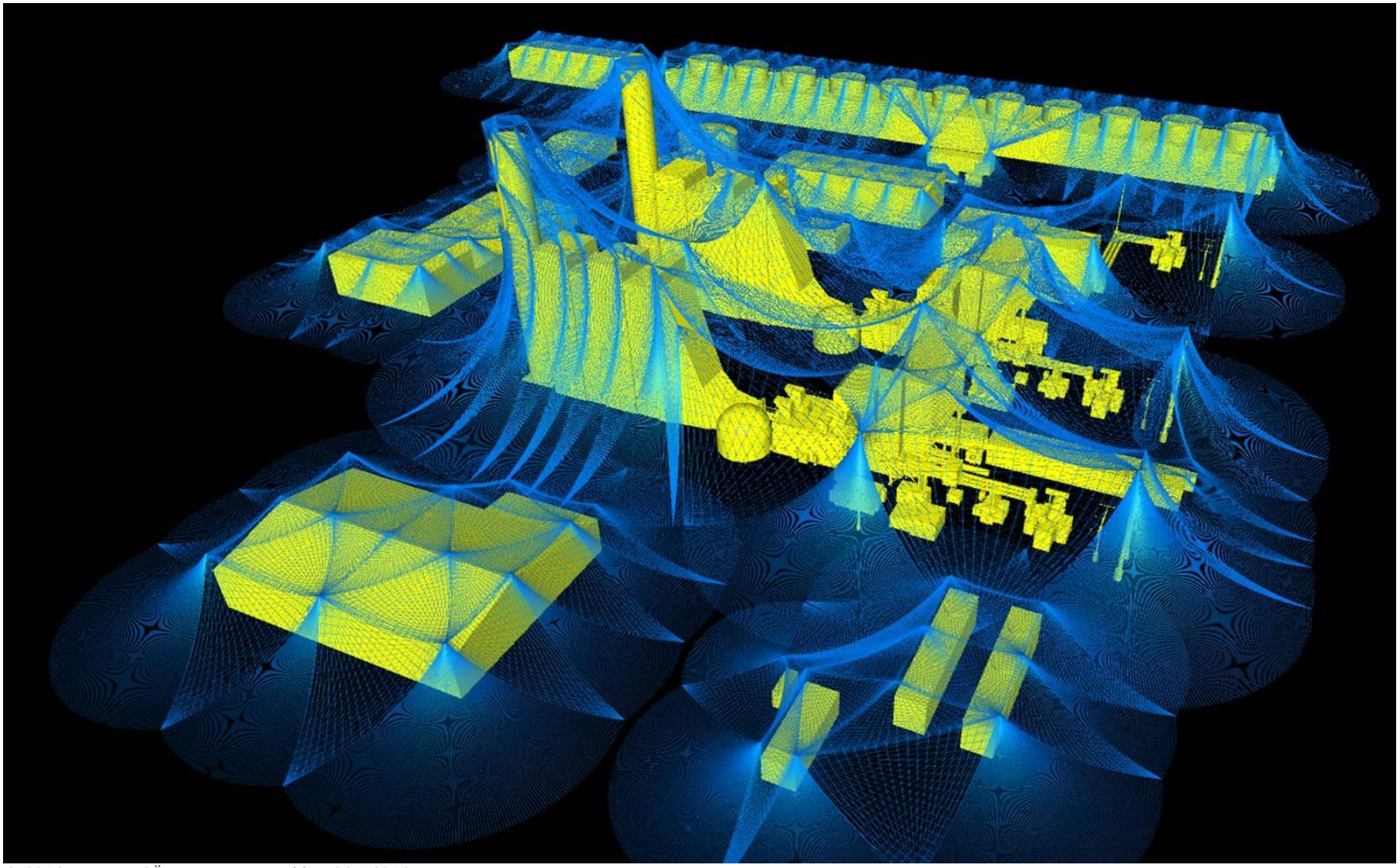

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Down Conductors

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Down-conductor systems
Typical preferred distances per IEC and NFPA

In accordance with IEC 62305-3:2010, Table 4

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

DEHN recommends:
Typical distance between down conductors ≤ 10 m on administration and industrial buildings.

NFPA 780 uses a ‘one size fits all’ approach of 30 m

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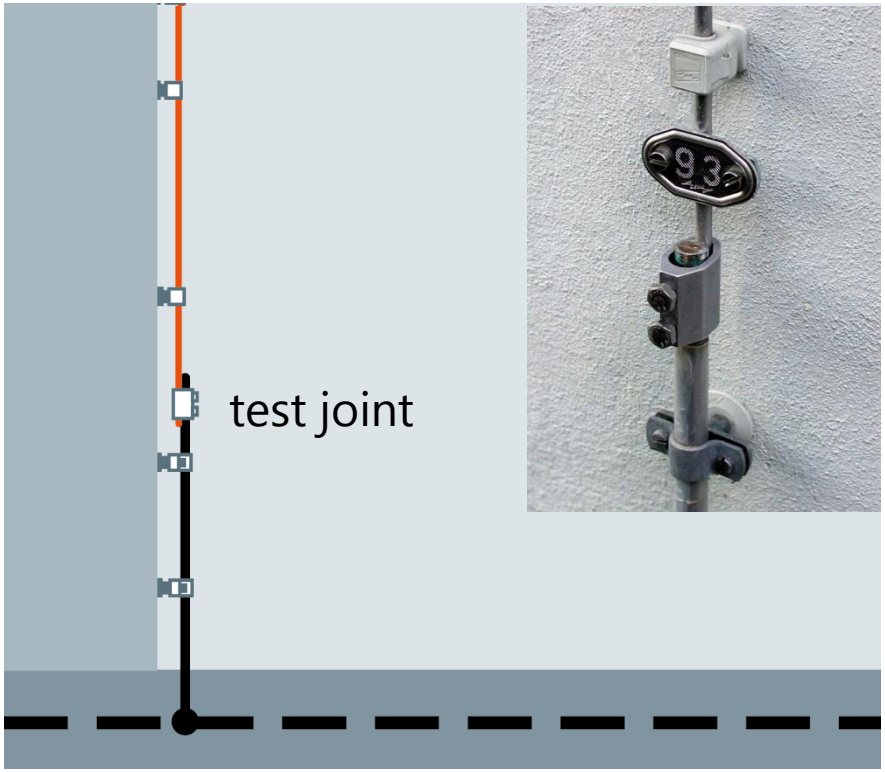
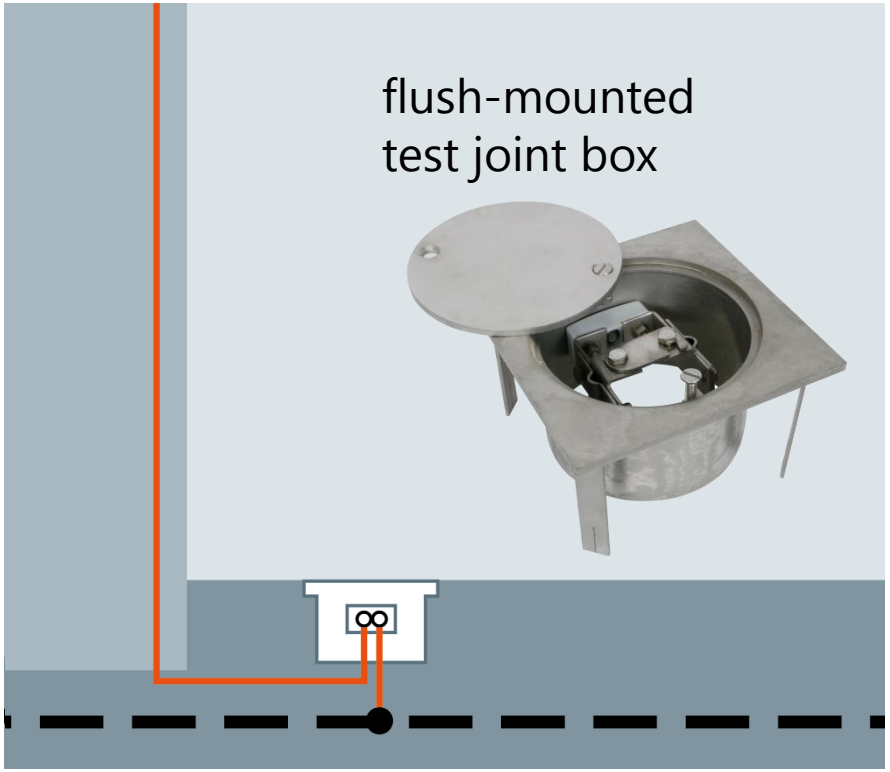
Installation of down conductors
Test joints

At the connection of the earth-termination, a test joint should be fitted on each down-conductor, except in the case of natural down-conductors combined with foundation earth electrodes.





Ref.: IEC 62305-3:2010, 5.3.6

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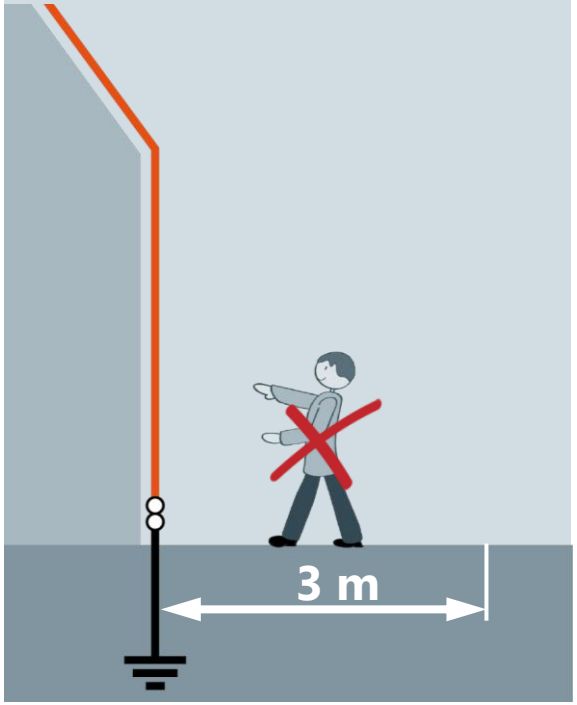
Protection measures against touch and step voltage

No life hazard if...

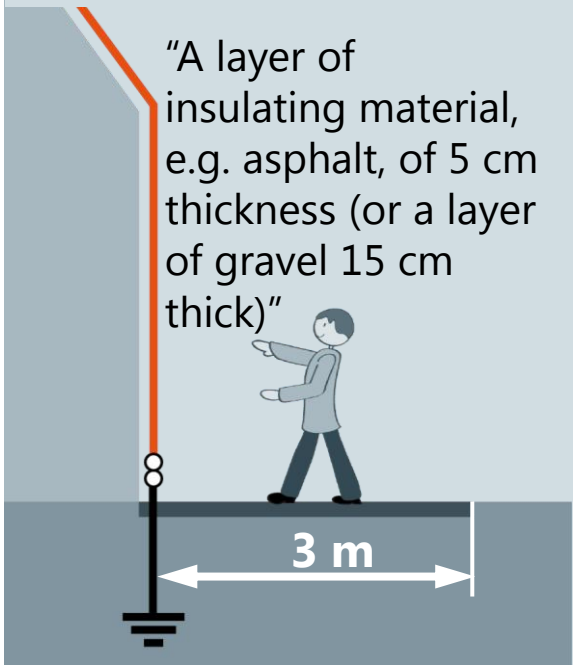
"There are no persons within 3 m from the down conductors."



"A system of at least 10 down conductors complying with 5.3.5 is employed."

"The contact resistance of the surface layer of the soil is not less than 100 kΩ."

"A layer of insulating material, e.g. asphalt, of 5 cm thickness (or a layer of gravel 15 cm thick)"



Ref.: IEC 62305-3:2010, 8.1

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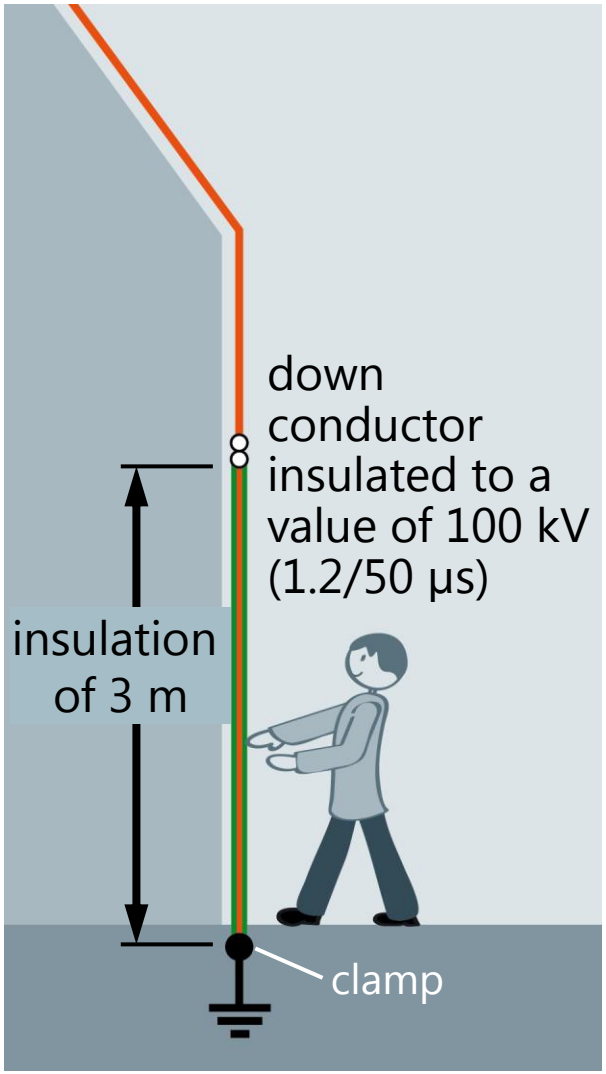
Protection measures against touch voltage



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 giving a 100 kV, 1,2/50 µs impulse withstand voltage, e.g. at least 3 mm cross-linked polyethylene
- physical restrictions and/or warning notices to minimize the probability of down-conductors being touched

Ref: IEC 62305-3 :2010; 8.1

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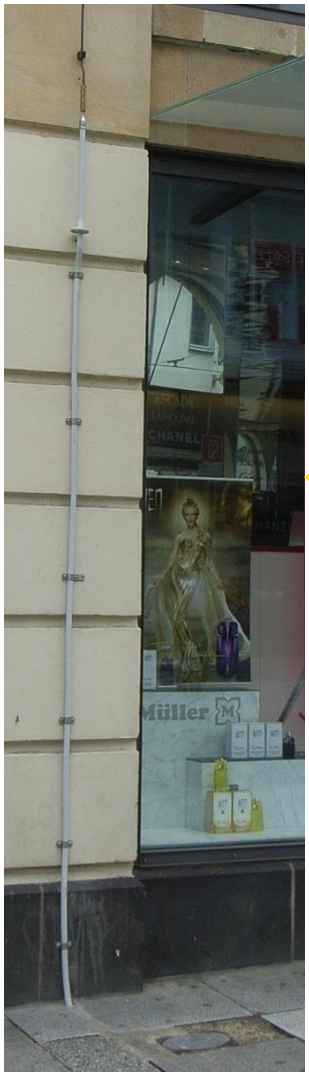
CUI Conductor Application



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Earthing

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Earthing System Design

- For this planning, we created a ring earthing system type B according to IEC 62305 with which the reinforcement structure is connected. If there are adjacent structures existing, between which electrical power supply lines and measuring and control lines are installed, the earth-termination systems have to connect between reinforcement and down conductor and earthing system type B be connected with each other. It would be advantageous to reduce the currents in the lines via many parallel paths. This aim is fulfilled by means of an intermeshed earth termination system.
- Per NFPA780, each down conductor shall terminate at a grounding electrode. For this grounding electrode, a 9-foot long, ½- inch diameter copper-clad steel ground rod driven to a depth of 10 feet is used in this design even though a ground ring electrode could be used without the ground rods.

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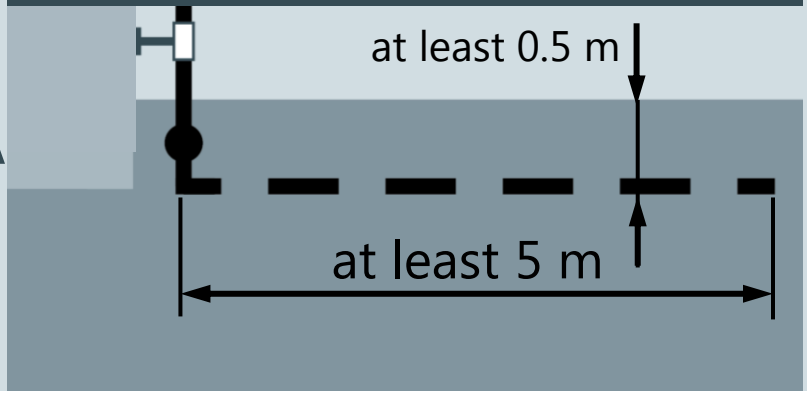
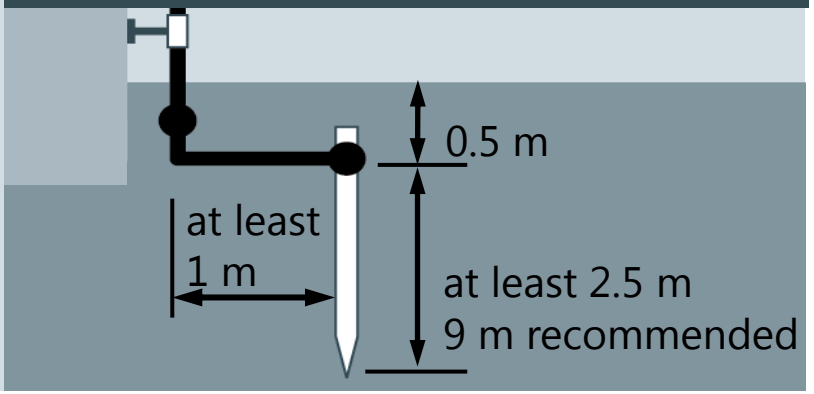
Earth electrode arrangements according to IEC 62305-3:2010

type A

horizontal (radial) earth electrode per down conductor

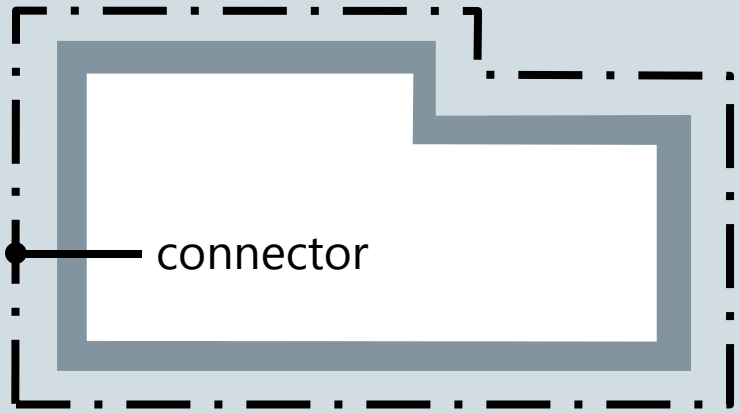


vertical earth electrode (earth rod) per down conductor

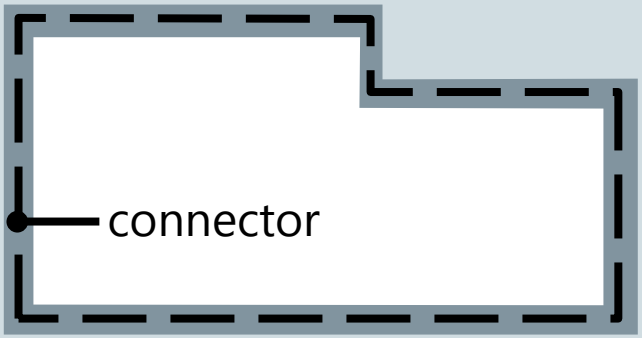


type B

ring earth electrode (at least 80% in soil)



foundation earth electrode (DIN 18014)



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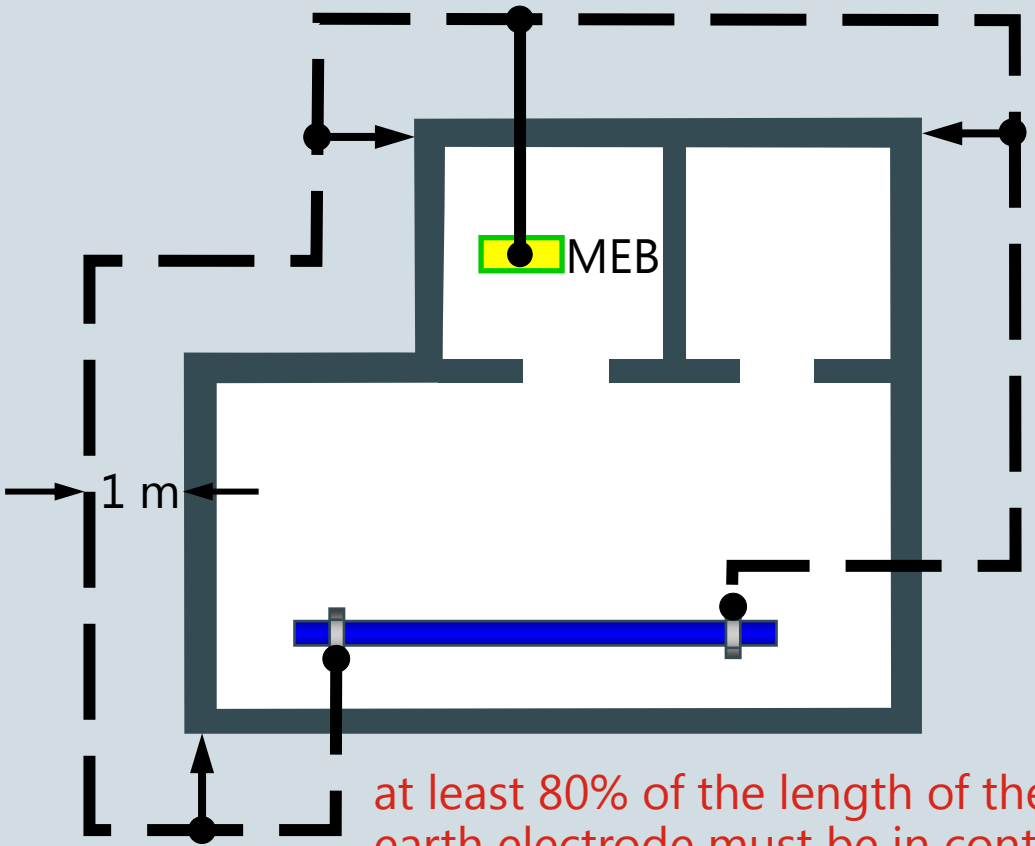
Earth-termination systems
Type B arrangement, ring or foundation earth electrode



MEB: Main Earthing Busbar

- 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. Such earth electrodes may also be meshed.

Ref.: IEC 62305-3:2006, 5.4.2.2

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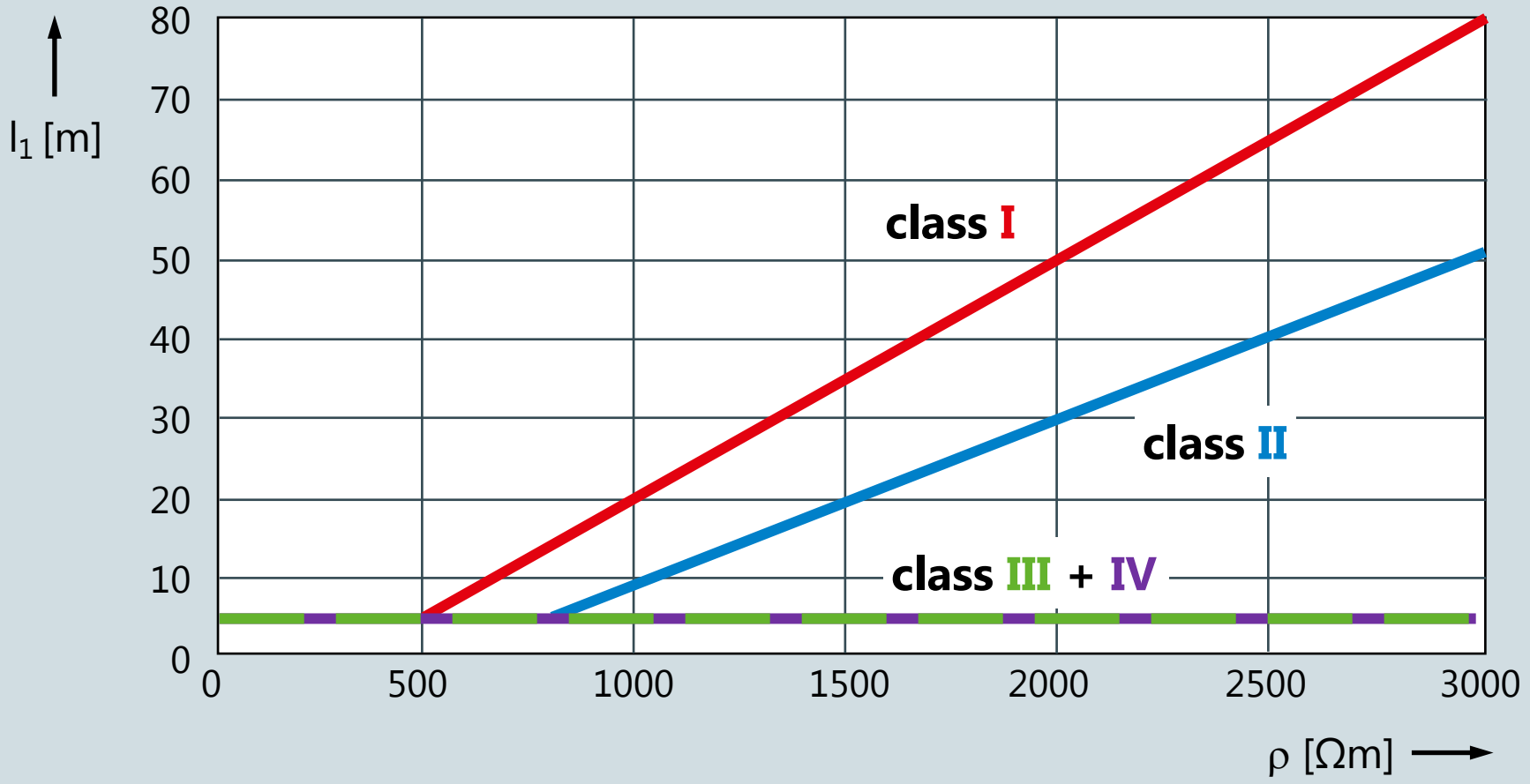
Minimum length of each earth electrode according to the class of LPS



Note: Classes III and IV are independent of soil resistivity ρ

Ref.: IEC 62305-3:2010, 5.4.2.1 Figure 3

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Summary

UL will now offer a UL Master Label for IEC 62305 compliant lightning protection systems.

IEC 62305 risk assessment is normative, NFPA less detailed risk assessment is informative.

IEC 62305 risk assessment results in four LPS classes, with air termination, down conductor, and earth termination systems dependent on LPS class. NFPA 780 risk assessment results in a go/no go one size fits all LPS, with a rolling sphere equivalent to IEC LPS Class 3.

NEC requires risk assessment for critical operations power systems (COPS)

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Inspection and Maintenance

IEC 62305-3:2010

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D.6 Maintenance and inspection

D.6.3 Qualifications

Only qualified personnel having the necessary training and expertise shall be permitted to maintain, inspect and test the LPS system of explosives facilities.

Inspection requires personnel who

a) have technical knowledge and understanding of the theoretical and practical requirements for installation in hazardous areas and for LPS equipment and installations,

b) understand the requirements of visual and complete inspections as they relate to the installed LPS equipment and installations.

NOTE Competencies and training may be identified in relevant national training and assessment frameworks.

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IEC 62305-3:2010

E.7.1 Scope of inspections

Inspection of the LPS should be conducted by a lightning protection specialist in accordance with the recommendations of Clause E.7.

The inspector should be provided with the LPS design report containing the necessary documentation of the LPS such as design criteria, design description and technical drawings. The LPS inspector should also be provided with previous LPS maintenance and inspection reports.

All LPS should be inspected on the following occasions:

- **during installation of the LPS, especially during installation of components which are concealed in the structure and will become inaccessible;**
- **after the completion of the LPS installation;**
- **on a regular basis according to Table E.2.**

Maximum period between inspections of an LPS

Protection level	Visual inspection year	Complete inspection year	Critical situations [a, b] complete inspection year
I and II	1	2	1
III and IV	2	4	1

[a] Lightning protection systems utilized in applications involving structures with a risk caused by explosive materials should be visually inspected every 6 months. Electrical testing of the installation should be performed once a year. An acceptable exception to the yearly test schedule would be to perform the tests on a 14 to 15 month cycle where it is considered beneficial to conduct earth resistance testing over different times of the year to get an indication of seasonal variations.

[b] Critical situations could include structures containing sensitive internal systems, office blocks, commercial buildings or places where a high number of people may be present.

Ref.: IEC 62305-3:2010, Table E.2

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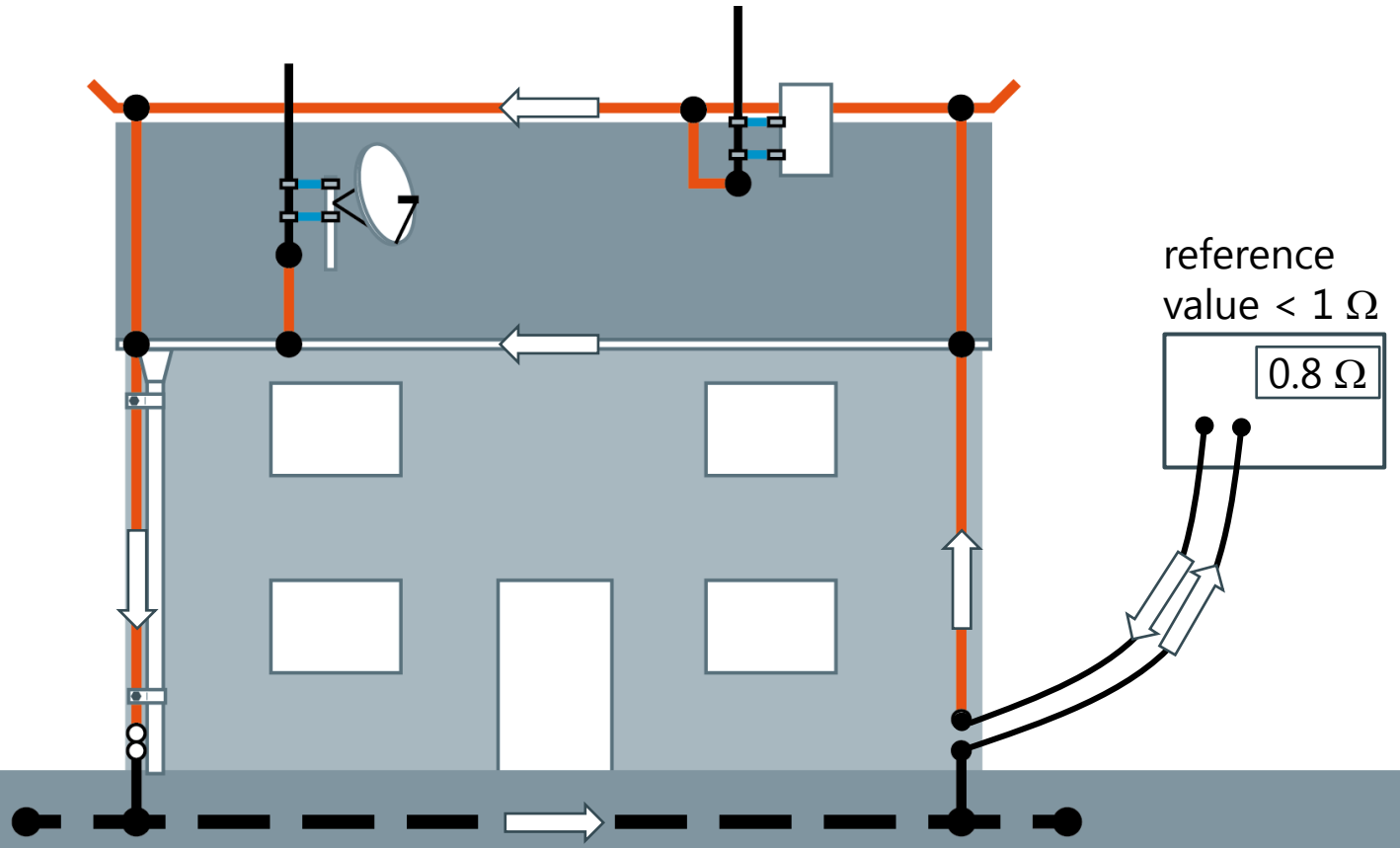
E.7 Maintenance and inspection of the LPS

E.7.2.5 Documentation of inspection

The LPS inspection report should contain the following information:

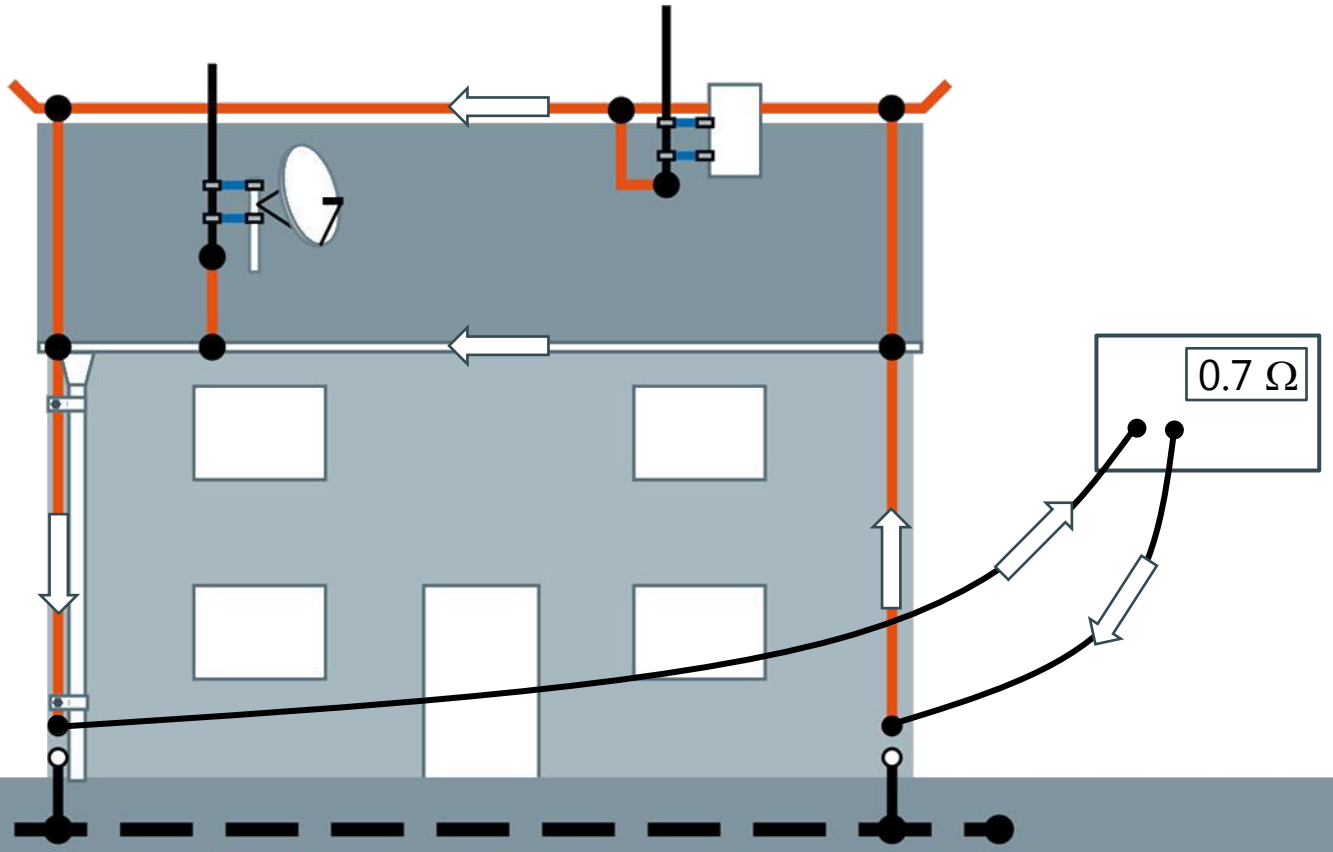
- **general conditions of air-termination conductors, and other air-termination components;**
- **general level of corrosion and the condition of the corrosion protection;**
- **security of attachment of the LPS conductors and components;**
- **earth resistance measurements of the earth-termination system;**
- **any deviation from the requirements of this standard;**
- **documentation of all changes and extension of the LPS and any changes to the structure. In addition, the LPS construction drawings and the LPS design description should be reviewed;**
- **the results of the tests performed.**

Continuity measurement between earth entry and down conductor



Ref.: IEC 62305-3 supplement 3 (VDE 0185-305-3 supplement 3):2012-10

Continuity measurement between two arresters



Ref.: IEC 62305-3 supplement 3 (VDE 0185-305-3 supplement 3):2012-10

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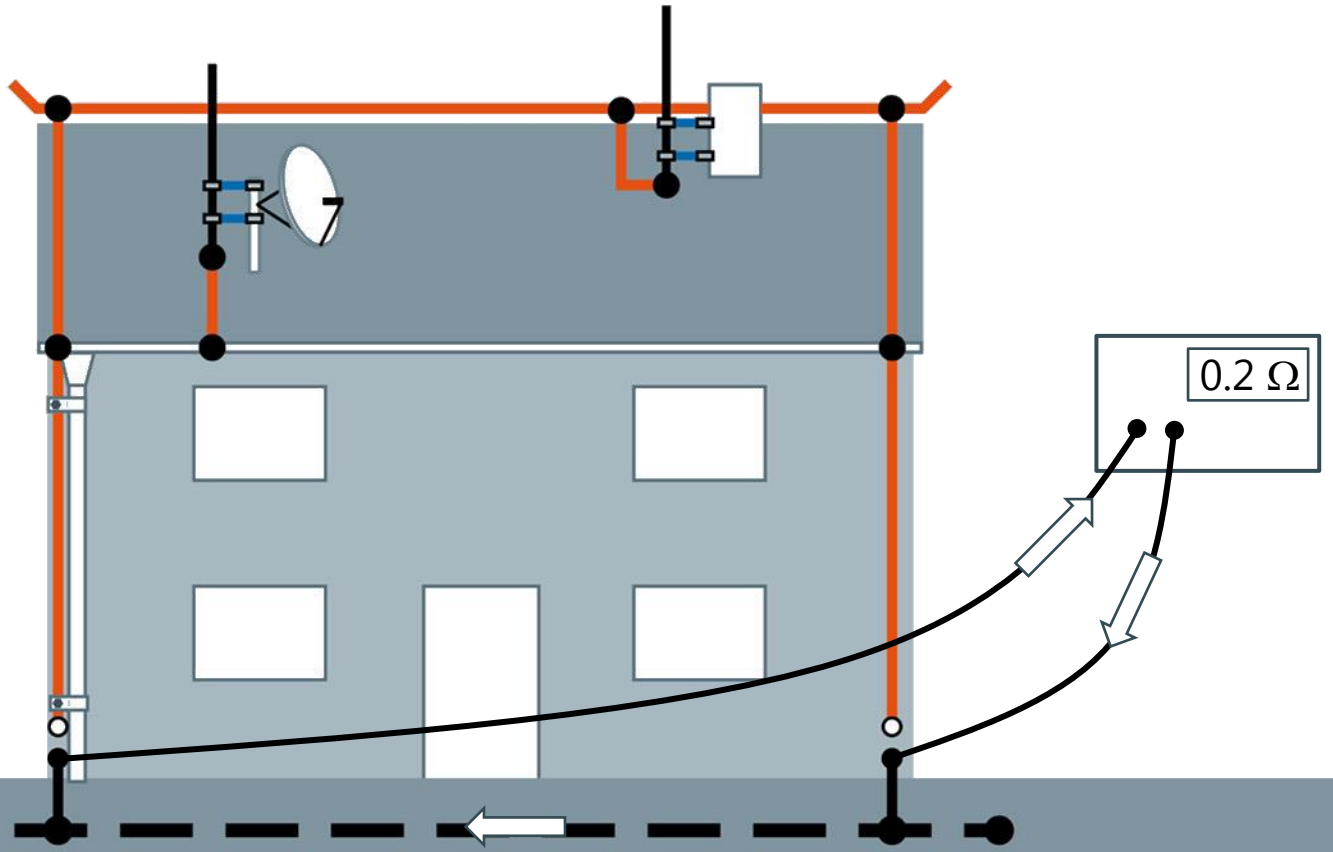
Continuity measurement between two earth entries



Ref.: IEC 62305-3 supplement 3 (VDE 0185-305-3 supplement 3):2012-10

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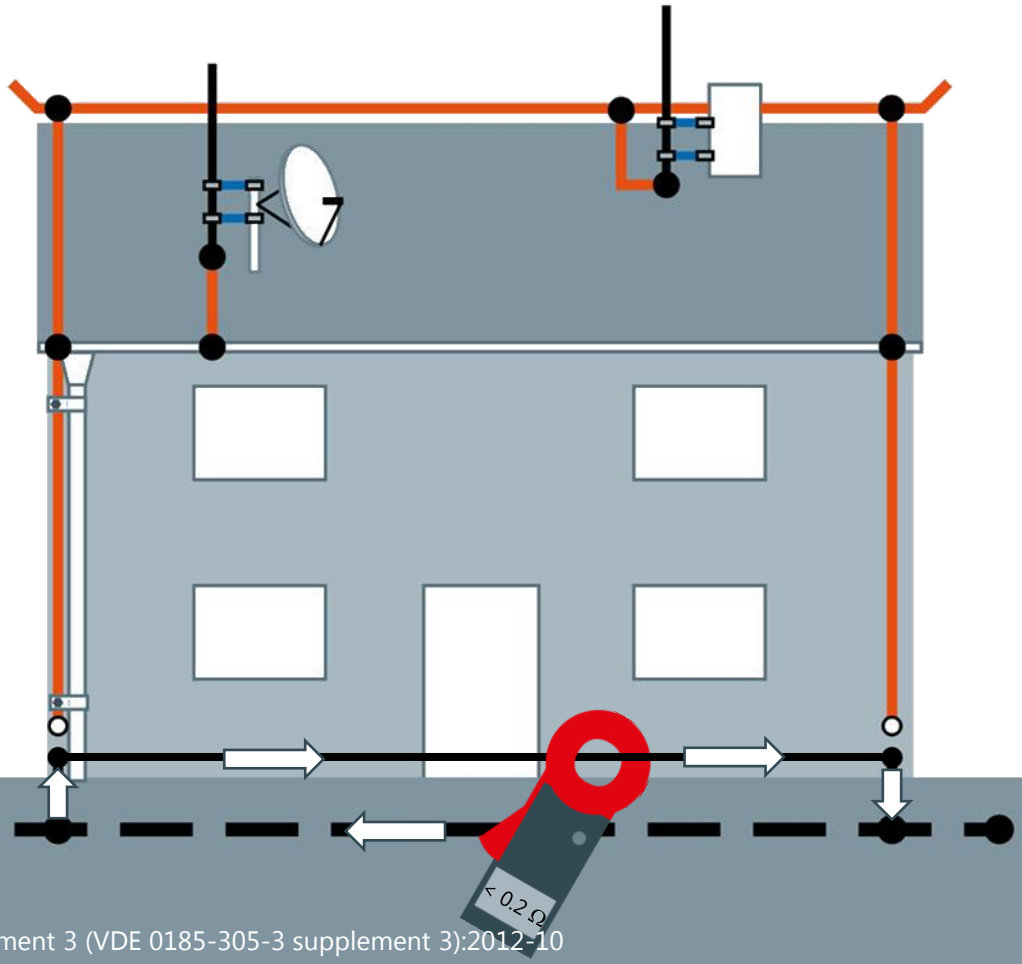
Continuity test between two earth entries



Ref.: IEC 62305-3 supplement 3 (VDE 0185-305-3 supplement 3):2012-10

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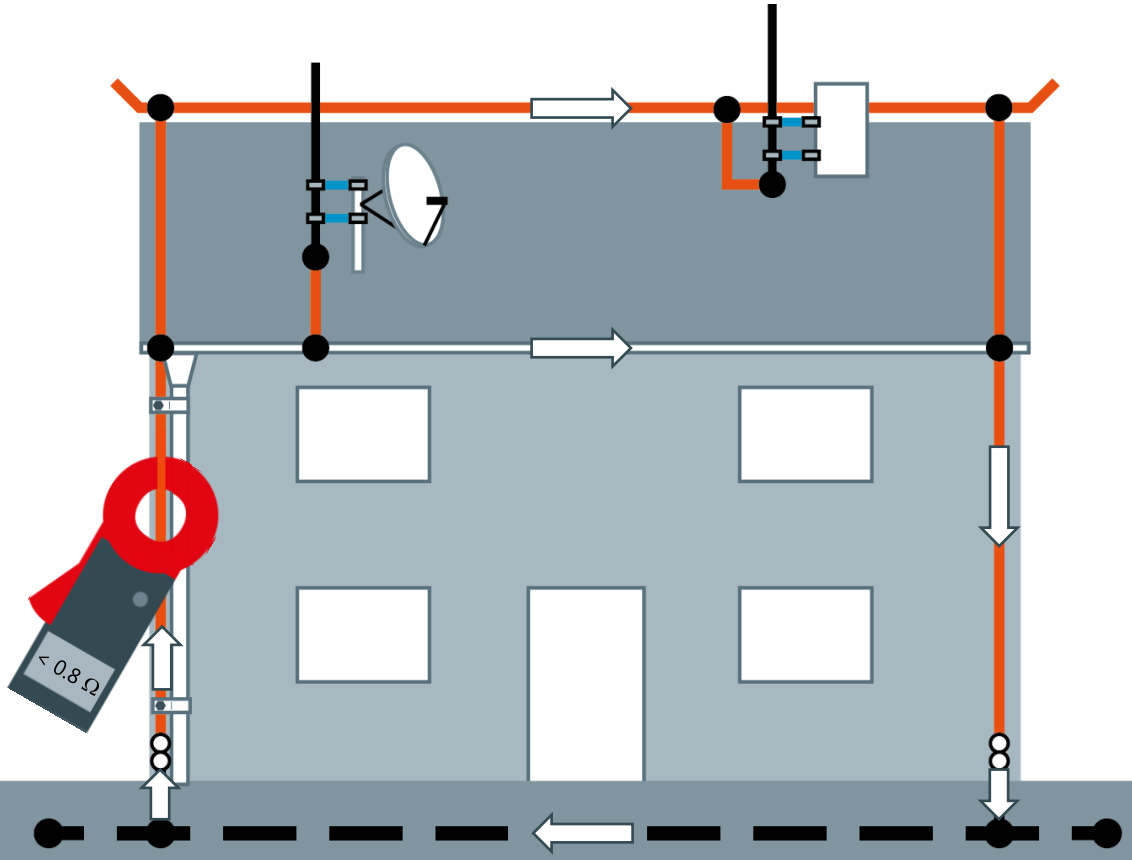
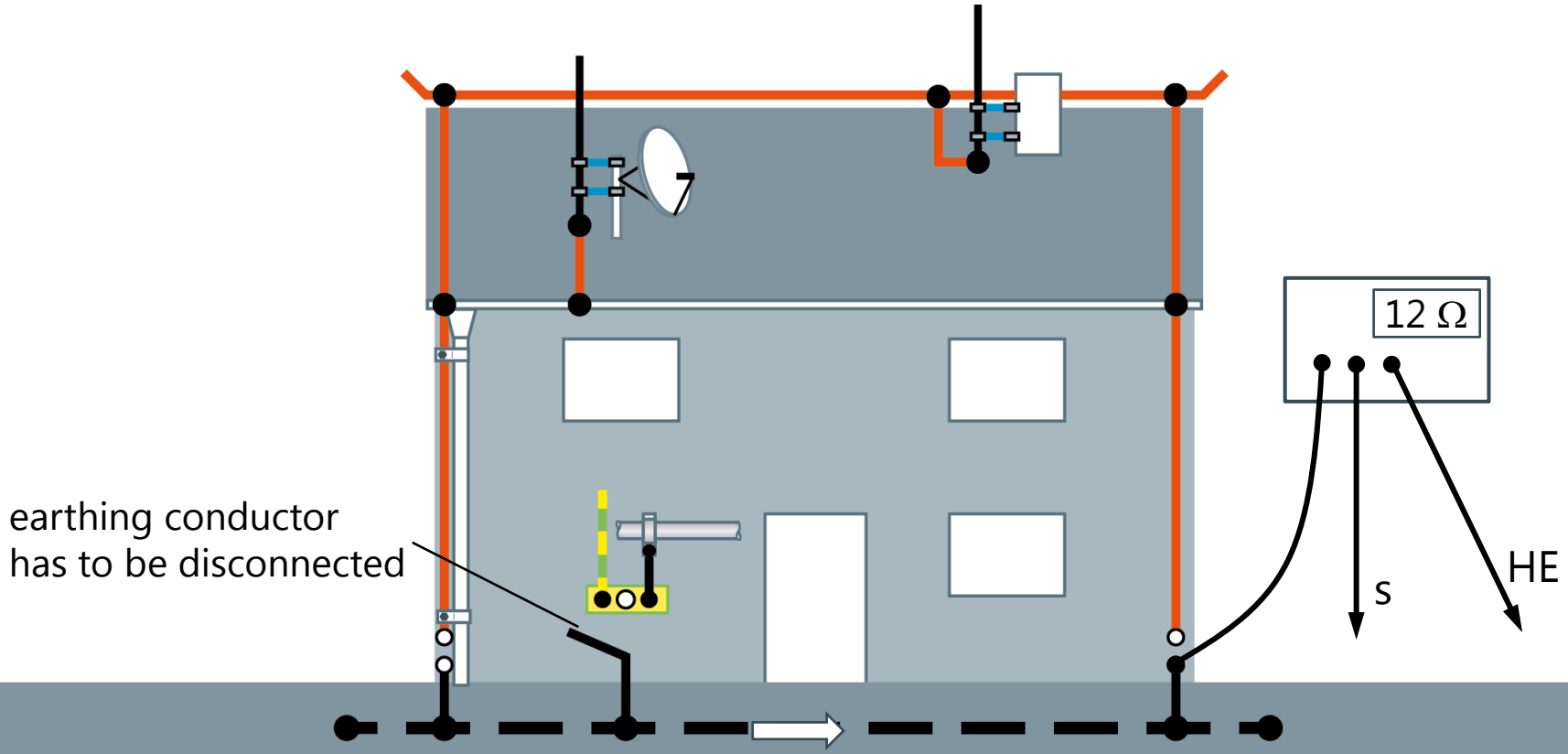
Continuity measurement by means of a tong tester in case of closed test joints



Ref.: IEC 62305-3 supplement 3 (VDE 0185-305-3 supplement 3):2012-10

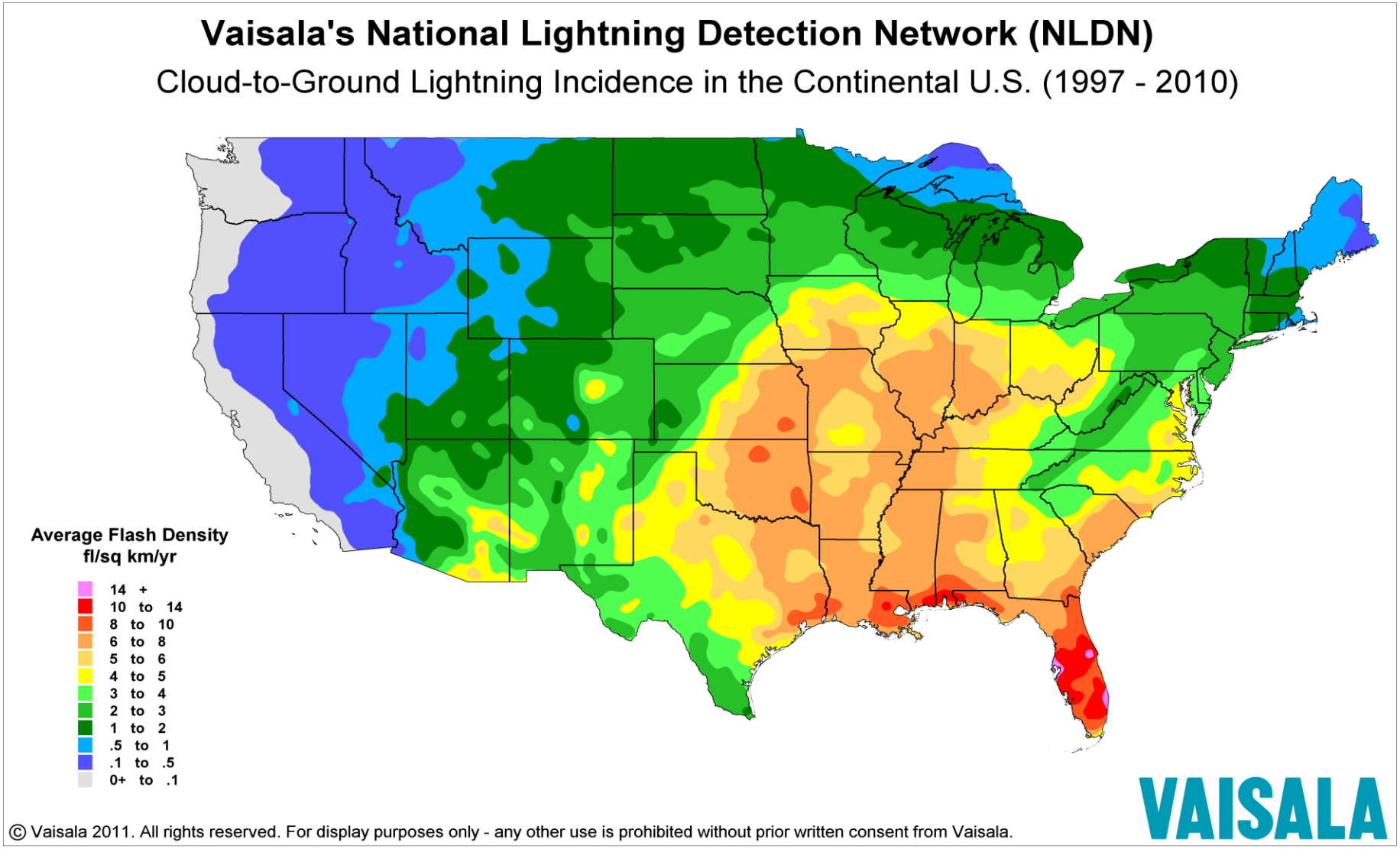
Measuring the earth resistance R_A of the earth-termination system



Attention: In case of TT systems, the residual current operated device is ineffective!

Ref.: IEC 62305-3 supplement 3 (VDE 0185-305-3 supplement 3):2012-10

Lower 48 Distribution of Lightning
Includes Cloud to Ground Lightning Only



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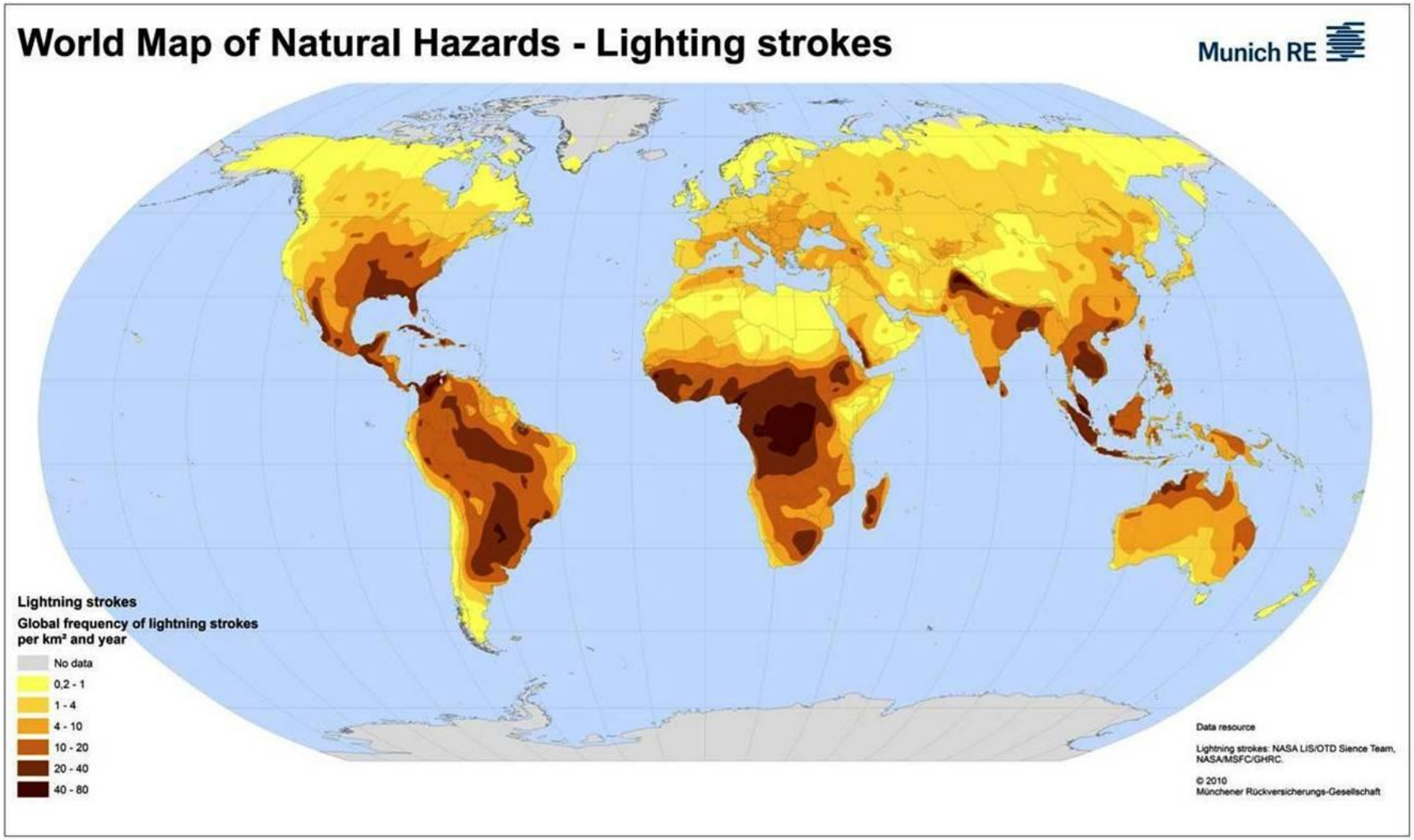
Lightning Stroke Density
Includes both Intercloud and Cloud to Ground



Source: Munich RE; Report 2010

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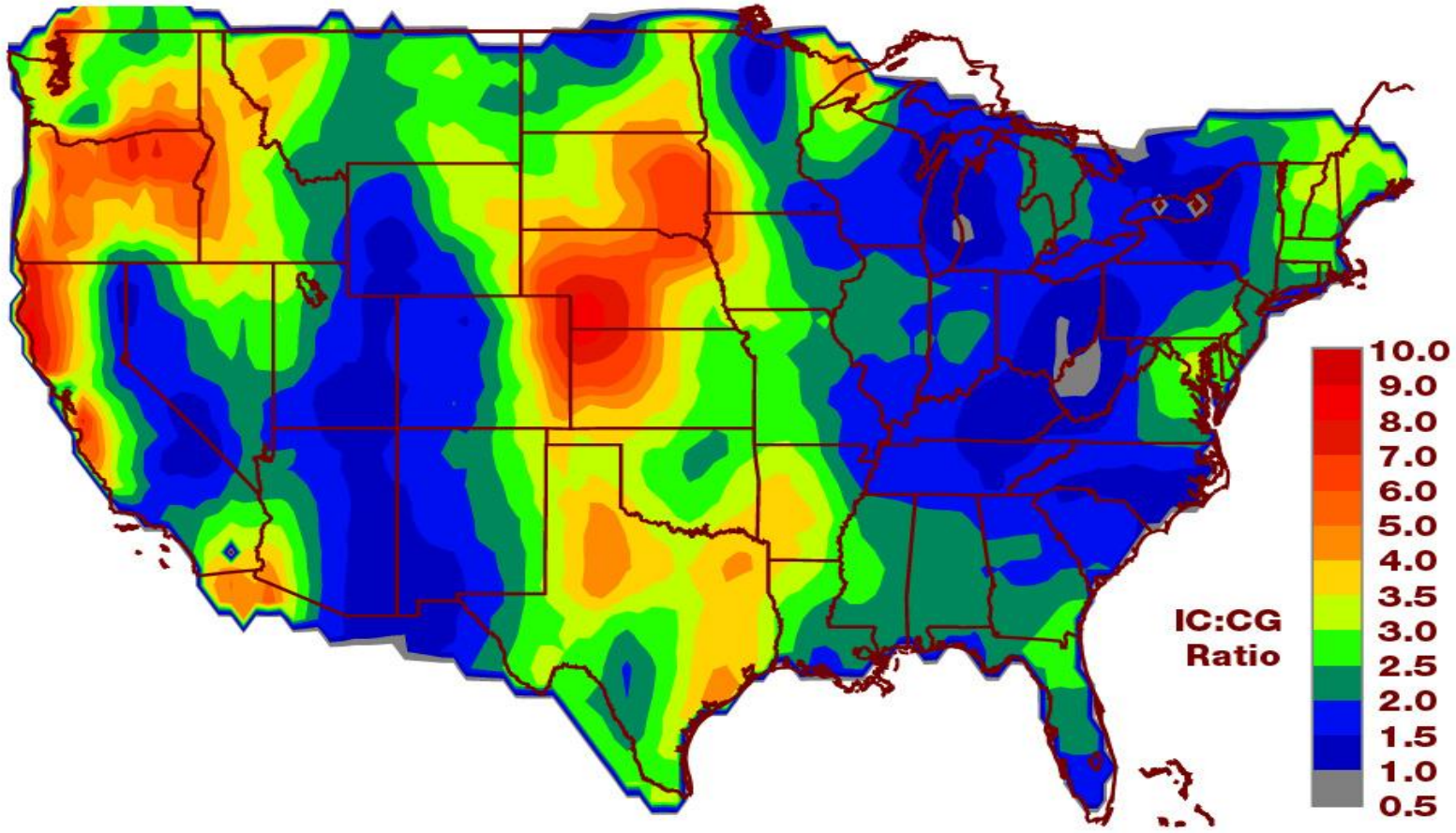
Ratio of Intercloud vs. Cloud to Ground Lightning

Ratio varies by a factor of 10 across the US. The Rocky, Appalachian, and Sierra Nevada mountains have a large proportion of ground flashes. Cold front storms produce the larger positive lightning flashes. Because of this mountain sites have particularly severe lightning problems.



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E.5.1.2 Isolated LPS

An isolated external LPS should be used when the flow of the lightning current into bonded internal conductive parts may cause damage to the structure or its contents.

NOTE 1: The use of an isolated LPS may be convenient where it is predicted that changes in the structure may require modifications to the LPS.

An LPS that is connected to conductive structural elements and to the equipotential bonding system only at ground level, is defined as isolated according to 3.3.

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 with the separation distance of 6.3.

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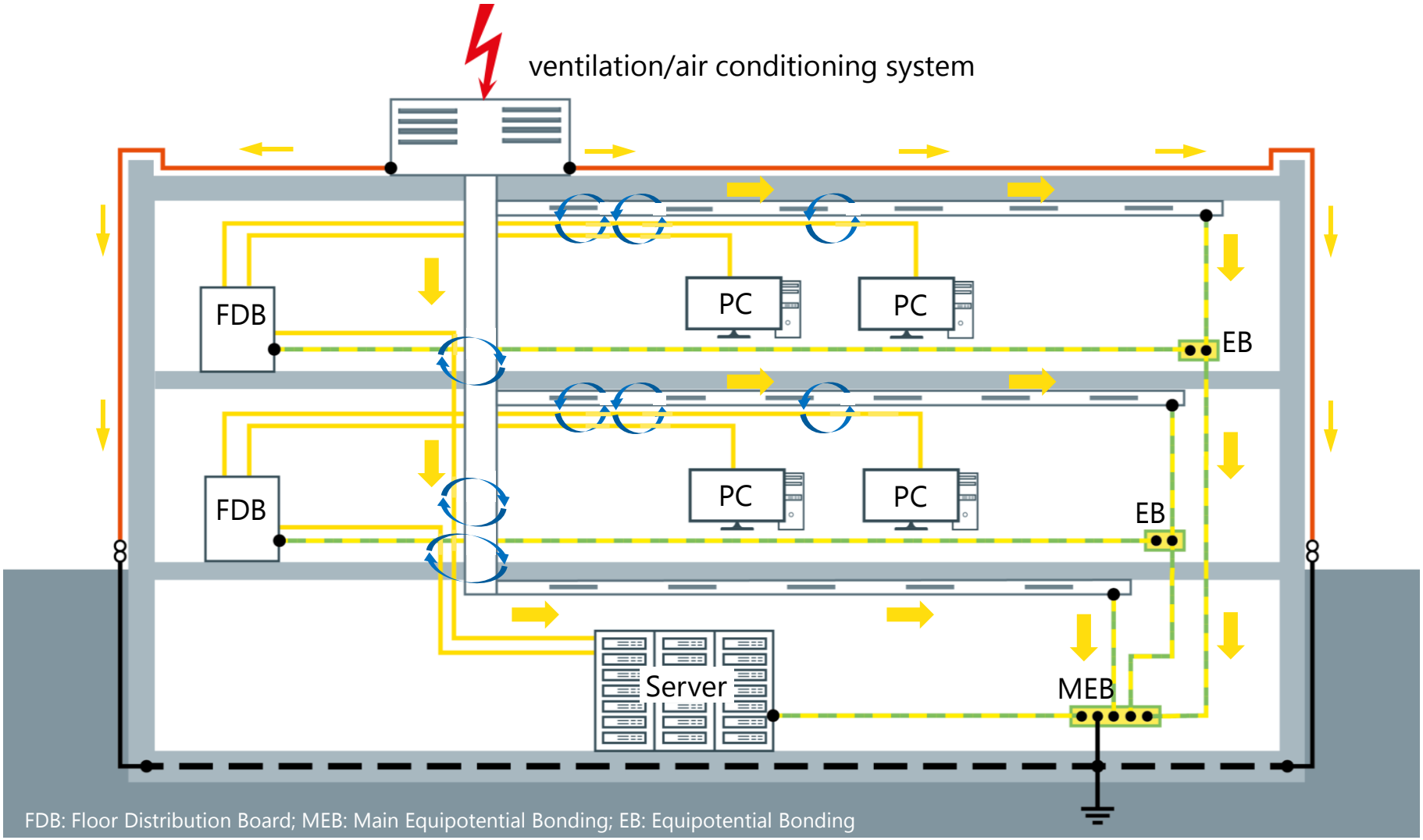
Direct connection of roof-mounted structures
Partial lightning currents inside the structure



FDB: Floor Distribution Board; MEB: Main Equipotential Bonding; EB: Equipotential Bonding

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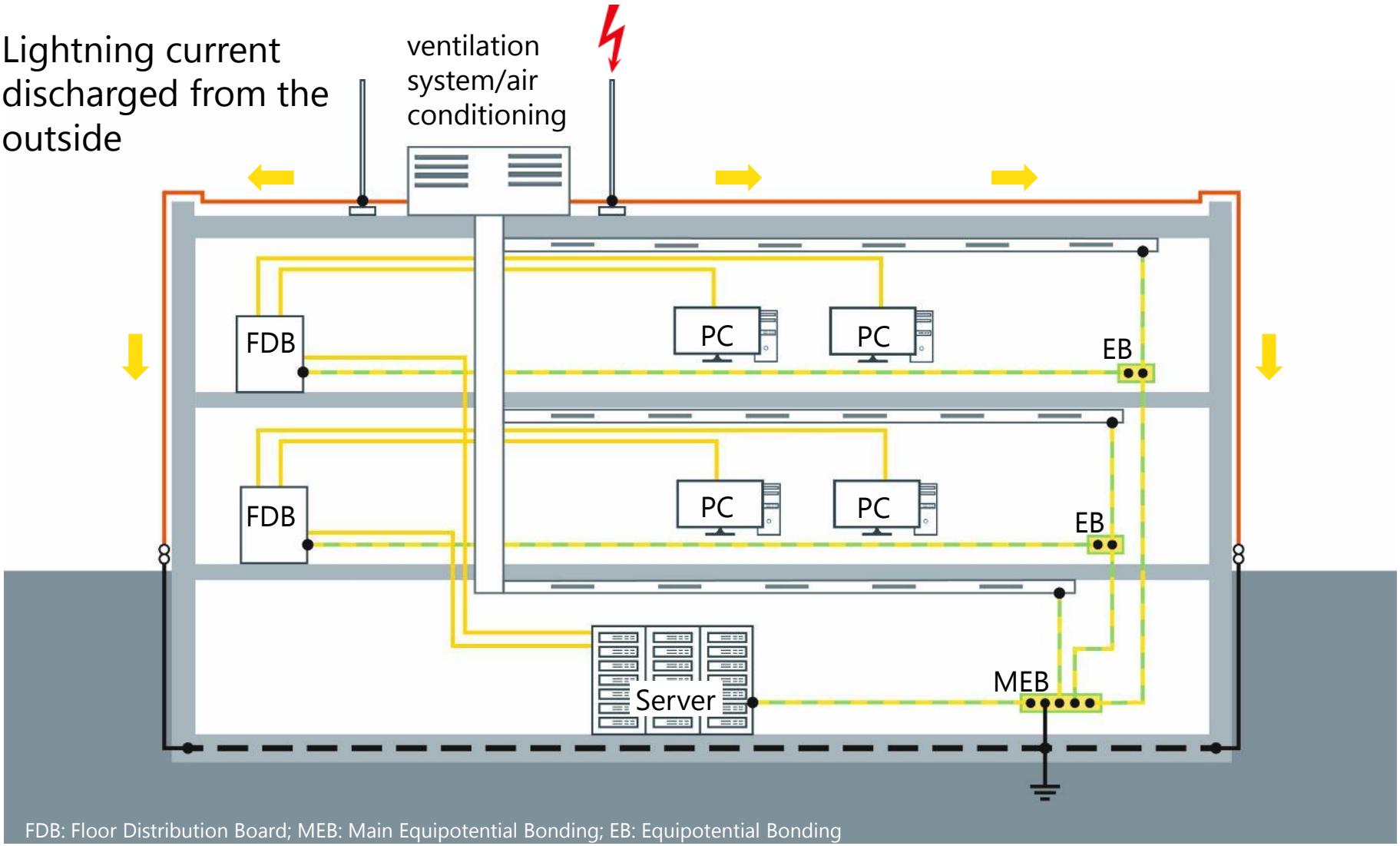
Protection of roof-mounted structures with isolated air-termination system



FDB: Floor Distribution Board; MEB: Main Equipotential Bonding; EB: Equipotential Bonding

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6.3 Electrical insulation of the external LPS

6.3.1 General

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:

$$s = k_i \cdot \frac{k_c}{k_m} \cdot l$$

- 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 down-conductor (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 (see E.6.3 of Annex E).

NOTE The length l along the air-termination can be disregarded in structures with continuous metal roof acting as natural air-termination system.

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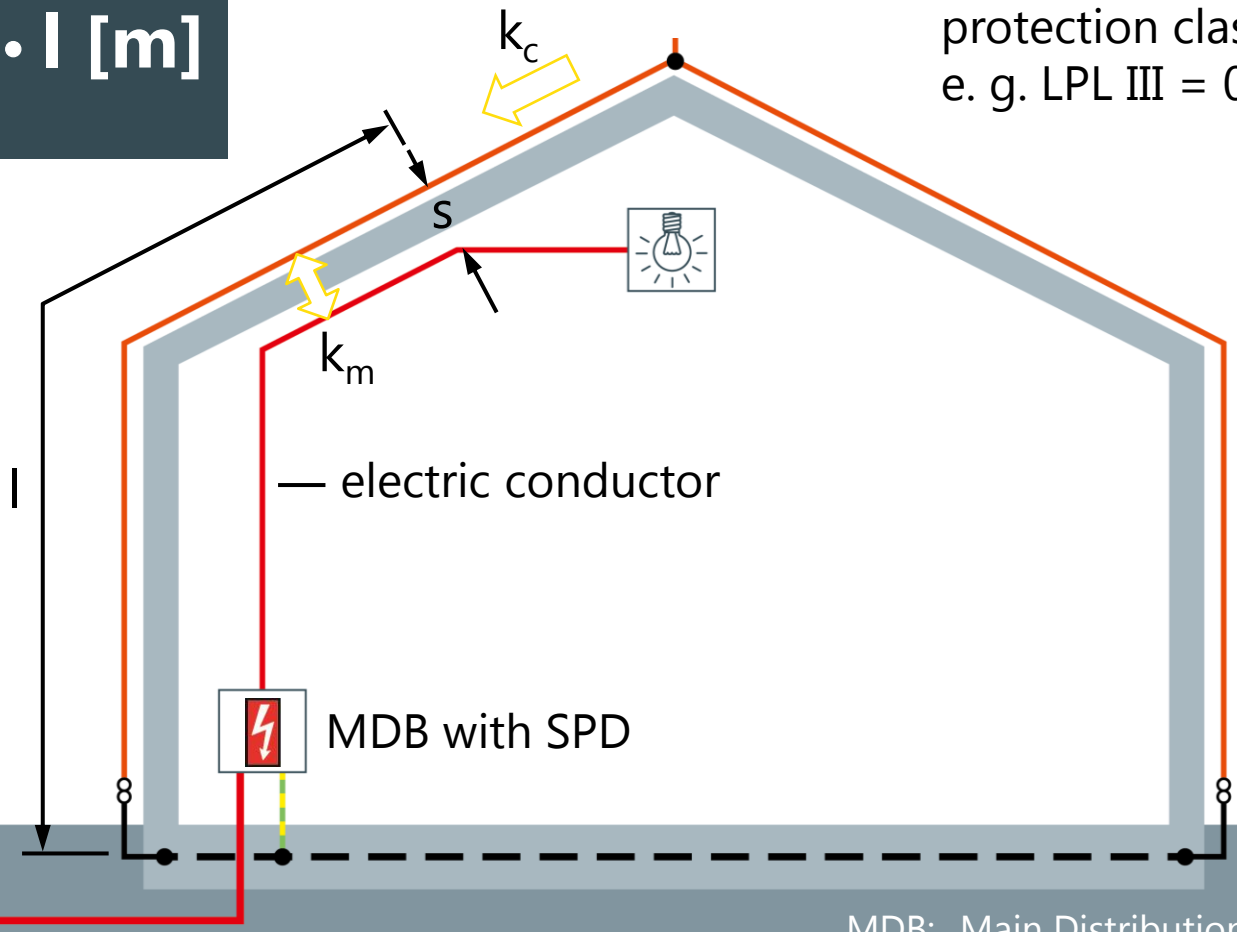
Separation distance (s)
Problematic installation of metal conductors

$$s = k_i \cdot \frac{k_c}{k_m} \cdot l \; [m]$$

k_T=dependent on protection class LPL
e. g. LPL III = 0.04



Ref.: IEC 62305-3:2010; Annex E, Figure E.38 modified

MDB: Main Distribution Board
SPD: Surge Protective Device

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Isolation of external LPS
Values of coefficients k_i and k_m

Class of LPS	k_i
I	0.08
II	0.06
III and IV	0.04

Insulating material	k_m
Air	1
Concrete, bricks	0.5
DEHNiso	0.7*

*value of DEHNiso determined by DEHN in laboratory tests

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.

Ref.: IEC 62305-3:2011-10,Table 10/11

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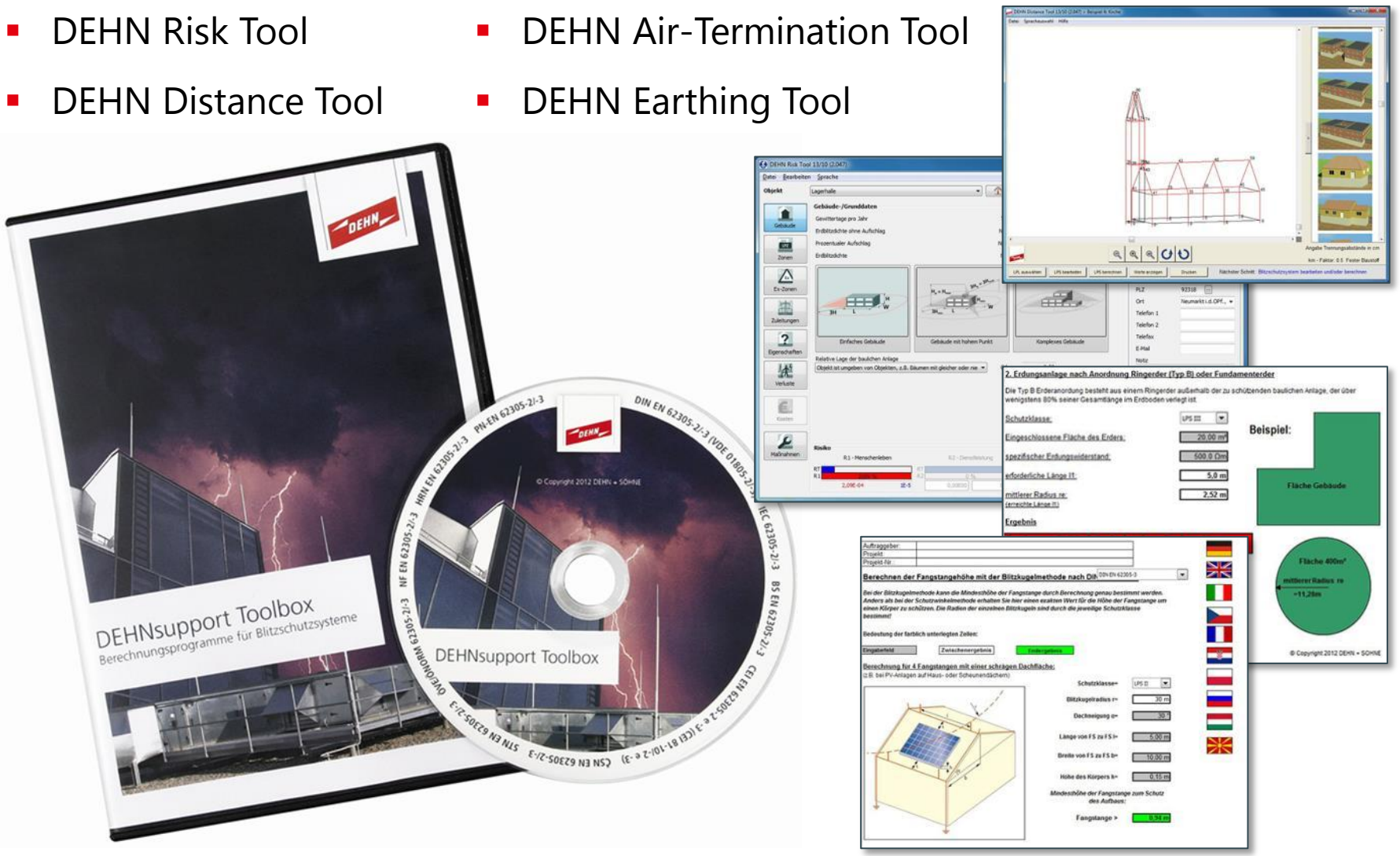
DEHNsupport Toolbox

- DEHN Risk Tool
- DEHN Distance Tool
- DEHN Air-Termination Tool
- DEHN Earthing Tool



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