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Lightning protection risk analysis for structures

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„Nincs még egy olyan lenyűgöző és kutatásra érdemes terület, mint a természet tanulmányozása. Az emberi értelem legfőbb célja megérteni ezt a nagyszerű alkotást, felfedezni a benne ható erőket, és az ezeket irányító törvényeket.” (Hungarian) [1]

In translation:

“There is no other area as fascinating and worth exploring as the study of nature. The ultimate goal of the human intellect is to understand this great work, to discover the forces within it, and the laws that govern them.”

Nikola Tesla

Serbian - American physicist
and inventor [2]

ABSTRACT

Humanity during its anthropogenesis has been in constant struggle with natural forces since ancient times. In this struggle, the all-round protection of artificially created objects has played and also today is playing a prominent role, one of the main areas of which is the lightning protection of structures. Nowadays, it is based on state-of-the-art risk analysis methods based on exact mathematical models, according to which general guidelines, rules and regulations can be defined. The common aggregating documents of these are called standards [3]. Lightning protection risk analysis calculates and contains the specific lightning protection adequacy of the given structure, considering the parameters of buildings and their installations (e.g.: lightning protection installations, cables, flooring etc.). During the technological development risk analysis methods must be made more accurate and should be improved in compliance with the requirements determined for new buildings.

My field of research is according to common belief, it is enough to protect against lightning strikes only with some kind of lightning conductor (e.g.: air termination system, down conductor cable, grounding system). In my view however, theoretical and practical experience affirms that beyond these three factors there are several other parameters that have a considerable effect, which we need to take into consideration in a mathematically exact way when assessing and calculating risks. Therefore, my field of research is the lightning protection risk analysis of buildings, with special attention to the inspection of different general and special parameters and their changes. It was an objective motivation that several risks and risk assessment calculation methods are already present in different fields of life (e.g.: financial, economic, technical fields, etc.) During the inspection of these, specialists defined a lot of rules and set these down into standards (e.g.: MSZ[1] EN[2] 62305-1,2,3,4) [4]. My subjective motivation was reinforced by the fact that I have dealt with a comparative analysis of two US arc flash standards as an electrical engineer and I personally consider the monitoring of the methods of lightning protection risk management as a priority and its continuous development, determined by technological progress.

[1] **MSZ**: **M**agyar **Sz**abvány (**H**ungarian **S**tandard)
[2] **EN: E**uropean **N**orm

INTRODUCTION

Lightning can cause great damage. It endangers human life and property. If something or someone's state (or operation) is danger and there is any protecting opportunity against it, we talk about safety or/and safety science [5]. The task of lightning protection is to protect human life and property. This task is performed by the lightning protection system with various devices and solutions. External lightning protection can damage the roof structure, walls, etc. of the building. It protects by way of lightning rods. It is a structure made of a conductive material that conducts lightning current to the ground. However, this system does not protect against the secondary effects of lightning. Overvoltages induced by lightning can also enter the house via the wires connecting the building (electricity network, internet, etc.), causing great damage. For this reason, in addition to the lightning arrestor, we also need to protect our equipment with surge protection. Lightning protection in Hungary is regulated by the MSZ EN 62305 Edition 2 standard. During the technological development, it is necessary to continuously refine and improve the risk management methods in accordance with the requirements determined by the new constructions. My research area is the exploration of the correlations of the output results determined by the input parameters, in the case of different types of buildings, the identification of the risks, identified by their analysis, as well as the qualitative results of the quantitative output parameters, in determination of its effects. Lightning protection systems for buildings are designed and constructed for the protection of human life and property. In my research plan, based on the detailed research goals defined above, I set the research direction to establish an unprecedented order of priority for input parameters in lightning protection risk management of buildings, in relation to typical buildings holding a significant number of people (e.g.: hospital, condominium, school etc.). I carried out this activity based on my self-developed risk calculation IT[3] program I created. This program also shows the sub-components of the R[4]$_1$ risk. My research started in October 2017, based on MSZ EN 62305-2:2012 Edition 2 standard.

My research activities were determined by **personal, technical and scientific motivations** at the same time.

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[3] **IT**: **I**nformation **T**echnology

[4] **R_1:** Risk of loss of human life, in Hungarian: az emberi élet elvesztésének kockázata.

My **personal motivation** was the technical interdisciplinary relationship between human and his built environment based on norms and normatives, which is also embodied in standardization with regard to the safety of human life and property.

My **technical motivation** was given by the topic of my bachelor thesis which I had written about arc flash analysis at our University in 2013 and was strengthened by the fact that as an electrical engineer I had previously dealt with the comparative analysis of two American arc flash standards and personally I attach great importance to the monitoring of lightning protection risk management methods and its continuous development as a result of technological development.

My **scientific motivation** based on these two pillars was given by the scientific need contributing to the theoretical research of lightning-related issues and to the standardization closely related to the practical solutions of the lightning protection.

Both studying the MSZ 274 additionally the currently valid MSZ EN 62305 standard family and seeing lots of input parameters, I arose the need to examine their simultaneous and combinatorial mechanisms of action in the risk management of the lightning protection in buildings focusing on just the protection of the human life.

As the **research questions** formulated in myself both there is a directing principle that can be used to demonstrate the possibly more dominant effect of certain input parameters as an output result on the lightning protection adequacy of structures and whether it may be justified to intervene in the process professionally in cooperation with the stakeholders during the design phase of the structures by controlling?

It also occurred to me whether the electric vehicles with potentially non-metallic (e.g.: composite) bodies, which are expected to be conquered nowadays, are safe from the point of view of protection of human life and property during lightning strikes?

Actuality of topic

The significance and topicality of the research topic is given by the fact that the protection of human life and property coincides with the development of societies, to which the protection of structures against lightning strikes is closely and inextricably linked.

The lightning protection risk analysis calculates and includes the unique lightning protection adequacy of a particular building, taking into account the parameters of buildings and their installations (e.g.: lightning protection equipment, cabling, flooring, etc.). As technology advances, the risk management methods need to be refined and improved to meet the requirements of new buildings. The new version of this standard is published every 4 to 5 years because the computational methods need to be refined, and there are practical experiences that we had not thought about before and they need to be integrated into the new version of the standard. As our building environment changes, new life situations arise that need to be managed by standards. Such reasons are, for example, the protection of new technical devices from the secondary effects of lightning, or newer architectural solutions implemented even by trends.

Based on our experience it can be said that the construction of various green roof solutions has become a trend and fashion these days. It is enough to think of large (luxury) penthouse[5] apartments with terraces, loft apartments[6], hotel skybars[7] or sports fields (e.g.: ice rinks, basketball courts) built on top of shopping malls. These were not common architectural solutions for a couple of years or decades, but slowly, for example, nowadays all condominiums are built on the top floor of a penthouse. Accordingly, the calculation methods and lightning protection solutions must be adapted to the expected damage events and requirements. This is one of the reasons that the future draft of the MSZ EN 62305 family of standards is under development because it will contain new risks, new calculation methods and adjustments.

Formulation of the scientific problem

It is generally believed that it is sufficient to protect against lightning with a lightning rod. While 50-100 years ago this was really enough, because at that time we did not have the electrical equipment that sometimes needed special protection, so today only the lightning rod is not enough. At that time, it was enough to protect against fire caused by lightning by external protection, but this is not enough nowadays either, because of the need for individual protection of electrical devices and equipment inside the building [6].

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[5] **Penthouse**: originally a property on top of large office buildings, nowadays a large terrace apartment on the top floor of buildings with a terrace base on the top of the apartment below.
[6] **Loft apartment:** residential building made of a hall-like building with high ceilings and large spaces.
[7] **Skybar:** open catering units built on top of buildings but usually on top of hotels.

While in the past our environment consisted of relatively few components (e.g.: building, heating system, energy supply), by now our artificial environment has become much more complex, thus making lightning protection risks more complex. At the same time, the earlier standard, with its simpler calculation methods, kept pace with the state of the art and technological development for some time, but after a while it was no longer suitable for this, so MSZ EN 62305 standard family came into force. In my opinion and in my research, theoretical and practical experience confirm that in the case of an object under investigation we have to consider the effect of several parameters at the same time, and we have to take these effects into mathematical precision in risk analysis and risk calculation. The more complex a building is, the more parameters are taken into account when calculating risk. Standard MSZ EN 62305-2:2012 calculates significantly more parameters than its predecessor, so after its introduction a new computational situation was difficult for most to understand, because suddenly much more had to be considered. The old lightning protection standard was a heavily simplified model with only a few parameters (e.g.: building purpose, height, roof material, air quality, secondary exposure control, etc.) and could be classified in a quarter of an hour. In contrast, the new standard contains more than 50 input parameters.

In parallel, the time and complexity of performing the risk calculation increased significantly. The high number of parameters can also make the design and construction of the lightning protection system of the building considerably more difficult, therefore knowing the priority order of the existing unique parameters specific to the given building can reduce its complexity. As a concrete practical benefit of my prospective research results, as the building is being designed, during the lightning protection design phase, there will be visible points to which the use of lightning protection solutions, which are almost impossible to implement afterwards, will be avoided.

The task of lightning protection risk calculation is to ensure that the level of lightning protection system to be installed on the building takes into account the building, its environment and the characteristics of the wires connected to it. The standard consists more than 50 input parameters. It calculates the building's lightning protection risk by knowing the input parameters. If the result (the risk of loss of human life – R_1) is below 1×10^{-5}, then the building is lightning safe. If it is above, lightning protection measures are required. Based on the above, my research area covers the lightning protection risk analysis of buildings, with special regard to the different general and specific parameters and their changes.

Objectives of research

- Grouping of input parameters
- Focusing on the strong parameters group[8], identification of extremely strong[9] parameters
- Comparison of grouping of current standard and future draft parameters
- Detection of possible errors in a future draft standard
- Lightning protection for non-metallic bodies
- Lightning protection recommendations for different structures
- Making recommendations

My hypotheses of the research regarding topic

The research hypotheses were determined by the technical, economical and construction problems encountered in the design of lightning protection of buildings. After performing risk calculations and analysing the results afterwards, some risk factors came into focus. After reading the standards, several technical issues have come to light. I performed some risk calculations due to constructions in real life and encountered some ideas for my research. My ideas also made an interest into the examination of the draft version of the standard for the future, so I decided to extend my research. When I started my research and my work I got to know about other technical “co-areas”.

My research started in **October 2017** with reading and analysing the MSZ EN 62305-2:2012 Edition 2 standard with taking account into some practical problems and remarks.

Based on these, I have sought answers to my research questions by formulating the following hypotheses since 2017:

[8] **Strong parameters group**: parameters whose unit changes have a decisive influence on output.
[9] **Extremly strong**: whose unit changes raises the output immediately above the R_T allowed limit.

Hypothesis 1 (H1): During lightning protection risk management of MSZ EN 62305-2:2012, **not all input parameters may affect the output equally**, therefore they **may be grouped** into strong and non-strong categories.

in Hungarian: *Az MSZ EN 62305-2:2012 szabvány szerinti kockázatkezelés során* ***nem minden bemeneti paraméter hathat egyformán*** *a kimenetre, ezért* ***lehet ezeket csoportosítani*** *erős és nem erős kategóriákba.*

Hypothesis 2 (H2): Within the strong parameters group, **some extremely strong parameters may be identified.**

in Hungarian: *Az így képzett az erős csoporton belül* ***azonosítható egy-két kiemelten erős*** *parameter.*

Hypothesis 3 (H3): Final Draft IEC (FDIS)[10] 62305-2:2018 **incorrectly takes into account** the time spent on the type of roofs where persons can stay any time but not all protection measures have been taken into account in order to reduce human grouping in different cases.

In Hungarian: *Az MSZ EN 62305 jövőbéli* ***tervezete[10] hibásan veszi figyelembe*** *a zöld tetőn való tartózkodás idejét.*

Hypothesis 4 (H4)[11]: The parameters of the Final Draft IEC (FDIS)[10] 62305-2:2018 **may also be grouped into strong and non-strong categories.**

In Hungarian: *Az MSZ EN 62305 jövőbéli tervezetének[10] bemenő paraméterei* ***szintén csoportosíthatóak*** *erős és nem erős kategóriákba.*

[10] **FDIS**: **F**inal **D**raft **I**nternational **S**tandard, used version: IEC FDIS 62305-2:2018 (81/607/FDIS)

[11] **H4 hypothesis** was formulated in July 2018, due to draft version of IEC 62305 Edition 3, version IEC FDIS 62305-2:2018. There wasn't available this version till at my closing date of my scientific research on **30th of June 2020.**

Literature review

Humanity has long feared lightning, making this area of electricity one of the oldest areas of engineering science. The interest in lightning is both one for knowledge and at the same time to lessen the fear of it. Even the ancient Greeks were thinking a lot about the causes of lightning and they already had the knowledge of electro-technology that we still use in the technical field. In ancient times, scientists of that time also realized the fundamental relationships (e.g.: Thales magnetic, electrostatic phenomena) responsible for our current problems (electrostatic discharge, discharges, etc.). It is not by chance that this kind of powerful scary physical "force" also appears in mythology (e.g.: on the side of Zeus as scattered lightnings [7]) or in different arts and religions.

In the Middle Ages, as in almost all fields of science, there was a decline in this area as well. One of the first significant steps was taken by Otto von Guericke, who investigated the properties of electric sparks and invented the electric machine [8][9]. Benjamin Franklin and the first lightning rod. Benjamin Franklin (1706-1790) invented the first lightning rod on June 15, 1752. From 1747, he increasingly experimented with electricity. He has proved that lightning was actually a "big" spark that is an electrical phenomenon (Figure 1) [10][11]. He wanted to use the result of his experiment in practice, so he Figured out that metal rods should be placed on or next to objects to be protected (predominantly buildings at that time) to prevent lightning strikes.

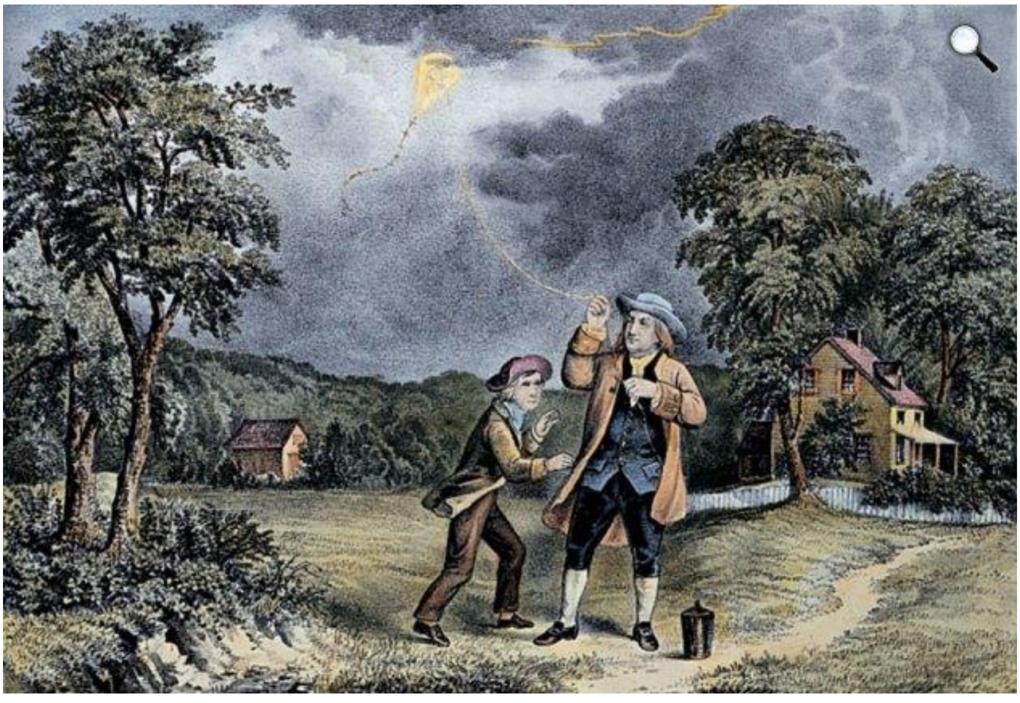

Figure 1: Benjamin Franklin during his experiment [11]

Since the invention of the lightning rod, we are able to protect various buildings (e.g.: condominiums) and thus human life against lightning. The lightning protection systems of buildings are designed and implemented for the protection of human life and property. Based on the detailed research objectives defined later in my research plan, I will set out a research direction to prioritize input parameters for lightning protection risk management of buildings in relation to typical buildings with a significant human population (e.g.: condominiums, hospitals, schools, etc.).

I carry out this activity based on my self-developed IT program I have created. This was created in MS Excel environment with VBA[12]**.** Its macros had been developed and changed by me in order to perform the sensitivity check. This program automatically calculates the lightning protection risk components using the current standard's calculation method and then aggregates them.

There are several literatures about this topic. Standard MSZ 274 was published first in 1952 about lightning protection. Decades later it was replaced by standard MSZ EN 62305. About the IT programs, company DEHN[13] has a risk assessment tool to calculate the risks and they also have some guidebooks of lightning protections, catalogues about materials etc. Out of DehnSupport program, there are other risk calculations softwares available on the market (e.g: ViKoP[14])

I wish to highlight the work of Prof. Emeritus Dr. Tibor Horváth about this topic. He has published several books about lightning protection in the past and also calculated manually some risks about different variations. He also collected these data in a special chart for LPS[15] selection in the past so the engineers, developers could use it as a technical basement. And the result of this work was the MSZ 274 standard. The history of standards in Hungary is presented in Chapter 1[16].

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[12] **VBA**: **V**isual **B**asic for **A**pplication.
[13] **DEHN SE + Co KG**, Neumarkt, Germany
[14] **ViKoP**: Lightning assessment software of OBO BETTERMANN Ltd. [120] [121]
[15] **LPS**: **L**ightning **P**rotection **S**ystem
[16] **See:** p.20-47

Research methods

I divided my research **activities into three main parts** and used different research methods in these parts.

In the first part of my research I studied both the documents of the standard family and the standards under modification which are related to lightning protection. I delimited the subject of my research based on not only the extensive literature search additionally processing of the domestic and international literature but also on the publications relevant to the topic as well.

In the second part of my research, I performed the sensitivity tests on the risk of loss of human life in accordance with the requirements of the valid MSZ EN 62305-2:2012 standard. Seeing the multitude of input parameters, I decided that it is expedient to form some grouping with analysis.

To form the groups, I performed theoretical and practical sensitivity tests using the method of mathematical analysis by calculating the slopes of the multivariate function[17] variable-by-variable[18] for the risk of loss of human life. By comparative analysis I determined 22-25 pieces of dominant input parameters based on the theoretical sensitivity test, which are named as theoretical strong parameters groups. Selecting some input parameters from this group, thus forming variation cases - considering the others constant until then - I calculated the value of the risk of loss of human life (R_1) for the three chosen building types about the research. The research needed 51 840 calculations for the condominium, for the office building and for the assembly plant together.

I performed the algebraic calculations using the VBA programming language of the MS Excel application operating in the MS Office environment, using my macros which are created by me. Data management in my self developed IT program was automated by my macros (Annex I.)[19]. In the case of the structures under research, the specific values of my variation calculations for the risk of loss of human life (R_1) are included in the CD data carrier attached to the doctoral dissertation (Annex III.)[20].

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[17] **Marked as R_1** in MSZ EN 62305-2:2012.
[18] The independent variables are represented by the input parameters.
[19] **See:** Annex I., p.161-163
[20] **See:** Annex III., p.167

In the third part of my research, I examined the different and special materials used for lightning protection as a co-area of my topic. I made a theoretical engineering opinion and recommendation on the specific lightning protection requirements of non-metal (e.g.: composite) body electric cars as a possible area of the theoretical research and practical implementation in the future. Nowadays, it is not in the standardization process at the moment, the performance of sensitivity tests based on model experimentation may be an area of engineering and standardization field of research in the future. I also highlighted the danger of lightning about both some special infrastructures and some halls, structures in reality auspices of the protection in with connection both our human life and our built environment.

Finally, I both performed a comparative analysis of the systematic relationship among - research questions - hypotheses - results of their harmonised correlations and based on these I formulated my scientific results corrected with research limitations.

Research limitations

During my limitations, I applied **thematic and time constraints**. Determining the location (point of impact) of the lightning strike using neither rolling sphere nor safety angle method for the selected structures were the subjects of the research as a **thematic limitation**. Accepting the lightning strike as a fact, I made only reasonable references to them during the lightning protection risk management of the structures. I limited the theoretical and practical sensitivity tests only to the calculations and presentation of the results of the sample examples that theoretically support my scientific results due to the extremely large number of variations in the values and degrees of the input parameters and their grouping. The new contents of technical and fire protection etc. which are generated by changing the input parameters and their economical effect on investments were also not the subject of my research. Neither the other parts of MSZ EN 62305 standard family nor the codification process were the part of my research.

By **timely limitation**, I mean the completion of my research process on **June 30, 2020.**

Structure of the dissertation

The dissertation contains **five chapters**. Chapters contain my research, my objectives, and my results. It also has an introduction and a conclusion as well.

In Chapter 1, the lightning protection regulations, definitions, materials of lightning protection and protection options are presented.

In Chapter 2, the calculation method of the currently valid standard and its applied parameters and outputs, the research process, its results and areas of utilization and details of my self-developed IT program will be introduced in connection with Annex I.

In Chapter 3, both the future content of the current standard and a presumed error are presented.

In Chapter 4, one of the technical co-areas related to lightning protection, the topic of lightning protection of vehicles with non-metallic (e.g.: composite) bodies is explained.

In Chapter 5, lightning protection aspects of different structures, infrastructures and edifices are presented through several real-world buildings.

1. REGULATIONS RELATED TO LIGHTNING PROTECTION

1.1 Introduction

Lightning protection is a set of design, construction and establishment activities which, in the event of a lightning strike, serve to prevent the occurrence of a potential damage event, catastrophe, and to create conditions of life and property security. Accordingly, various standards and regulations have been adopted to provide effective lightning protection.

1.2 Concepts

It is important to know different concepts for designing and setting up lightning protection. This chapter introduces the most important concepts and definitions.

Earthing for lightning protection

System made of metal which has a wet-soil connection which it's not enough to be in the ground. Its purpose is to distribute the lightning current providing the minimum potential rise (Figure 2).

Figure 2: Foundation earth electrode [12]

'A' and 'B' type earthing

Type 'A' earthing has vertical grounding probes placed in the ground. Framed closed ring that surrounds the building is called the type 'B'.

The types are shown in Figure 3.

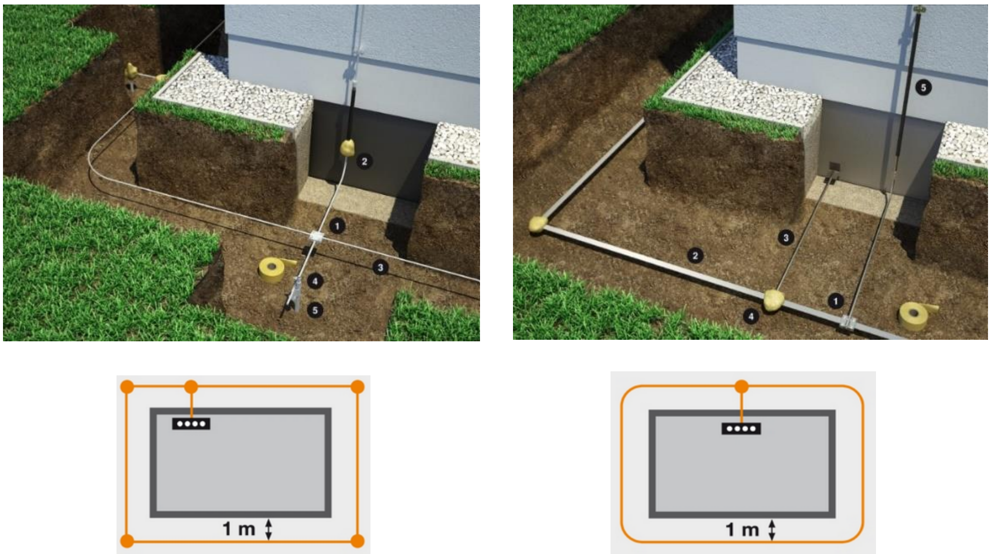

Figure 3: 'A' and 'B' types of grounding and their schematic drawing [13][14]

Safety distance

Minimum distance between the external lightning protection and the internal metal parts (s_1 and s_2 on Figure 4). It means that the potential difference caused by lightning current does not cause any secondary discharge. Moving to the ground, the safety distance is decreasing linearly (Figure 4). Based on the definition, the lightning rod and the metal parts can be connected only close-above the ground.

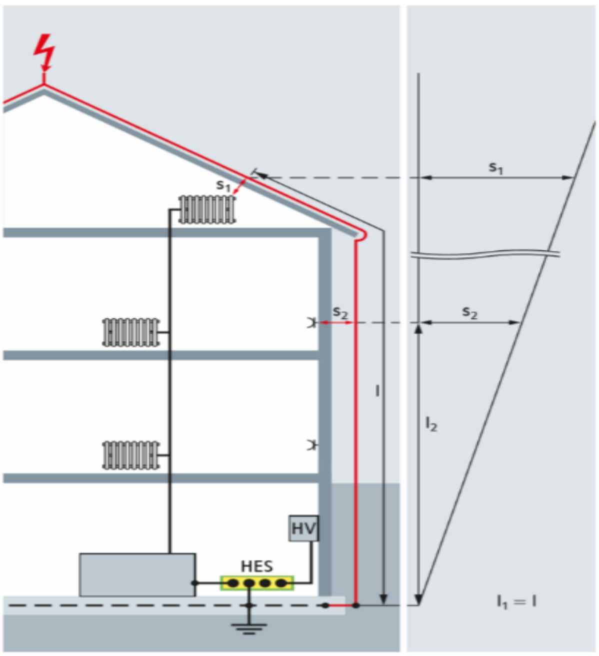

Figure 4: Safety distance [15]

Connecting lines

Conductive materials connected to a building that are connected to a remote earth potential. Power cables (230 V AC[21]), low power cables (communication cables, e.g.: internet, antenna, etc.) and metal pipelines (e.g.: water, gas) are included.

Isolated lightning protection

With this solution we can guarantee the highest possible security for the equipment. In this case, the lightning protection system is constructed with special conductors with high voltage isolation or the arrestors are held "away" in a safe distance (Figure 5).

Figure 5: Arrestor held in a safety distance [16]

Conductor

Lightning strike conducting metal tool. Its task is to protect the object and human life from lightning. It may be in the form of a rod or a horizontal guide rail.

Grounder

It is not the same as earthing. An earthing device is a specific device designed to bring the lightning current into the ground and distribute it in a way that does not endanger the environment.

[21] **AC**: **A**lterning **C**urrent

Arrestor

Its function is to deliver the lightning current to the grounder.

Secondary discharge

During a lightning strike, a discharge occurs due to a potential difference between different metal structures.

Natural lightning protection structure

That part of the structure which was originally not part of the lightning protection system but belongs to the structural part of the building. However, due to its design it is capable of fulfilling certain functions of a lightning protection system.

Dangerous touch and step voltages

Near a lightning strike, a potential funnel is formed (Figure 6). The potential is decreasing going away from the point of lightning strike. Between different points, dangerous potential difference can be formed. Its unit is volts. It can reach a level when the affected person (or animal) can be injured or killed.

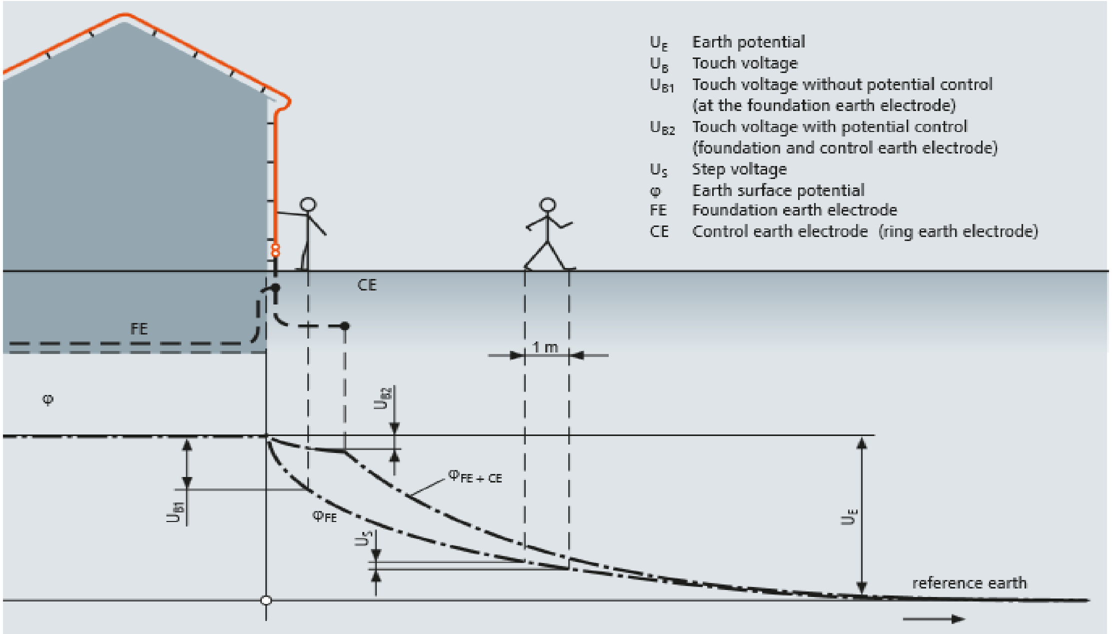

Figure 6: Dangerous step and touch voltages [17]

Lightning protection system (LPS)

Lightning protection system protects against lightning strike. This can be achieved by a combination of different tools. The higher the calculated risk, the higher the LPS required. It has four grades. Technically, each level is different, the lower the degree, the higher the system protection level.

The set of measures and structural elements that provide lightning protection to the building. Parts of LPS as follows:

- Air termination system
- Down conductor system
- Earth-termination system
- Secondary discharge control / separation distance compliance
- Lightning equipotential bonding / lightning protection potential equalization.

Protected area

The part of the object or building where the lightning bolt is unlikely to hit, which is designed with a rolling sphere method corresponding to the given LPS class, so it is safe to stay there.

Protection measures

Measures that reduce the risk (danger).

1.3 History in Hungary

The first lightning protection standard in Hungary was MSZ 274, published in 1952. This standard has been updated and expanded every 10 years, last version of it was revised between 1979 and 1982. In Hungary at that time the application of standards was mandatory, but accession to the European Union brought about a change. According to one of the directives of the European Union, the application of Community standards (EN) is voluntary, so the question arises how the practical application of this principle affects the lightning protection national (MSZ) standard and how it has been affected by the change. The BM[22] decree 2/2002 (I. 23.) incorporated the content of MSZ 274 as the applicable rule, thus making the application of these lightning protection rules mandatory. The mandatory application of the current lightning protection standard (MSZ EN 62305-2:2012) was first prescribed by BM Decree 28/2011 (IX. 6.) of 2011. The lightning protection according to the old system is not a standard system, it is called "*nem norma szerinti…."* in Hungarian. The new system designed and built according to MSZ EN 62305 is already called the lightning protection standard, in Hungarian "*norma szerinti…*".

My research is also based on the requirements of this new standard.

1.4 The lightning protection of existing buildings

In Hungary, in recent years, several standards/laws have been introduced and there has been a legislative change. From a technical and economic point of view, it is a very important question for buildings without lightning protection, whether it is sufficient to build a lightning protection system based on the old - not the norm - or only based on the new, standardized system.

Another question for buildings is that when we renovate, remodel or replace, at what stage do we need to apply the current standard and no longer apply the old one?

There are also many economic implications of using the new standard. Existing lightning protection of existing buildings may be subject to non-standard design if the purpose of the building is not altered or replaced or its extension does not exceed 40% of the floor area.

1.5 Changing or extending the purpose of existing structures

From a lightning protection risk point of view, the question is how to deal with various modifications (e.g.: building extensions, improvements, etc.) or changes of the basic function of the building. What is the applicable legal obligation to comply with?

[22] **BM: M**inistry **o**f the **I**nterior (MoI), in Hungarian: **B**elügy**m**inisztérium

The answers to the questions raised are contained in Article of 140. § (1) of the OTSZ[23] as follows (original text):

*„Új építménynél, vagy meglévő építmény rendeltetésének megváltozása során vagy a meglévő építmény olyan bővítése esetén, melynek következtében az eredeti tetőfelület vízszintes vetülete 40%-*ot *mértékű bővítése esetén a villámcsapások hatásaival szembeni védelmet norma szerinti villámvédelemmel*[24] *kell biztosítani."* [18].

In translation: it is said that *"In the case of a new structure or a change in the purpose of an existing structure or an extension of an existing structure which results in a 40% growth in horizontal projection of the roof surface, lightning strike protection shall be provided by standard lightning protection."* [18].

The OTSZ thus gives a clear answer. If there is no change in the purpose of the existing structure, it is sufficient to consider only the spatial variation in the degree of horizontal projection of the roof. Changes in the extent of this area are also clearly defined by the OTSZ. In the past, some have argued that the top view area is the floor space, so for example, vertical extension does not change the floor area, while others say the floor area is the sum of the floor areas.

According to this latter view, a practical example is: if a five-storey building with a floor area of 300 m^2 is extended by an additional two storeys of 300 m^2 and 250 m^2, the floor space will be extended from $5 \times 300\ m^2 = 1500\ m^2$ to $1500 + 300 + 250 = 2050\ m^2$. In this case, the rate of change is $2050/1500 = 1.366 = 36.666\% \approx 37\%$, which is within 40% of the control. With the entry into force of the new OTSZ on January 22, 2020, it has been made clear that the expansion only applies to a possible change in the area of the top view. In addition to the expansion, another question is how do I know if there is lightning protection on the building? The OTSZ does not provide a definition for this issue, but the TvMI[25] provides a clear point. Therefore, the TvMI provides that lightning protection is considered to exist when modifying or extending a structure if its components (e.g.: receivers, arrestors, other equipment, etc.) are clearly identifiable or have a lightning protection design documentation or a valid inspection report.

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[23] **OTSZ**: **N**ational **F**ire **P**rotection **R**egulations, in Hungarian: **O**rszágos **T**űzvédelmi **S**zabályzat.
[24] **NV:** Lightning protection according to the norm, in Hungarian: **N**orma szerinti **V**illámvédelem.
[25] **TvMI**: **F**ire and **T**echnical **G**uidelines, in Hungarian: **T**űz**v**édelmi és **M**űszaki **I**rányelvek.

In many cases, these documents are not available due to the many decades which have passed since the original construction. However, it is possible for the lightning protection reviewer to make subsequent amendments to the review report if the lightning protection for the building was made due to standard MSZ 274 or 2/2002 BM decree or 9/2008 (II.22.) **ÖTM**[26] decree. However, it is no longer possible to make subsequent adjustments to the implementation plan. In cases where the expansion rate does not exceed 40% and there is lightning protection, there is still a possibility to build a non-standard lightning protection [18] [19].

1.6 Planning permissions for buildings

Modifications, extensions, and upgrades often raise the question of what is and what is not considered a planning permission for constructions. Where is the limit when it comes to applying the planning permission for buildings, and in which cases do I need to have a permission? Legislation prescribes which construction activities are subject to licensing and which are not. The planning permission for buildings are issued by the building authority department of the Mayor's office responsible for the matter. When submitting the application, the department will contact the various authorities depending on the purpose of the building. For example, in the case of a restaurant, the Public Health Authority (ÁNTSZ[27]) or the National Disaster Management Inspectorate (OKF[28]), which checks the lightning protection of the building. This authority defines requirements, e.g.: it requires if the building must be equipped with lightning protection according to the standard, it also verifies the existence of risk calculation and the inspection report. In addition, this authority shall verify that the risk calculation and the review report are issued by appropriately qualified and certified professionals. The electrical design documentation must be part of the submitted design plan and shall include a lightning protection plan as well. Minor renovations and extensions are not subject to a building permission for the building. These include the use of wall isolation solutions or solar panel installations, except for historic buildings. In such cases, it may be necessary to involve the designer and have the lightning protection checked by an appropriately

[26] **ÖTM: M**inistry **o**f **L**ocal **G**overnment and Regional **D**evelopment till 2008, in Hungarian: **Ö**nkormányzati és **T**erületfejlesztési **M**inisztérium 2008.
[27] **ÁNTSZ: P**ublic **H**ealth **A**uthority, in Hungarian: **Á**llami **N**épegészségügyi és **T**isztiorvosi **Sz**olgálat.
[28] **OKF: N**ational **D**isaster **M**anagement **I**nspectorate, in Hungarian: **O**rszágos **K**atasztrófavédelmi **F**őfelügyelőség.

qualified technician, because if the floor area of the building is not altered, it may easily be the case that the parameters of the building have changed and may influence the lightning protection adequacy of the building. This can be caused by the non-use of inappropriate but previously used (type identical[29]) materials. Practical experience also confirms that in many cases, for example, during roof renovation, the use of combustible materials instead of the previously used non-combustible rock wool is a decisive factor in the lightning protection of a building. It is best to use at least the same type or more modern materials in roof construction/sheathing, e.g.: metal instead of slate, replacement of combustible materials with non-combustible materials, etc. Of course, for different types of damage, if it is found that during the renovation the lightning protection has not been properly controlled and has not been adapted to the new "features" of the building, it will also have legal consequences, such as the refusal to pay compensation.

1.7 Cases of buildings without lightning protection

According to the OTSZ, before the January 2020 regulations, in the case of a dwelling house or terraced house, there was an exemption from the compulsory construction of lightning protection up to a 10 m ridge height. From a height of 10 meters, it was mandatory to carry out a risk calculation. If the result obtained did not justify the existence of lightning protection, then there was no need to install lightning protection on that building. From January 2020, however, it was no longer the ridge height of the building that had to be considered, but the highest and lowest point of the building. In the case of other buildings (e.g.: accommodation, health care buildings, etc.), a minimum level of lightning protection is mandatory and there is no exemption from the risk calculation.

1.8 The lightning protection obligation for new building

In the case of a new building, lightning protection and risk analysis must be carried out according to the latest regulations. The statutory design and construction rules in force at the time the application for the building permit is made, if any subsequent legislation changes during execution, then it no longer has to be complied with.

[29] **Type identical**: protection material with the same properties. Here, the meaing is for the degree of flammability of the substance.

1.9 Effect of lightning, some economic impacts of lightning strikes

In the technical jargon there is a well-known saying:

„What had not burned down, was flooded by the firemen."

This saying also indicates that a lightning strike can directly and indirectly cause very high levels of damage [20] [21]. The material damage is due to the ignition and induction effects of lightning, which, together with the additional costs, constitute the specific economic damage. Such costs may include, for example: costs for heritage protection, professional restoration, logistics, etc. Ignition and induction effects can cause further damage, so-called explosion damage, which is protected by surge and explosion protection as a separate field. In the case of primary lightning strikes, the lightning strike directly hits the object. The roof structure may be damaged, the walls may move, but it is not uncommon for furniture and exhibits inside the building to be damaged.

According to MABISZ[30] statistics, nearly one-third (31.1%) of reported damage is caused by lightning. From this percentage, 16.5% was caused by direct lightning and the remaining 83.5% was caused by the secondary effect of lightning strike (Table 1 and Figure[31] 7) [22].

Reason of damage	Reported damage (pcs)
Flooding	5 947
Rainstorm	5 210
Hail	9 491
Roof-flooding	4 828
Storm	44 405
Lightning strike	**5 203**
Lightning strike inductive effect	**26 411**
TOTAL	**101 495**

Table 1: Storm Damage in Hungary between 1st of June – 31st Aug 2012 [22]

(Edited by author)

[30] **MABISZ**: **A**ssociation of **H**ungarian **I**nsurers, in Hungarian: **Ma**gyar **Bi**ztosítók **Sz**övetsége
[31] **See**: p.30 (next page)

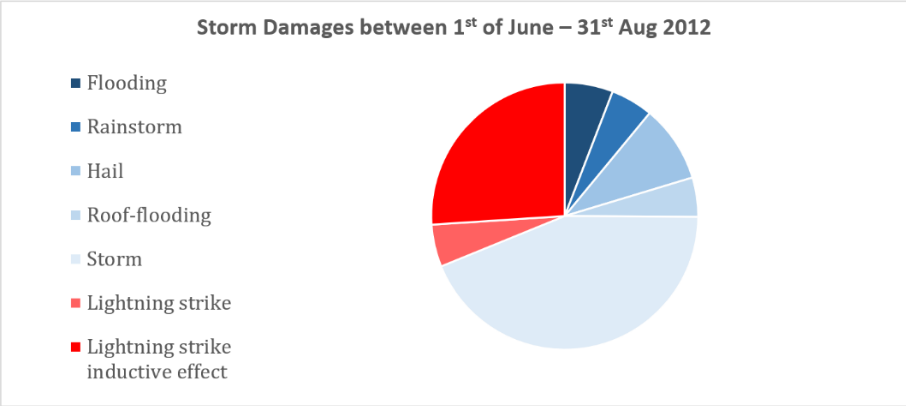

Figure 7: Storm damage in Hungary between 1st of June and 31st Aug 2012, in percentage [22] (Edited by author)

To avoid these incidents, buildings need to be provided with adequate protection.

„A lakástulajdonosok közel 80%-a egyetért abban, hogy ingatlanvagyonuk a legnagyobb értékkel bíró tulajdonuk, amelynek védelmére áldozni kell. Ez különösen akkor fontos, amikor országszerte hatalmas károkat okoz a szélsőséges időjárás." [23]

In translation, it is said that *"80% of flat owners agree that their properties are their most valuable s, on the protection of which they need to spend. This is especially important when extreme weather causes huge losses across the country."* [23]

1.9.1 Secondary effects of lightning strike

In the event of a lightning strike, not only our property (house, apartment, etc.) but our electrical equipment may also be in danger. The electromagnetic field of a lightning strike can cause damage for up to several kilometres away by induction. In the event that lightning strikes the connecting wire, a wave of surge voltage is set off. When it reaches a particular property, it breaks through insulations and reaches to the endpoints, damaging the connected – in most cases, the valuable – equipment. Such vulnerable devices are televisions, radios, computers, IT systems, laboratory and medical equipment, house equipment with electronic control (refrigerators, washing machines, kitchen appliances) etc. The most at risk devices are those that have both high and low current connections simultaneously. Colloquially they are called 'power cords' and 'network cables'. In this case, the induced overvoltages meet in the device, thus destroying the electrical components of the device.

It is important to know that lightning conductors do not protect against the secondary effects of lightning. One solution in these cases would be disconnecting the devices from the wall plug. It is important in this situation to disconnect the device not only from the power socket, but also from the antenna, internet cable, etc. Surge voltage may travel not only via power cables, but also e.g.: via coaxial cables to the sensitive devices. This is especially true in case of televisions, setup boxes and satellite receivers, since these devices are connected to non-energy networks, through which surge voltage may be transferred. From my own experience I would suggest is that it is sensible to disconnect sensitive and expensive devices during the time one spends away on summer holiday travels.

The value of protected devices can not practically be appraised, since each household owns devices of different value. The owner may take direct material loss, but the indirect intangible and further material losses may be much larger: data, information stored on computers, notebooks, network drives, time loss due to faulty measurement devices and equipment, loss of work time, etc.

This kind of potential loss is a very annoying type of risk, since if no one is at the given site during an electrical storm, there is no opportunity for intervention. The solution is the protection with active devices.

In case of lightning strikes, not only our properties (house, apartment, etc.) might be in danger, but also our electric devices as well.

Lightning strikes have **two kinds of effects**:

- **Direct (or primary) effect** when lightning strikes the building directly. A lightning conductor is used to protect against it (not compulsory for private houses).
- **Indirect (or secondary) effects** when the lightning strike itself does not cause the damage, but the surge voltage generated as a consequence of the strike. The standard [4] calculates with a 2 km side distance from the connected service lines on left and right sides.

When managing the risk of loss to human life, we must also consider the hazard of the 'environment' of the building. This danger not only threatens the building but also its surroundings. This is the case with industrial installations where hazardous chemicals are present, or for example radioactive material may be released.

In certain industrial buildings (such as the Százhalombatta oil refinery or Paks), accidental inhalation of substances could cause cancer. This is a separate risk, in which case the requirements are stricter because such cases must never occur. This is known as an emergency incident[32]. Similar to natural disasters, Disaster Management makes a special plan (an emergency plan) for what to do in such a case. Many people are affected by these kind of threats, and even entire parts of a settlement may need to be evacuated. Such a reason could also be airborne, e.g.: a hydrocarbon or radioactive cloud. These examples also show that a lightning strike is a very high source of danger and, in the most severe cases, can even cause a radioactive disaster. It is also important to mention the danger of dangerous touch and step voltage outside the building. In this case, e.g.: livestock can also be endangered because a dangerous step voltage can develop on the surface of the earth and cause death of the animals.

Obligation to provide protection against the primary effects of lightning:

The primary effects of a lightning strike can be protected by a lightning protection system. For some of the structures, there is an obligation specified from OTSZ or from the standard to develop, regularly inspect and maintain the lightning protection system. The OTSZ sets minimum requirements for different types of buildings but does not exempt them from the risk calculation. If the result of the risk calculation determines the use of a higher LPS grade, then it is mandatory for that given building. For buildings where OTSZ does not prescribe minimum requirements, lightning protection must be defined by risk management.

They include for example:

- Educational institutions (OTSZ minimum requirements)
- Hotels (OTSZ minimum requirements)
- Hospitals (OTSZ minimum requirements)
- Industrial Halls (risk management)
- Larger condominiums (risk management)
- Buildings for larger nightclubs (minimum requirements of OTSZ)
- Explosive industrial installations (OTSZ minimum requirements)

[32] It is called in Hungarian „havária". **Havária**: *„Természeti csapás vagy emberi tevékenység során előállt vészhelyzet"* [24]

1.9.2 Protection against the secondary effects of lightning

Besides cutting the power, we can protect our appliances with active surge protection devices (Figure 8).

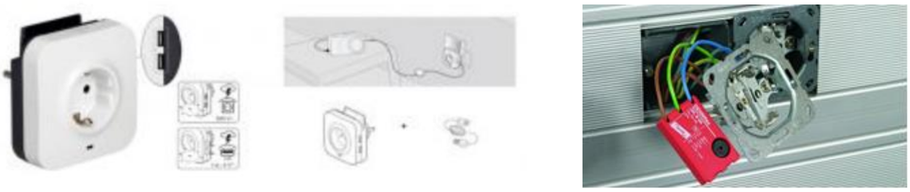

Figure 8: Various protection sockets [25] [26]

The best solution is multistage surge protection. This means 3 steps for a larger building, and usually two for a single-family house, excluding the second step. This first stage is at the main power distribution point, the second at the sub distribution point (at each floor) and the third is at the electrical device, at a maximum 10 meters distance. In practice, this means that a surge arresting device is installed in the distribution cabinet, e.g.: next to the electricity meter(s). The third stage must be no more than 10 meters from the device to be protected, including the possible charger and extension cords (Figure 8). As many devices need protection as many separate third stage devices are needed besides the protected appliances within the mentioned 10 meter distance. The best protection is provided by placing this device directly next to the device to be protected. It is very important to know that these surge protection devices provide proper protection only if they are properly grounded [27]. According to available data we can confirm that considerably more statements of damage are issued due to the secondary effects of a lightning strike. In the period of May-June, 2016, 90% of the loss incidents was connected to secondary effects of lightning, and the ratio was similar in the previous years as well [28]. As an example, here is a complex solution that actually exists, complete with surge protection. Arc defects in the system are small discharges. While in nature lightning times are microseconds long, low-energy discharges from arc failure can take days [29]. It produces a lot of heat in a small space, so it can ignite objects that were thought to be non-combustible. This is a very serious danger source because it can cause fire so it is very important to have some kind of protection against this kind of danger. Protection is possible with AFDD[33] equipment. As a complex solution, we have the ability to protect against overcurrent, stray current and arc failure with one device at the same time.

[33] **AFDD**: **A**rc **F**ault **D**etection **D**evice

Such devices are the AFDD+[34] equipment. These devices include integrated circuit breaker, circuit breaker and arc fault protection at the same time. The great advantage is that we only have to install one instead of three, saving a lot of time and money and we won't have compatibility issues. This equipment can be supplemented with surge protection to provide complex protection. The newer versions of this tools are becoming smaller and smaller, so the less space needed for the installation.

1.10 Materials of lightning protection

Various materials are available to build lightning protection systems. A selection of materials and cross-sections requires knowledge of the relevant standards and the various corrosion processes involved. The product standard for materials is contained in the standard MSZ EN 62561:2012 in Hungary [30]. This standard requires not only the materials to be used but also the minimum cross-sections to be used. Application of this product standard is mandatory. Most lightning protection systems are installed outdoors. The materials used are exposed to the risk of corrosion outdoors due to environmental influences. When designing and installing lightning protection systems, the material used has to be taken into consideration, because from a technical point of view these systems have to perform their functions for several decades (Figure 9) and only a few years of operation is unacceptable from a security and financial point of view. This requires the use of corrosion-resistant materials and solutions. There are different materials available for building lightning protection systems.

Figure 9: Rusted arrestors on different structures

On the left: Rusted arrestor on the wall of Castel Sant’Angelo[35] (Picture by author, 2017)
On the right: Rusted arrestor on old house, close to Zakopane, Poland (Picture by author, 2020)

[34] **AFDD+** tools: Tools which include the overcurrent protection, circuit breaker and arc fault protection.
[35] **Castel Sant’Angelo**, Rome, Italy, 2017

Selection of materials requires knowledge. The installation requirements are set out in MSZ EN 62305-1,3,4:2011[4] and MSZ EN 62305-2:2012 Edition 2 [4], and the product standard for materials is contained in MSZ EN 62561: 2012 [30]. This standard sets out not only the materials for lightning protection systems to be used but also the minimum cross-sections to be used. Application of this product standard is mandatory. This means that only certain materials may be used in the construction process. These materials must be known by the architects, lightning protection designers, construction companies and also by the lightning protection inspector. The available materials are developed and produced by several companies, so the usable (licensed) materials can be found in different catalogues. They have been tested after their development.

1.10.1 Types of usable materials

The following materials may be used in lightning protection[36]:

- Steel
- Stainless steel
- Galvanized steel[37]
- Aluminium
- Aluminium alloy
- Copper
- Metal coated materials
- Composite materials (with PVC[38] or high voltage insulation coating).

Steel, stainless steel

According to international definition [32], steels are iron (Fe) materials with a carbon (C) content up to about 1.7% - 2% and may contain other substances. There are exceptions, such as certain chromium steels with a carbon content greater than 2%. Stainless steels are substances which, due to their chemical composition, are not oxidized, so they are resistant to the harmful chemical processes created by various environmental influences. Hot dip galvanized steel [33] also means steel which has been zinc coated (Zn) on its protective surface. Zinc plating of different surfaces is also called galvanizing [31], for which there are several methods [33].

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[36] **MSZ EN 62561:2012** obligations.
[37] **Galvanized steel**: zinc-coating on iron material for protection [31].
[38] **PVC**: **P**oly**v**inyl **c**hloride, polymer of vinyl chloride.

Aluminium and aluminium alloys

In addition to the different steels, aluminium and various aluminium alloys are also common materials. In most cases, "pure" aluminium is made of a soft material, with an alloyed version in both soft and semi-hard versions. This wire is available in coil design and has a curved shape after unscrewing, so it is important to straighten the conductor. As a soft version of this type of aluminium, it can be screwed and straightened. Installation technicians can easily straighten this component by clamping one end of the fiber into a drill.

Copper

Copper is also used in lightning protection installation. Copper and copper alloys are the most versatile materials used by engineers. Due to its favourable properties, such as strength, conductivity, corrosion resistance, machinability and formability, it can be widely used. Several types of products are available, e.g.: strips, cables, conductor holders, clamps.

Metal coated materials

Nowadays, some metal coated materials have appeared (Figure 10).

Figure 10: Zinc (Zn) coated steel, copper (Cu) coated aluminium & tin (Sn) coated copper arrestors [34]

These are metallic materials that are coated with other metals in micron thickness, such as copper-coated steel (Fe/Cu), copper-coated aluminium (Al/Cu), tin (Sn) coated copper (Cu/Sn). These materials have two great advantages. One is that they are cheaper than their "solid" counterparts. For example, copper-plated steel is significantly cheaper than the solid copper version. Another benefit is the visual aspect. The use of copper conductors is aesthetically pleasing for the appearance of a copper-roofed building. In the past, for example, in the case of churches, copper plating was a popular cladding solution, and in the case of monuments, this solution is often seen to this day. The coating is corrosion-resistant until it is damaged, from which point the material begins to deteriorate during the electrochemical corrosion process. Depending on this, the use of the material requires a great deal of caution by construction workers.

Any form of throwing or tossing material is strictly prohibited. Some construction companies often instruct construction workers to treat the material as an explosive. Interestingly, the bonding of copper and aluminium metals is extremely electrochemically harmful, but due to the special coating technology, this "pairing" does not cause electrochemical corrosion to occur without external damage. In practice it is possible to use not only circular profile but also rectangular profile materials.

Composite Materials

Composite materials are aliased materials. They are materials that consist of two or more components with different properties (chemical, physical, etc.) that result in the combination of a new substance. Such properties can be e.g.: stronger mechanical properties, corrosion resistance, lower weight etc. Among lightning protection materials, for example, insulated conductors are such that a good electrically insulating coating is applied around the conductor. Special coating (electrical insulation) on material is equivalent to 90 cm air insulation (Figure 11). In lightning protection, the word 'composite' is not used; instead, the word 'insulated conductor' is commonly used to build protection. There are two types: one is the PVC coated conductor. Here the function of the insulation is to protect against corrosion. The other is the conductor with high resistance insulation. The purpose of this isolation is to prevent induced high-voltage insulation. By using it, we can avoid discharges to metal elements or possibly to man. Some types can be seen in Figure 11.

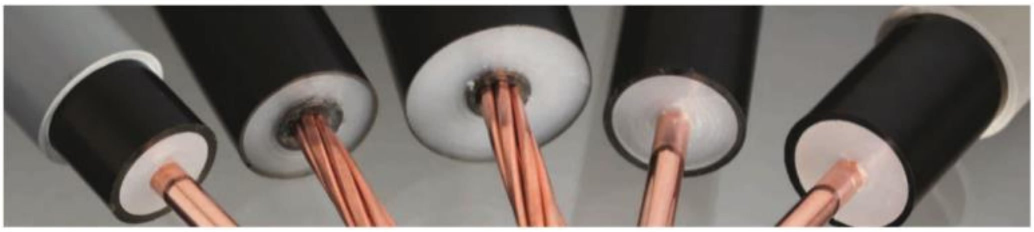


Figure 11: Types of composite materials [35]

1.10.2 Connection options for different metals

Metallic materials should not be galvanically bonded to any metallic material. Different metals can only be "paired" with specific materials. This is because of the different standard potentials of metals. If the wrong combination is chosen, moisture will form a galvanic cell and cause electrochemical corrosion of the materials.

The pairing options are listed in Table 2. From the Table 2, it can be seen that the "most dangerous" material is copper (Cu) because it cannot be bonded with steel (Fe) or aluminium (Al), only with corrosion-resistant steel. In practice, this means that the use of copper must be closely monitored during construction, because in many cases the use of aluminium structural elements is widespread, so there is a high chance of realizing copper-aluminium connections due to inattention.

	Steel	Aluminium	Copper	StSt
Steel (St/tZn)	yes	yes	no	yes
Aluminium	yes	yes	no	yes
Copper	no	no	yes	yes
StSt	yes	yes	yes	yes

Table 2: Pairing possibilities about different metals [36]

(Edited by author)

Not all metallic materials can be combined with other metallic materials. The question then arises as to what needs to be done and what solution exists, if we still want to achieve galvanic coupling of such 'non-pairable' materials? The solution is to use two-metal connecting elements (e.g.: types of clamps). The version shown in Figure 12, is suitable for forming a copper-aluminium connection. This element consists of three parts. The upper clamping plate is made of copper, the lower is made of aluminium and a double-layered plate, between the upper half of copper and the lower part of aluminium. The aluminium-copper connection is very electrochemically dangerous, but the middle plate of said device is made by a special process which does not develop electrochemical corrosion. This solution can securely connect copper and aluminium materials. Such materials are called cupal[39] materials.

Figure 12: Two-metal clamp (cupal) [37]

[39] **cupal**: Word made up of chemical symbols of copper (Cu) and aluminium (Al) and the word 'to pair'. Not an acronym.

1.10.3 The lightning protection structural elements and their materials

Different types of structural elements are needed to build a lightning protection system. In public, the lightning protection system is called lightning protection. The reality, in contrast, is that a lightning protection system consists of several number of structural elements, each of which have different functions and, accordingly, different material/electrical properties. Lightning protection system structural materials include:

- receiving rod
- arrestor
- grounding
- support elements
- other structural elements.

The purpose of the catch / discharge element is to catch the lightning and direct it to the ground. Aluminium, copper, steel and coated variants are available as structural materials. The materials of receiving rods are aluminium and hot-dip galvanized steel. The minimum cross-section is 176 mm^2. For wind load reasons, the standard allows the last 1 meter section to be 10 mm in diameter (Figure 13).

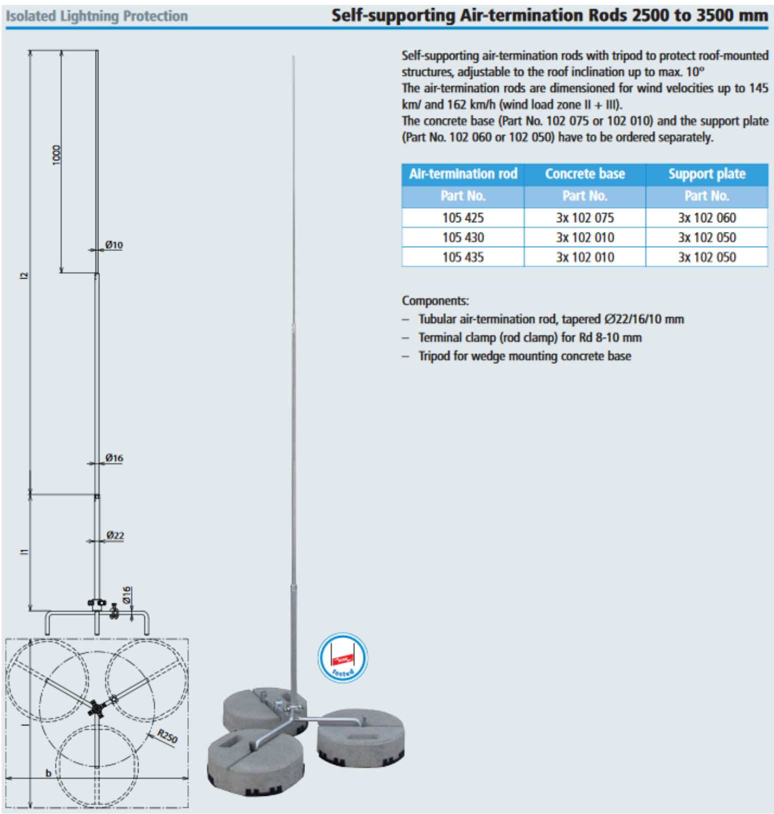


Figure 13: Arrestor with 10 mm diameter at the last 1 m part [38]

For conductors, the minimum cross-section is 50 mm^2. For circular profile materials this means 8 mm diameter, for rectangular (flat) profile conductors the minimum wall thickness of 2.5 mm is mandatory. It is important to note that the conductivity of stainless steel is worse than that of an unalloyed counterpart, so that this material has a minimum cross-section of 75 mm^2. For wire ropes, there is also a minimum requirement for the diameter of the filaments. 1.7 mm for hot dip galvanized wire and 1.63 mm for aluminium. The use of smaller fiber diameter wires can only be used for potential equalization purposes.

The grounding's task is to conduct and distribute the lightning current from the arrestor to the ground. Materials can be stainless steel, copper plated steel, hot dip galvanized steel, copper and tin (Sn) plated copper. For type 'A'[40], hot-dip galvanized steel grounding rods, the minimum cross-section of 150 mm^2 and a minimum diameter of 14 mm may be used. The use of pipe earthing and profile earthing is permitted. The minimum metal cross-section must be 150 mm^2 and the minimum outer diameter of 25 mm or less. The wall thickness must be at least 2 mm. In the case of a profile earthing device, the cross-section must be at least 290 mm^2 and the wall thickness must be at least 3 mm.

The purpose of the **supporting elements** is to fasten the lightning current conducting metal structural elements to the building. Because of materials with different standard potentials, it is important that only materials that are "pairable" are used. This can be achieved either by insulated versions of the mounts (polymeric insulation of the clamping surface) or by the appropriate choice of material.

Other components, e.g.: different fastening weights, screws, clamps etc. There may be a need for galvanic connection of different types of metallic materials. Not all metallic materials can be bonded to other metallic materials for the reasons described in section 1.10.2[41] The question then arises as to what needs to be done and what solution exists, if we still want to achieve galvanic coupling of such "non-pairable" materials? The solution is described in section 1.10.2.[41] with cupal materials.

[40] **See**: Figure 3, p.21
[41] **See:** p.37-38

1.10.4 Corrosion of materials[42]

Most lightning protection systems are installed outdoors. The materials used are exposed to the risk of corrosion outdoors due to environmental influences. Due to definition, the corrosion is the failure of materials to loose pure material state due to contact with their environment. One problem that arises is that the electrical conductivity of the various oxide layers is much worse than that of their pure metal counterparts because of their higher resistance, which can result in significant heating at different contact points. This creates a dangerous ignition effect. Another problem is that with such increased resistance, the lightning current is looking for another way to the ground. When designing and installing lightning protection systems, this has to be taken into consideration, because from a technical point of view these systems have to perform their functions for several decades and only a few years of operation is unacceptable from a security and financial point of view. This requires the use of corrosion-resistant materials.

1.10.5 Types of corrosion

There are several types of corrosion. Types of chemical, electrochemical and physical corrosion. The structural materials of lightning protection are metals due to the need for conducting lightning currents. In the case of metallic materials, knowledge of corrosion and its avoidance is particularly important.

Chemical corrosion refers to the failure of metals due to various environmental influences. The metals are then converted to oxides, hydroxides, sulphides and carbonates by substances taken from their environment. In practice, this process is known as rusting. The vernacular uses the word rust for iron, but chemically it actually refers to the oxidation of metals.

Electrochemical corrosion occurs when two metals of different electrode potentials [39] are in contact with one another and galvanically interconnected by a conductive medium (electrolyte). Then a galvanic cell[43] is formed, whereby one of the parties is transformed into some kind of oxide and loses its pure metal character.

[42] **In latin language "corrodo"**, it means in English: to erode.
[43] **Galvanic cell**: connecting two materials of different standard potentials with a conductive medium.

The standard potential shows the electromotive force (potential) of various metals relative to hydrogen (H) in Table 3. When two metals are connected to a conductive medium, the potential difference between them will be the difference between their standard potentials. For example, at copper-aluminium connection as below:

$$U = \Delta U = +0.34\ V - (-1.66\ V) = 2\ V\ DC^{44}$$

Name of metal	Chemical sign	Standard electropotential (Volt)
Magnesium	Mg	– 2,38
Aluminium	Al	– 1,66
Zinc	Zn	– 0,76
Iron	Fe	– 0,43
Cadmium	Cd	– 0,40
Nickel	Ni	– 0,23
Tin	Sn	– 0,14
Lead	Pb	– 0,126
Hydrogen	H	0
Copper	Cu	0,34
Silver	Ag	0,79
Mercury	Hg	0,8
Platinum	Pt	1,2
Gold	Au	1,42

Table 3: Standard potentials of metals [39]
(Edited by author)

Physical corrosion occurs due to the weakening of the bond among the crystals. The result of this process is, for example, the appearance of cracks. Cracking or fracture by mechanical stress alone cannot be called physical corrosion unless there is a chemical effect associated with an environmental impact. There are two types depending on whether the element is mechanically loaded or not. If not, we are talking about stress-free corrosion, but if the structural element is subjected to mechanical stress (e.g.: tensile stress), then it is called stress corrosion. In this case, the corrosion effects on a more aggressive level of the structural element.

1.10.6 Protection against corrosion

It is possible to protect against this type of damage. Protection can be achieved by passive, active corrosion protection or also using corrosion resistant materials.

Passive corrosion protection means applying a suitable coating. Then a specific type of corrosion-resistant surface (heat, chemical, etc.) is applied to the surface to be protected. An important selection criterion is the type of bonding of the materials used,

[44] **DC**: **D**irect **C**urrent

the type of protection (heat, chemical) and the environmental aspects (e.g.: UV[45] resistance). In addition, the appropriate aesthetic appearance is an important consideration. Passive protection options are shown in Figure 14.

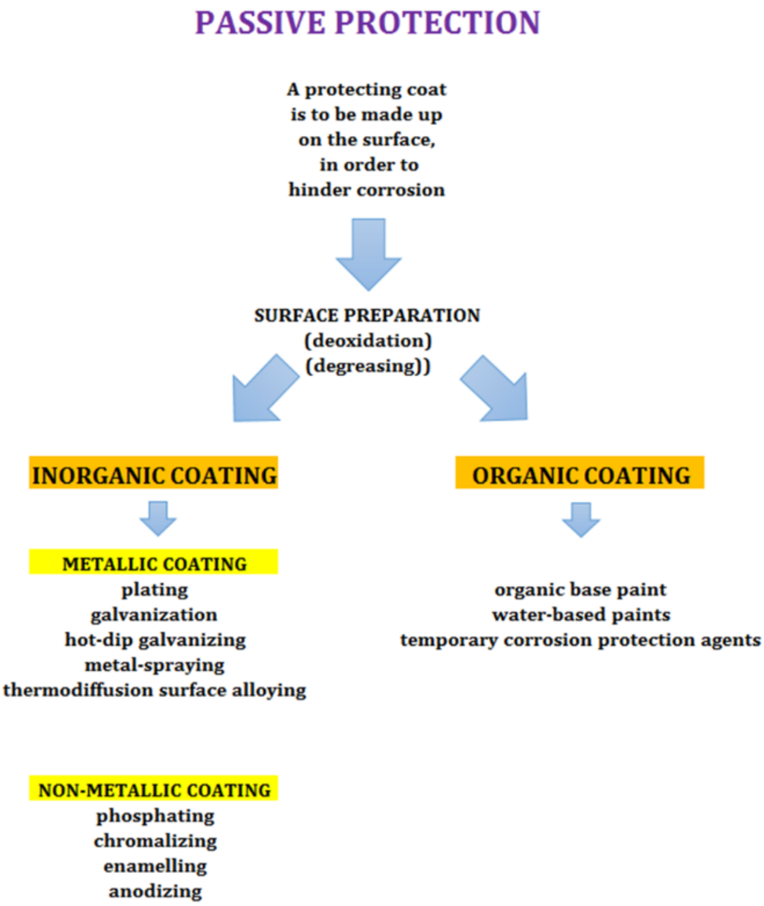


Figure 14: Passive protection options
(Edited by author)

Active corrosion protection. When we connect an external power source to a metal or alloy, the corrosion rate changes. If the metal is polarized anodically, the corrosion current density will increase (helping local cells to function) and the corrosion rate will increase (if passivation does not occur). In contrast, when the metal is cathodically polarized, the corrosion current density is reduced (the external power source is working against local elements), so the corrosion rate is reduced. With proper cathodic polarization, the corrosion rate can be reduced to zero. This is the so-called external power source. Principle of active cathodic protection.

[45] **UV**: **U**ltra**v**iolet [40]

Of course, other considerations must be taken into account in its implementation (e.g.: the relatively high current density should not cause corrosive stray currents to move to other objects or the metal to be damaged by the cathode process). In practice, this is the case, for example, with a high-pressure gas network laid in the ground where 60-70 V DC is connected to the gas pipeline.

The use of corrosion-resistant materials means the use of alloys. There are two types of materials. Different metals combined with other metals (alloys) and weather resistant steels. Metallic alloys are expensive materials.

1.10.7 Corrosion protection aspects of lightning protection

When designing lightning protection, it is important to consider not only the chosen material, but also other considerations.

They are as follows:

- built-in materials should be accessible
- if enclosed sections are to be installed, they shall be hermetically sealed
- not having a discontinuous weld outdoors [41]
- there should be no collection point for dirt.

1.10.8 Potential for corrosion in lightning protection materials

There are several types of corrosion sources when installing lightning protection systems, all of which need to be prepared for. It is important to apply appropriate corrosion protection because e.g.: for materials located in difficult to access places (height, cultural facilities, etc.), we may incur additional high repair costs.

Chemical corrosion occurs in two instances when lightning protection is installed. One of the cases is the use of outdoor materials affected by humidity and rain. Most materials are installed outdoors so preventing this type of corrosion is important. The other case is the earth-installed drain, which is used in addition to the moisture/water in the ground, even in various acidic environments. Experience has shown that the corrosion effect at crossings is very problematic and heightened. In practice, this means the passage of materials between air-ground and concrete-air media. It is extremely important to choose the right material, because it is possible to replace the structural elements outdoors, but with few exceptions, it is no longer possible to change the materials placed in the ground. These materials must be functional for as long as practically possible during the life of the building. For outdoor materials, the most important requirement is for the protection against corrosion caused by water. Examples of such materials are alloy aluminium and hot dip galvanized steel like V2A[46] [42]. In practice, the use of these materials is widespread because of their excellent heat load resistance, which is important because lightning current can carry a high degree of heat load [43]. Environmental considerations are also important when selecting materials. Unlike the urban environment, the humidity near the seashore is aggressive, due to its salt content and makes the structures more prone to stress [44], so it should be taken into consideration. In addition to corrosion caused by water, the corrosion resistance to acidic media is an important criterion for materials used in the ground.

For example, the hot dip galvanized steel in soil corrodes before the lifetime of the building (10-30 years). The solution is to use an alloy containing 2% molybdenum. One type of material is V4A[47] [45]. It is a stainless, highly corrosion resistant material. A special mark on the surface indicates the type of alloy, since the unalloyed version also looks the same as the type of alloy and is thus easily identifiable by the lightning protection inspector, who is particularly attentive to the use of these materials (Figure 15).

Figure 15: Unalloyed (on the left) and alloyed version of steel (on the right) [46]

[46] **V2A**: international code is 1.4301 [42]
[47] **V4A**: international code is 1.4571 or 1.4404 [45]

Electrochemical corrosion occurs when two metals of different standard potentials come into contact with one another and are galvanically bonded by a damp medium (e.g.: rain, mist, water from sprinkling, etc.). In practice, this case may occur with electrical connections or at the connection of the mechanical supports outdoors where moisture can touch the surfaces. In the case of mechanical brackets, this is avoided by the application of plastic brackets or a plastic insulating layer on the bracket.

Multi-storey height use of both types of brackets is acceptable, as these arrestors are not heavy and not a criterion for high load capacity. For electrochemical corrosion or a typical example of its prevention, which affects many buildings, is the use of steel in concrete during grounding. The steel material in the concrete is then contacted with a steel grounding device in the ground. At first thought, one might think that joining the two iron materials would not be a problem, but in reality this should not be done. The steel in the concrete behaves as if it were (wet) copper in the soil, thus creating an electrochemically iron-copper connection which should be avoided (Figure 16).

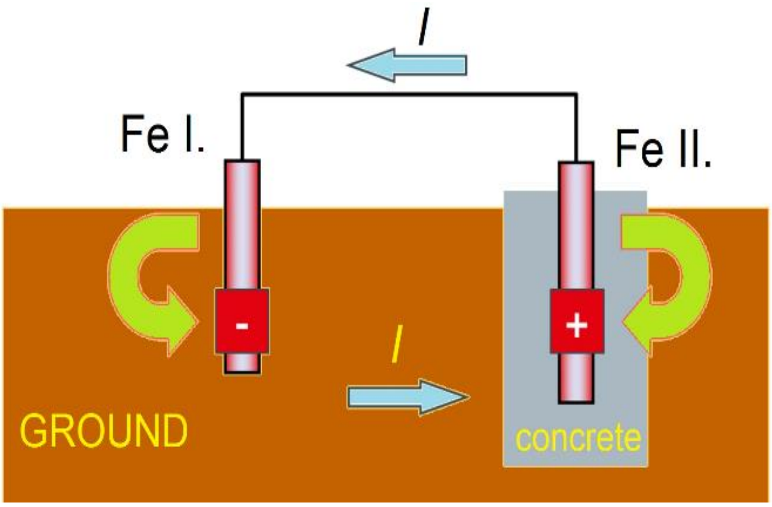


Figure 16: Connected iron in ground and in concrete [47]
(Edited by author)

The solution in the ground is the use of stainless steel. It is the grounding's task to inject lightning current coming from the arrestor into the ground. This can be achieved if the medium is damp, that is, the earth must be moved/placed in a damp medium. From the design point of view, there are many cases where the building has thermal insulation, waterproofing, stone chips or the concrete foundation itself is made of waterproof concrete.

In this case, due to the aforementioned insulation solutions, the galvanic connection of the conductor must be driven into a damp medium by a separate solution. This can be done using stainless materials. An important requirement is the outstanding durability, because the grounding structures placed under the building cannot be replaced. It is also important to note the choice of materials for brackets or clamps that may be included in the plaster.

Again, no materials should be placed in the plaster except copper and hot dip galvanized steel. The use of aluminium in ground and plaster should be avoided as the environment of the plaster is alkaline, which permanently damages this structural element and as a result, the aluminium cannot form an oxidation barrier.

Physical corrosion is not common with lightning protection systems. The specific weight of the 50 mm^2 cross-section aluminium wire is only 136 kg/km [48], so for a 100 m tall building this would only mean a total weight of 13.6 kg which is partially relieved at intervals by the vertical load in the supporting brackets at intervals.

1.11 Chapter summary

This article introduced the different regulations, materials used of lightning protection. In the development of lightning protection systems, one must be aware and take note of different regulations. Several rules must be followed simultaneously. Not only the design but also the installation rules must be taken into account. It is also important to know the technical options for designing these kinds of protection systems. In conclusion, it is imperative to know the MSZ EN 62305:2012 standard in designing a system and also important to understand MSZ EN 62561:2012 when selecting lightning protection materials. It is mandatory to comply with the standard and to take into account the corrosion stresses as summarized in this chapter.

2. PRESENTATION OF MY RESEARCH PROCESS

2.1 Introduction

„Research is formalized curiosity. It is poking and prying with a purpose.”[48]

(**In Hungarian:** A kutatás egy formális kíváncsiság, ami folyamatosan kíváncsiskodik a cél érdekében)

„Discovery consists in seeing what everyone else has seen and thinking what no one else has thought” [49]

(**In Hungarian:** A nagy felfedezés az, amikor mi is azt látjuk, amit mindenki más, csak épp olyat gondolunk róla, amit még soha senki.)

There are several ways for defining the concept of research. In my opinion and experience, the basis of research is the observation and the formulation of new ideas and thoughts on the basis of new experiences. Research is a process present in all walks of life. Whether it is in small tasks related to our day-to-day tasks, or research for a larger, more complex problem. In our current society, we have much easier access to data and information, and virtually anything can be found very easily. As information became readily available, the focus of the problem-solving process shifted to the research method, the process of solving the problem. It is important that the researcher produces reliable results at the end of the research process. The essence of research is to produce results that others have not yet proven, and to make the results useful to others.

[48] **Zora Neale Hurston**, American author [49].
[49] **Dr. Szent-Györgyi Albert**, Hungarian Nobel-Prize winning doctor and biologist [50].

Research is a vital part of development in the scientific world. It helps to understand the phenomena and their characteristics, accepting or even rejecting the facts. It creates new knowledge. It helps us to improve our knowledge.

How do we gain new knowledge? How is the research process going?

How do new results come about?

The process, methodology and results of my research will be presented in this chapter. I used the sensitivity analysis to conduct the research. Research is a multi-step, complex process consisting of several steps.

2.2 Concept of knowledges

The basis of our development is that the human being acquires knowledge which it can then apply in the course of its activities in nature. It makes decisions based on its knowledge. It is with this knowledge that he unwittingly participates in the development process. There are two ways to gain knowledge in our daily lives. One is to know (learn) static knowledge, and the other is to learn about different processes and phenomena. Based on these, we have two kinds of knowledge [51]. One is cognitive knowledge, another is lexical knowledge. This means that we have static data in the topics. Such as knowing a phone number, a formula, a book address, etc.

Another type of knowledge is knowledge of processes, actions, activities. Such knowledge is, for example, knowledge of the operation of a machine, of a physical phenomenon, or of conducting a type of research activity. Both forms of knowledge can be learned. In research, the goal is to prove an idea, divination or a though which can be a complex, multi-step and complex task.

Harmonisation of the theoretical lexical knowledges and the practical experiences can form simultaneously a complex useable knowledge base.

2.3 Steps of my research[50]

My research process consists of several steps, the main steps of which are as follows (Figure 17):

- Topic / identification of problem
- Setting up hypotheses
- Conducting research
    - Collection of background information (e.g.: literature)
    - Work organization (purchase of tools, materials, programs)
- Data analysis based on MSZ EN 62305 standard family
- Summary of my results, theses and suggestions.

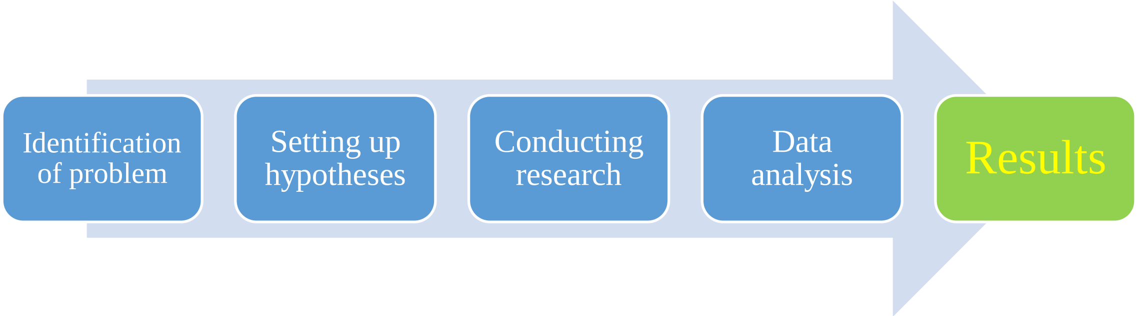


Figure 17: Schematic diagram of my research process
(Edited by author)

2.4 Stages of my research

My research consisted of three main phases. In the first phase, my self-developed IT program needed for sensitivity testing was created. This was done using the calculation method of the MSZ EN 62305-2:2012 standard. The second phase of the research involved the identification of strong and non-strong parameters using sensitivity analysis. I carried out my research with the self-developed MS Excel based IT program with my macros I created. In the third phase, given the already known strong parameters in the design phase of buildings, during the pre-construction lightning protection design phase, was to make comments and recommendations to the architect. Such a suggestion could be e.g.: taking into account the r_f[51] factor when designing the roof structure of a building.

In addition to the three main phases, my research was supplemented with the examination of two co-areas, which are described later in my dissertation.

[50] Due to the research some points have been repeated several times.
[51] $\mathbf{r_f}$: factor reducing loss depending on risk of fire.

2.5 Risk calculation method

The definition of the concept of risk is not an easy task and it differs in each speciality. Regarding buildings, the external impacts affecting the normal operation can be concretely identified (e.g.: earthquake, lightning strikes, etc.). We may consider the occurrence of external impacts damaging buildings and the likelihood of the occurrence of negative events as risks. Alternatively, the following definition may be taken to mean risk [52]:

"Effect of uncertainty on objectives"

Standard series MSZ EN 62305 at the moment consists of four parts (Figure 18). Risk assessment calculations are found in the document MSZ EN 62305-2.

Relationship between the pages of MSZ EN 62305:

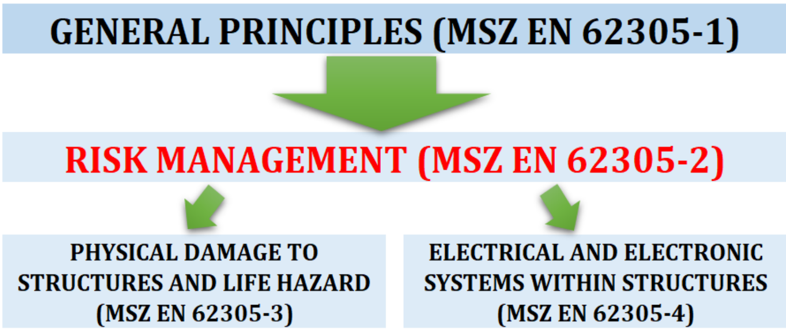


Figure 18: Content of the MSZ EN 62305 family of standard [4]
(Edited by author based on MSZ EN 62305)

The standard defines four possible risks at lightning strike incidents (Table 4):

Risk symbols	Risk description
R_1	**Risk of loss of human life (including permanent injury)**
R_2	Risk of loss of service to the public
R_3	Risk of loss of cultural heritage
R_4	Risk of loss of economic value

Table 4: Type of risks [53]
(Edited by author based on MSZ EN 62305-2:2012)

Out of these four risks in my view, I have considered the risk management of the loss of human life and its calculation of both theoretical and practical risk analysis for (R_1) as the basis of my further research.

We consider the source of damage as the point where the lightning may strike. The standard defines four possible points of strike (Table 5 & Figure 19) [53] [54] [55]:

Source symbol	Source description
S1	Flashes to a structure
S2	Flashes near a structure
S3	Flashes to a line
S4	Flashes near a line

Table 5: Sources of damages [53]
(Edited by author based on MSZ EN 62305-2:2012)

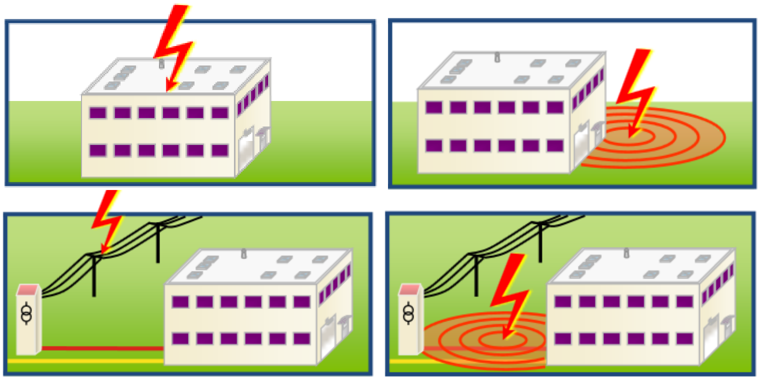


Figure 19: Sources of damages in the life [54]

The standard defines three types of damage (Table 6):

Damage symbols	Damage description
D1	Injury to living beings by electric shock
D2	Physical damage
D3	Failure of electrical and electronic systems

Table 6: Types of damages [53]
(Edited by author based on MSZ EN 62305-2:2012)

The Table 7 shows that the possible sources of lightning strike (see S1-S4) may cause several types of damage (see D1-D3) simultaneously.

Source symbols	Source description
S1	Flashes to a structure
S2	Flashes near a structure
S3	Flashes to a line
S4	Flashes near a line

Table 7: Relationship of sources and types of damages [53]
(Edited by author based on MSZ EN 62305-2:2012)

The calculation of risk is specifically included in the standard. The standard defines a building as legally protected if the calculated risk (R_1, R_2, R_3, R_4) is less than the officially stated value (R_T) in the standard. An exception is the risk of public service disruption (R_2), where the National Fire Protection Regulations (OTSZ) currently requires a stricter reference value than R_T, but it returned to the standard value from 2020 January. In technical terms, there is always residual risk.

The risk calculation takes into account the parameters of the building and its installations (e.g.: lightning protection structures, cables, floors, etc.). The result of the risk calculation gives a value whether the tested building is protected against lightning or not. The conceptual outline of the computational process is given in Figure 20 is shown. The result of the risk calculation shows whether the building is legally protected by lightning protection or not. If the result shows that it does not, further lightning protection measures have to be taken and the calculation must be performed again. If the result is repeatedly "unprotected" then the lightning protection measures must be improved until the result is "protected".

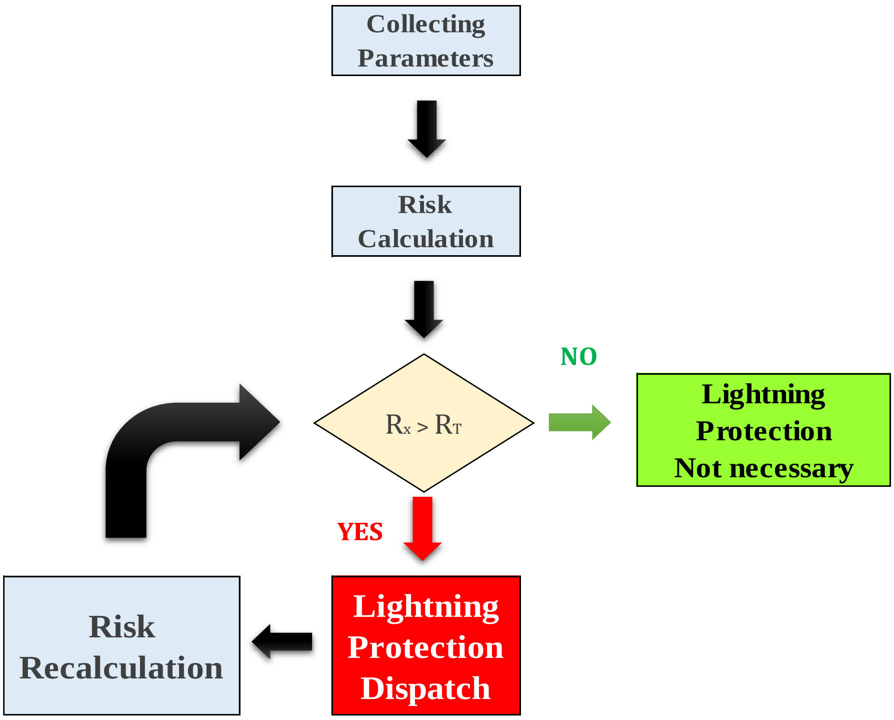


Figure 20: Risk assessment process [53]
(Edited by author based on MSZ EN 62305-2:2012)

The risk of losing human life (R_1) consists of 8 parts. We calculate just the risk of losing R_1 human life by adding up these partial calculations:

$$\mathbf{R_1} = R_A + R_B + R_C + R_M + R_U + R_V + R_W + R_Z$$

The partial calculations of standard use the multiplication method like:

$$\mathbf{R_X} = N_X \times P_X \times L_X,$$

where the parts are (Table 8):

Part symbols	Description of multiplication part
N_x	Number of dangerous events per annum
P_x	Probability of damage to a structure
L_x	Consequent loss

Table 8: Multiplication factors [53] [119]
(Edited by author based on MSZ EN 62305-2:2012)

Defined as components of R_1: {A, B, C, M, U, V, W, Z} ϵ x, for N_x, P_x and L_X .

2.5.1 Some main input parameters of MSZ EN 62305-2:2012

The standard MSZ EN 62305-2:2012 calculates with more than 50 input parameters.

Introduction of the main input parameters for risk calculation:

***L, W, H** – Dimensions of building*

Length – building length (in meters)

Width – building width (in meters)

Height – building height (in meters)

The collection area of the building is the area around the building at a distance of 3H[52]**.** In the case of a rectangular building with a roof without protrusions, it can be calculated with formula:

$$\mathbf{A_D} = L \times W + 2 \times (3H) \times (L+W) + \pi \times (3H)^2.$$

In the case of a protrusion (e.g.: chimney), a union of area around the highest point at distance of $3H_T$[53]and 3H around the building (Figure 21).

Different softwares are available to determine the collection area.

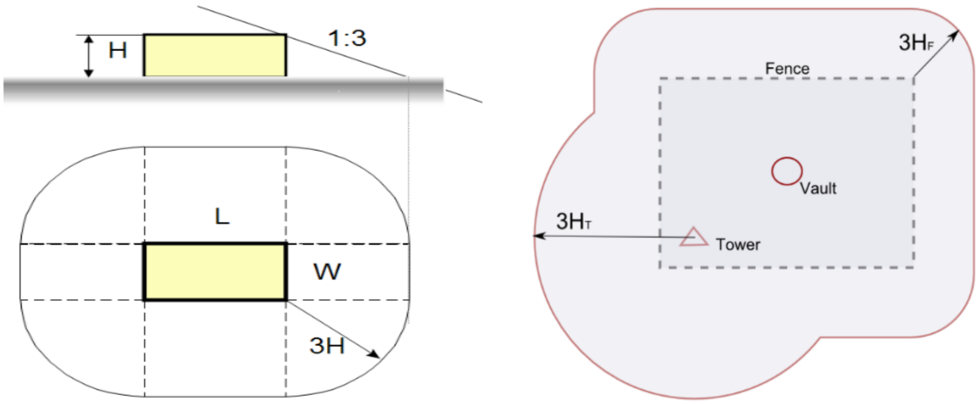


Figure 21: Collection areas of rectangular based building.
On the left: without a protrusion, ***on the right:*** with protrusion. [56]

N

$\boldsymbol{N_G}$ *– Number of lightning strikes per year per km²*

The average frequency of lightning strikes in a given area. Its unit is number of lightning strikes / km^2 / year. Value can be found in TvMI in its Annex-F.

$\boldsymbol{C_D}$ *– Location factor*

Specifies the relationship of the building to its immediate surroundings. It has four values for the input parameter, regarding e.g.: building stands on hilltop or e.g.: structure is surrounded by higher objects.

[52] **3H**: three times the height of the building.
[53] $\mathbf{3H_T}$: three times the height of the protrusion.

Parameters of connecting wires (telecom and high power in Table 9):

Part symbol	Description
L_L	Lenght of cable
C_I	Line installation factor, it depends on the cable type (aerial or buried)
C_E	Line environmental factor, it depends on the building location (rural, suburban, urban or urban with tall buildings)
C_T	Line type factor, it depends on the cable type (HV, LW)
C_{LD} , C_{LI}	Factor depending on shielding, grounding and isolation conditions

Table 9: Some other input parameters [53]
(Edited by author based on MSZ EN 62305-2:2012)

Additional input parameters are below:

***P**$_{SPD}$ – Parameter for coordinated overvoltage protection*

The protection is multistage, a related parameter, it is the construction of this overvoltage protection system. There are stages, and the corresponding coordinated surge protection is built. One of protection measures.

***K**$_{S3}$ – Factor relevant to the characteristics of internal wiring*

Loop parameter associated with the cable path. When routing cables from a plan view of the cable routing plane, loops may develop along the path. In the design documentation, the trace of the cable tray is usually given, and that of other cables is not. Unfortunately, this is an uncoordinated, uncontrollable process that cannot be controlled, so the worst value should be used when using a parameter.

***U**$_W$ – Withstand voltage of a system*

Overvoltage resistance of low and high current equipment. The manufacturer declares its value. For high-current installations it can be 1.5 or 2.5 kV, for low-current installations, it can be 1; 2.5; 4 and 6 kV.

P_{LD}*, *P_{LI} *– Parameter of connecting wires*

Parameter related to different wiring methods of connecting wires (e.g.: shielding measures, shielding grounded or not, etc.).

r_t *– Reduction factor associated with the type of surface*

Factor reducing the risk associated with flooring material. Used for indoor and outdoor flooring.

P_{TU}*, *P_{TA} *– Parameter associated with dangerous touch and step voltage*

Parameter related to soil isolation and its equipotential equalization. For example, if there is 15 cm of gravel on the ground level or 5 cm of asphalt around the building. Safeguard measure.

r_p *– Factor reducing the loss due to provisions against fire*

Parameter related to fire alarm system deployment. Its value varies depending on whether an automatic fire alarm system or a manually operated system is located in the tested building. If none, the value should be set to the highest value ($r_p = 1$).

r_f *– Factor reducing loss depending on risk of fire*

It depends on the specific fire load needle. If the amount of combustible material in a building is ignited, what is the specific heat of the environment and the resulting amount of heat is produced per square meter (MJ/m^2). If the roof is flammable, the r_f factor should be high.

LPS classes

It has four classes (**IV to I**) and a state of **none**. The highest is '**I'** and the lowest is **'IV**'. State of "**none**" means that there is no external lightning protection installed.

P_B *– Probability of physical damage to a structure (flashes to a structure)*

A factor related to the level of external lightning protection. Safeguard measure.

P_{EB} *– Lightning protection equipotential bonding*

All metallic conductors entering the building must be wired. Devices that are normally in operation must be wired with overvoltage protection. Connecting metallic networks (e.g.: gas, water, other cables) that do not work should also be connected.

The Table 10 contains the connection between LPS class and parameter P_B and P_{EB} defined in the standard:

LPS class	P_B	P_{EB}
I	0.02	0.01
II	0.05	0.02
III	0.1	0.05
IV	0.2	0.05
NONE	1	1

Table 10: P_B and P_{EB} values depending on LPS class [53]
(Edited by author based on MSZ EN 62305-2:2012)

L_F *– Loss in a structure due to physical damage*

Typical loss value depending on function.

h_z *– Factor increasing the loss when a special hazard is present*

A parameter that increases the risk associated with a given number of employees and the number of building levels. It is also called panic danger[54] in use.

L_O *– Loss in a structure due to failure of internal systems*

Parameter used only for hospital and explosion hazardous buildings.

[54] It is called '**panic danger**' in daily usage in Hungarian slang language.

n_z *– Number of possible endangered persons in zone*

Number of people staying in a zone because they may have different numbers in different zones (e.g.: smoking, dressing rooms, halls, etc.).

n_t *– Expected total number of persons*

The sum of the number of people in each zones in the building

t_z *– Time in hours per year that persons are present in a dangerous place*

People may be present in different zones (e.g.: smoking, dressing rooms, halls etc.) for different periods of time.

2.5.2 Result of the calculation (R_1 output)

The result of the calculation is the value R_1, which represents the value of the lightning protection risk. This parameter R_1 is the sum of the partial results R_A, R_B, R_C, R_M, R_U, R_V, R_W, R_Z. If the value is less than or equal to $R_T = 1 \times 10^{-5}$ ($R_T \geq R_1$) then the building can be considered lightning protected, if greater than 1×10^{-5} lightning protection measures are required. In many cases, for the sake of transparency, the result in practise is compared to $R_T = 1 \times 10^{-5} = 100\%$, so the percentage of the result obtained.

2.5.3 A short example to calculate with some input parameters

A theoretical building dimensions (in meter):

Length, Width and height:		L, W, H = 30 m; 20 m; 20 m
Number of dangerous events per annum per km^2:		$N_G = 1.75$
Location factor:		$C_D = 1$
Lightning protection level:		LPS I
Length of power-line:		$L_L = 200$ m
Type of power-line:	Buried →	$C_I = 0.5$

Length of telecom-line: $L_L = 100$ m

Type of telecom-line: Buried → $C_I = 0.5$

Internal soil parameter: Wood → $r_{ta} = 10^{-5}$

External soil parameter: Grass → $r_{tu} = 10^{-2}$

Risk of fire $r_f = 0.1$

Fire protection $r_p = 0.5$

Number of people inside the building $n_z = 100$

Number of people outside the building $n_z = 15$

Total number of staff $n_t = 15 + 100 = 115$

$R_1 = 0.7460 \times 10^{-5}$

Because $R_T \geq R_1$ → **Building protected**

My self-developed IT program shows the sub-components of R_1 risk (Figure 22):

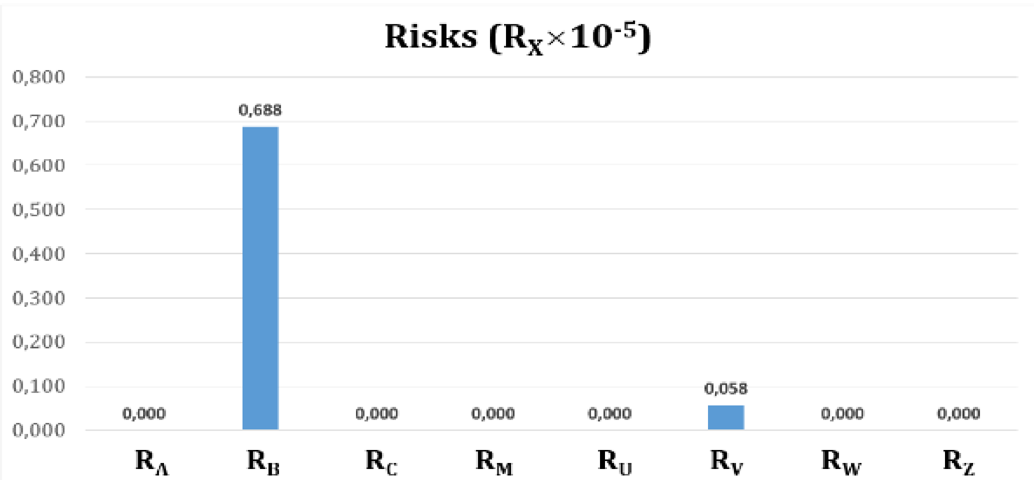


Figure 22: R_1 risk components
(Edited by author)

2.6 The lightning protection design process in practice

Designing a building is a very challenging enterprise. The use of a building lasts for several generations so special attention must be paid to each phase. The architect prepares the concept plan based on the preliminary needs. The final concept plan is followed by the permitting processes. During the licensing plan (engterv[55]), various public authorities (e.g.: OKF, ÁNTSZ), public utilities, etc. are contacted. The construction plan is then prepared. If everything is in order, the building permit will be issued, thus the builder will acquire the right to build on the given plot. Once the building is completed, the owner will take the building into use with a commissioning permit.

Lightning protection design begins in the design phase of the building at the design desk of the architect. Then, according to the planned properties of the building, the lightning protection designer assesses what possibilities there are to implement lightning protection. It is important that the architect and the lightning protection designer work together from the very beginning of the design, because at this time it is still possible to integrate lightning protection solutions that are no longer feasible after the construction of the building.

Experience has shown that there are cases where the involvement of a lightning protection designer in the design of lightning protection has taken place after the start of construction or, in some worst case scenarios; after the building has been completed. Standard design of lightning protection is required for commissioning or, if it is not necessary, proof of the risk calculation that no lightning protection is required.

During the commissioning procedure, the OKF and the territorially competent government office also check whether the relevant electrical laws, regulations and standards are complied with. After that, it is no longer possible to apply lightning protection solutions that would have made lightning protection even cheaper and simpler. In some cases, it would have been possible to implement more aesthetically pleasing solutions if the design process had started at the design table together with the architect.

[55] **Engterv**: a short language version of the Hungarian wording of licensing plan (Engedélyezési Terv).

2.7 The sensitivity test

Sensitivity analysis is used to analyse the effect of single unit changes in the input parameters (independent variables) being examined on the output (dependent variable). In this case, the independent variables are the input parameters defined by the standard and the output is the R_1 risk value. The standard contains two kind of input parameters. One type of them has concrete values (e.g.: location factor - C_D with values of 0.25, 0.5, 1 and 2) and the other type can take any value. These input parameters are the parameters which have length only (e.g.: cable length - L, building height - H, etc.). The test covers all of these parameters. During the test, a change in the value of an input parameter at a time is used to determine the output change, examined separately for each input parameter. At the end of the test, we will see, if there is any parameter which, with a small change in its value, will have a decisive influence on the value of the output lightning protection risk (R_1). I carried out my research with the program I created following my set-up process (Figure 23):

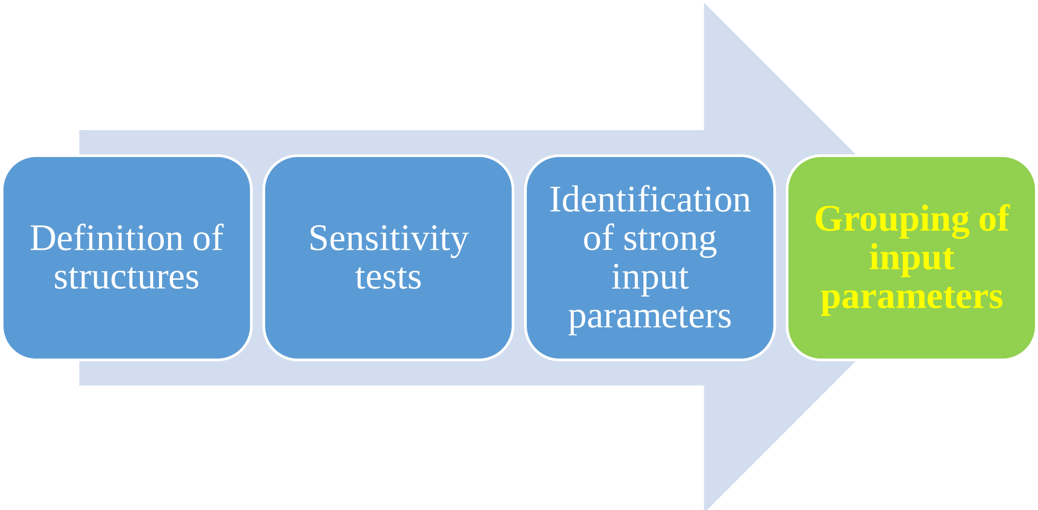


Figure 23: Sensitivity testing process
(Edited by author)

The result of the calculation is the value of R_1, which is the value of the lightning protection risk. This parameter R_1 is the sum of the partial results of R_A, R_B, R_C, R_M, R_U, R_V, R_W, R_Z. If the value is less than or equal to 1×10^{-5} (R_T), the building can be considered lightning protected, if it is greater than 1×10^{-5}, lightning protection measures are required. In many cases, for the sake of transparency, the result obtained is compared to $R_T = 1 \times 10^{-5} = 100\%$, i.e. the percentage of the result obtained.

2.8 The introduction of my self-developed IT program

The structure of my self-developed IT program[56] in MS Excel follows the terminology of input data – partial calculations – results (Figure 24). After entering the input parameters (Table 11)[57], the program displays the results of the partial calculations (Table 12[57] and Table 13[58]) in a separate section and displays them in a table. The system first calculates the collection areas in m^2 and then uses this to determine the sub-risks and then aggregates them (Table 14)[58]. The results of the table are represented by a graph (Figure 25)[58] so that the results of the various risk components are well illustrated. The program calculates the risk sub-factors (R_A , R_B , R_C , R_M , R_U , R_V , R_W , R_Z) separately with their strong– and low-current components and then aggregates them.

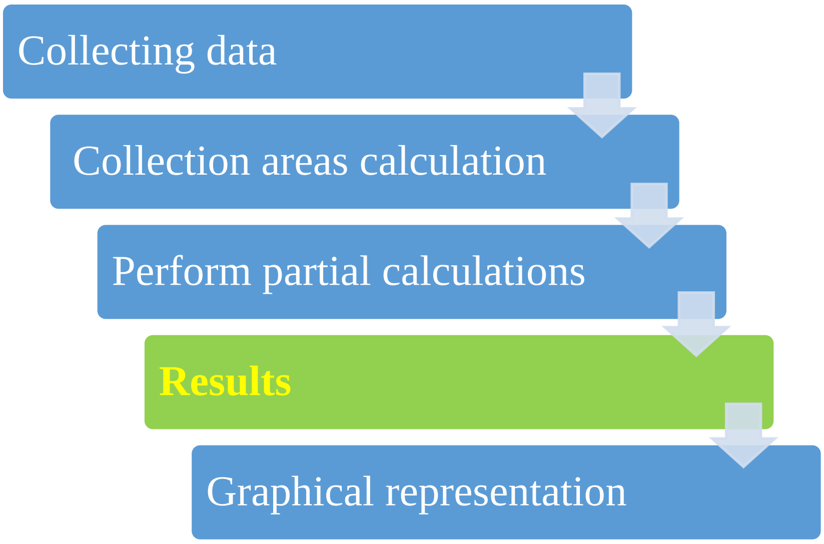


Figure 24: Calculation method of my self-developed IT program
(Edited by author)

The following main input parameters were used to present my self-developed program:

Building dimensions (meters):	L, W, H = 30 m ; 20 m ; 20 m
Number of dangerous events per annum per km^2:	N_G = 1.75
Location factor:	C_D = 1
Lightning protection class:	LPS III
Length of power-line:	L_L = 200 m

[56] MS Office Excel featuring with **V**isual **B**asic **A**pplication (**VBA**).
[57] **See:** p.64 (next page)
[58] **See:** p.65

Type of power-line:	Buried →	$C_I = 0.5$
Length of telecom-line:		$L_L = 100$ m
Type of telecom-line:	Buried →	$C_I = 0.5$
Risk of fire		$r_f = 0.01$
Fire protection		$r_p = 1$
Number of people inside and outside of building		$n_z = 100 + 15$
Total number of staff		$n_t = 15 + 100 = 115$

$\mathbf{R_1 = 0.8540 \times 10^{-5}}$ (Figure 25 & Table 14)[59],

because $R_T \geq R_1$ → **Building protected**

Input		Comment		Value
Power line				
Lengh (m)			L_L	200
Installation factor			C_I	0,5
Environmental factor			C_E	0,5
Transformator factor			C_T	1
Cable shielding			R_S	
Shielding, grounding, isolaton			C_{LD}	1
			C_{LI}	1
Telecom line				
Lengh			L_L	100
Installation factor			C_I	0,5
Environmental factor			C_E	0,5
Transformator factor			C_T	1
Cable shielding			R_S	
Shielding, grounding, isolaton			C_{LD}	1
			C_{LI}	1

Table 11: Entering data into my self-developed IT program
(Edited by author)

A_M =	$2 \times 500 \times (L + W) + \pi \times (500)^2$
A_M =	845398

POWER LINE	
$A_{L/P}$ =	40 x L_L (m)
$A_{L/P}$ =	8000
$A_{I/P}$ =	4000 x L_L (m)
$A_{I/P}$ =	800000

TELECOM LINE	
$A_{L/T}$ =	40 x L_L (m)
$A_{L/T}$ =	40000
$A_{I/T}$ =	4000 x L_L (m)
$A_{I/T}$ =	4000000

Table 12: Calculation of collection areas (Edited by author)

[59] **See**: p.65 (next page)

POWER LINE	
R_U =	$(N_L + N_{DJ}) * P_U * L_U$
N_L =	$N_G * A_{L/P} * C_I * C_E * C_T * 10\text{-}6$
$N_{L/P}$ =	0,00400000000000000000
N_{DJ} =	$N_G * A_{DJ} * C_{DJ} * C_T * 10\text{-}6$
N_{DJ} =	0,00000000000000000000
$P_{U/P}$ =	$P_{TU} * P_{EB} * P_{LD} * C_{LD}$
$P_{U/P}$ =	0,05000000000000000000
L_U =	$r_{tu} * L_{Tu} * n_Z \;/\; n_t * t_Z \;/\; 8760$
L_U =	0,00000008695652173913
R_U =	**0,00000000001739**

TELECOM LINE	
R_U =	$(N_L + N_{DJ}) * P_U * L_U$
N_L =	$N_G * A_{L/T} * C_I * C_E * C_T * 10\text{-}6$
$N_{L/T}$ =	0,00200000000000000000
N_{DJ} =	$N_G * A_{DJ} * C_{DJ} * C_T * 10\text{-}6$
N_{DJ} =	0,00000000000000000000
$P_{U/T}$ =	$P_{TU} * P_{EB} * P_{LD} * C_{LD}$
$P_{U/T}$ =	0,05000000000000000000
L_U =	$r_{tu} * L_{Tu} * n_Z \;/\; n_t * t_Z \;/\; 8760$
L_U =	0,00000008695652173913
R_U =	**0,00000000000870**

Table 13: R_U partial result summary section
(Edited by author)

R_A	0,002
R_B	0,786
R_C	0,000
R_M	0,000
R_U	0,000
R_V	0,066
R_W	0,000
R_Z	0,000
R_1	**0,854**

Table 14: Summary of risk components (R_A – R_Z)
(Edited by author)

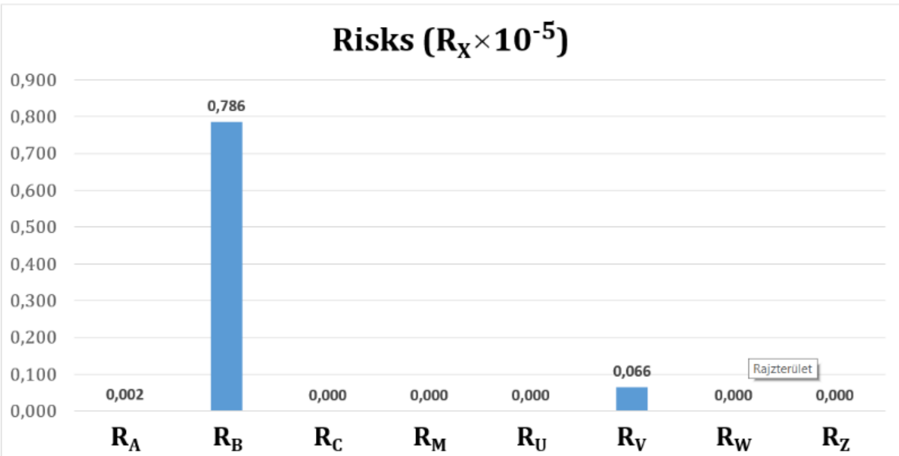


Figure 25: Graphical representation of the aggregated results of the risk factors (R_A – R_Z)
(Edited by author)

The detailed introduction of my self-developed IT program is described in Annex I[60].

[60] **See**: Annex I., p.161-163

2.9 The theoretical sensitivity test

I will perform a theoretical test and also a practical test of the parameters and will compare them.

The target is to identify or to explore the input parameters which may have decisive effect on the R_1 output. The slopes of the value sets of function will give the answer. To do this, the slopes of the value sets of function of the input parameters have to be examined when their values will be changed and the values of the other input parameters are handled as constant. The slopes were determined by based on the practical values of input parameters (attributes of the buildings) of the three chosen buildings in order to make the specific calculation feasible.

In my opinion, the method is to define the steepness of value set of function /$R_1 = y = f(x)$/. To do this, the research would be differential calculation. The result of the output is the steepness of the value set of function. In this case, the differential quotient is a new formula which shows the slope of the value set of function set at a chosen point. In this case the independent variable (x) with a value must be calculated into this formula, then the result is the slope of the value set of function at that examined point. The difference quotient is also called direction tangent (m), so the slope of the value set of function is the following in linear cases:

$$\mathbf{tg}\boldsymbol{\alpha} = \mathbf{m} = \frac{dy}{dx} = \frac{y_1 - y_0}{x_1 - x_0}$$

Except for height (H) input parameter, I have examined the slopes of value sets of function using the direction tangent method.

In order to carry out this sensitivity check I set up the following steps for the research:

Step 1: Performing the direction tangent calculations

Step 2: Collect the direction tangents

Step 3: Show the direction tangents in a common table and graph

Performing the direction tangent calculations

So, except for parameter height (H) all value sets of function of the input parameters are linear or constant. It means that their differential quotient is constant or zero, so the slope has a constant degree or zero degree.

All the differential quotients have been defined by using the direction tangent method. The direction tangents were calculated based on using the real attributes of a buildings. It means only the value of the examined input parameter were changed and the values of the other input parameters have been handled as constant. It means during the calculation that I substituted two values of the examined input parameter as x_1 and x_0 into the formula and got two R_1 results as y_1 and y_0. Therefore, y_1 , y_0 , x_1 and x_0 were calculated where y-values are the calculated R_1 output values and x-values are the values of the examined input parameter. Based on these four values (y_1 , y_0 , x_1 and x_0) direction tangents can be calculated. Due to this, the direction tangents give the slope of the value set of function and input parameters can be compared to each other.

Especially, the height has a special case because it is a quadratic independent variable in the formula. Its differential quotient is a linear function, so the slope is changing at all examined points. For this reason, I examined the height input parameter (H) separately, which of course has an effect on the output with the combined effect of the other parameters. In the height range according to the standard (H = 0 - 60 m), the slope test was performed at every 10 meters for the three buildings selected for my research by substituting the values of other input parameters for the 20 m height using as a function of the slope.

The results of my calculation are shown in the table as follows (Table 15):

	Slopes about value sets of function of input parameters for the building types in degrees (°)		
Height (H)	**Condominium**	**Office Building**	**Assembly Plant**
10 m	18,42	20,42	64,11
20 m	28,85	30,96	71,37
30 m	37,54	39,60	75,52
40 m	44,60	46,53	78,18
50 m	50,29	52,05	80,02
60 m	54,88	56,48	81,37

Table 15: Slopes about value sets of function of input parameters for the building types in degrees (°) (Edited by author)

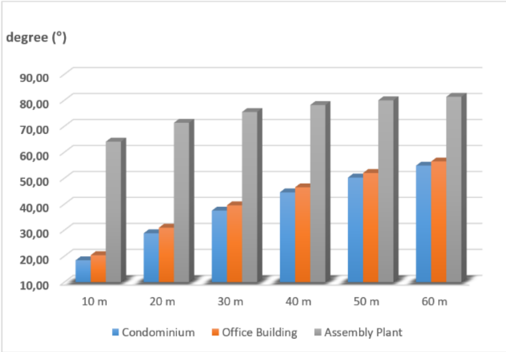


Figure 26: Slopes about value sets of function at different heights for the building types in degrees (°) in graphical form (Edited by author)

The Figure 26 shows that the slopes increase continuously for increasing height. Carrying out the theoretical sensitivity test for all three selected building types, its summary results are included in Annex II[61], separately for each building type in Table III-IV-V. I approached the calculations concerning the structures focusing on the changes in lightning protection (LPS classes). The second column in the tables contains the initial state without lightning protection (LPS: none), and then the other columns, moving to the right of it, always represent a lightning protection with a higher class (LPS none → LPS I). Based on these, it can be seen that the increasing class of lightning protection (none → LPS I) significantly reduces the effect of all input parameters on the R_1 output, the height parabola also becomes flatter, so the slope of its point-to-point tangent is getting smaller. This means that its effect on the output is reduced as well.

It is not yet possible to form groups from these input parameters, because based on their specific effect on the R_1 output, the possible grouping will only be determined by the practical sensitivity analysis.

Collecting the degrees from the direction tangents of input parameters

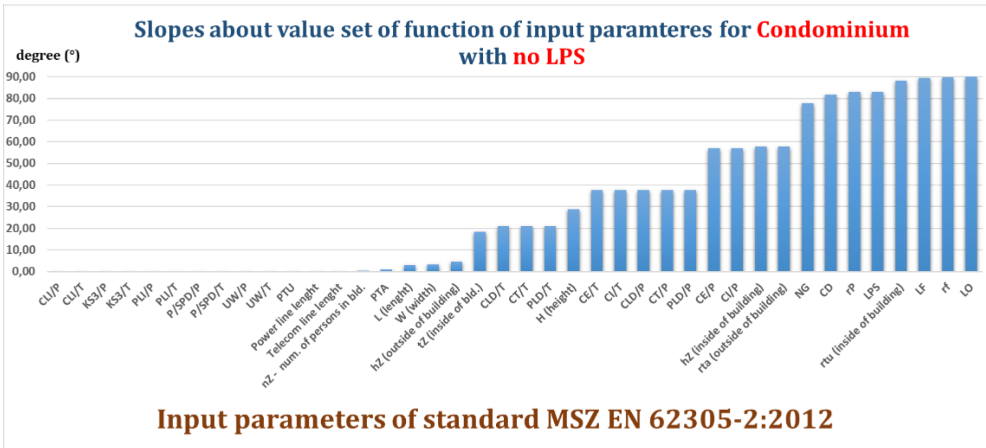
After identifying the direction tangents, they have been calculated to degrees and their values in degrees have been collected into a Table 16[62] and have been also shown in graphical forms in Figure 27[63]. The Table 16 contains the degrees of value sets of function about the input parameters for the three examined building types based on theoretical tests. It can be seen that there is a leap in the calculated degrees at each building and highlighted by red line from different values.

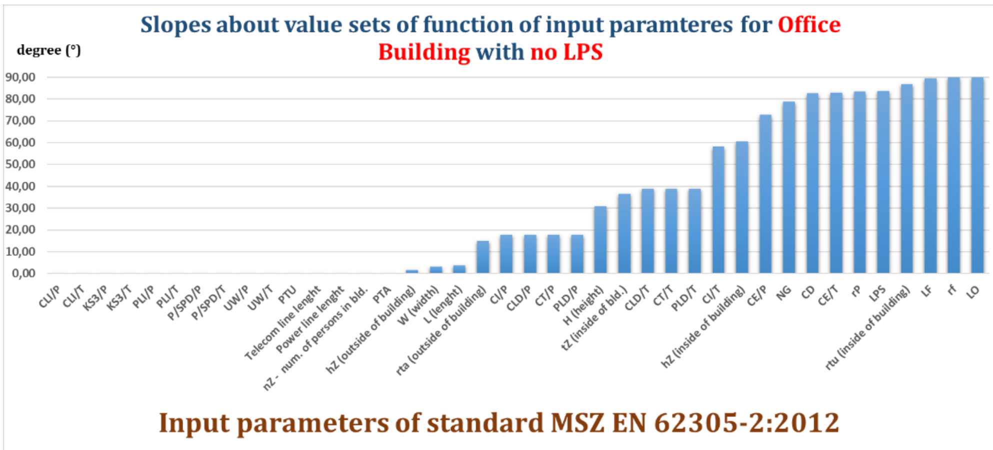
[61] **See:** Annex II, p.164-166
[62] **See:** p.69 (next page)
[63] **See:** p.70

Slopes about value sets of function of input parameters for the selected buildings with no LPS as follows in Table 16:

	Slopes about value sets of function of input parameters for selected buildings with no LPS in degrees (°)		
Input Parameters	**Condominium**	**Office Building**	**Assembly Plant**
L_O	89,99	89,99	89,99
r_f	89,92	89,93	89,91
L_F	89,64	89,35	89,98
r_{tu} (inside of building)	88,19	86,77	89,16
LPS	83,10	83,73	89,23
r_P	82,90	83,58	89,18
C_D	81,74	82,66	88,76
N_G	77,73	78,87	88,57
h_Z (inside of building)	57,84	60,58	85,83
r_{ta} (outside of building)	57,84	15,03	83,07
$C_{E/P}$	57,00	72,74	86,43
$C_{I/P}$	57,00	17,84	86,43
$C_{E/T}$	37,59	82,91	88,21
$C_{I/T}$	37,59	58,14	88,21
$C_{LD/P}$	37,59	17,84	82,89
$C_{T/P}$	37,59	17,84	82,89
$P_{LD/P}$	37,59	17,84	82,89
H (height)	28,85	30,96	71,37
$C_{LD/T}$	21,05	38,82	86,43
$C_{T/T}$	21,05	38,82	86,43
$P_{LD/T}$	21,05	38,82	86,43
t_Z (inside of bld.)	18,33	36,46	70,73
h_Z (outside of building)	4,54	1,53	58,72
W (width)	3,30	3,22	17,78
L (lenght)	3,08	3,68	14,38
P_{TA}	1,00	0,16	5,17
n_Z - num. of persons in b	0,29	0,12	0,70
Power line lenght	0,22	0,09	0,91
Telecom line lenght	0,22	0,04	0,91
P_{TU}	0,01	0,01	3,92
$C_{LI/P}$	0,00	0,00	0,00
$C_{LI/T}$	0,00	0,00	0,00
$K_{S3/P}$	0,00	0,00	0,00
$K_{S3/T}$	0,00	0,00	0,00
$P_{LI/P}$	0,00	0,00	0,00
$P_{LI/T}$	0,00	0,00	0,00
$P_{/SPD/P}$	0,00	0,00	0,00
$P_{/SPD/T}$	0,00	0,00	0,00
$U_{W/P}$	0,00	0,00	0,00
$U_{W/T}$	0,00	0,00	0,00

Table 16: Slopes about value sets of function of input parameters for selected buildings with no LPS in degrees (°). (Edited by author)





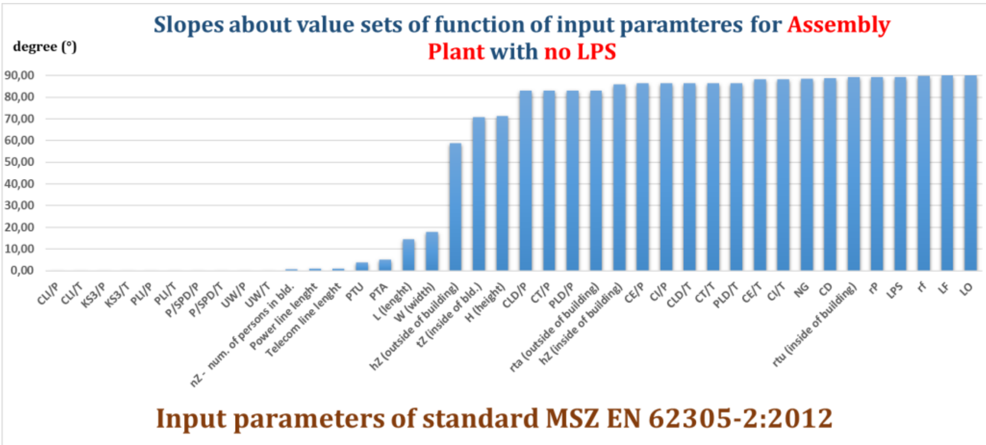


Figure 27: Slopes about value sets of function of input parameters for the selected building types with no LPS in degrees (°) based on Table 16 (Edited by author)

Showing the slopes of value sets of function in graphs and the comments

After collecting the data into a common chart (Table 16) [64] and showed in Figure 27, it can be easily seen that there is a leap among the slopes as well. The parameters may be

[64] **See**: p.69 (previous page)

categorized into two groups due to practical life, to changeable and to non-changeable parameters regarding to building's attributes. During the designing phase some parameters cannot be changed, e.g.: location factor (C_D), and some parameters can be changed. It means in reality that e.g.: the location factor is a decisive input parameter but its value cannot be changed during planning. It is defined by the environment of the building. It means that the input parameter value is fix, so the designer engineer must use it 100% properly because if he uses it wrong, the lightning protection may not to be accurate. These kind of input parameters have decisive affect on the output value despite they are not changeable. The other input parameters are changeable due to the building's attributes, so during the design of a lightning protection system they can be changed. Internal and external features of the building can be changed due to the architect designer. E.g.: the materials of the roof can be changed to non-flammable materials so r_f the input parameter also changes. For example, some changeable input parameters are r_p, r_{ta}, r_{tu}, LPS, r_f and h_z. The first four are protection measures. The r_{ta}, r_{tu} and LPS parameters belong to lightning protection design authority. Parameter r_p needs to be coordinated with the fire protection designer. The r_f is architectural parameter which belongs to the architect. This person can decide which material to be used for the roof structure. I incorporate parameter h_z into this group. Generally, this parameter cannot be changed, but due to some special instructions by the customer it may be changed. For example, personal presence to check e.g.: processes at different areas can be replaced by CCTV[65] remote monitoring in order to modify the value of parameter h_z. So, these parameters can be sub-grouped. The r_p, r_{ta}, r_{tu}, r_f and h_z parameters can be changed by co-designers and LPS can be changed only by the lightning protection designer. As mentioned above, these parameters can be changed by co-designers. These parameters are related to the building's attributes, and the architect – working together with the co-designers – can change them using the advices by the co-engineers. When one specified attribute is changed (e.g.: material of the roof), the input parameter is also changing as well. With these in mind, adequate lightning protection can be achieved. I would like to highlight that the input parameters shown in Table 16 above the red line (22, 22 and 25 pieces) are just the theoretical strong parameters groups which have decisive effect on the R_1 output but the practical testing will give the answer, if they can be grouped into the strong parameter group or not. The building design with the lightning protection is not a linear process

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[65] **CCTV: C**losed – **C**ircuit **T**ele**v**ision

anymore because the lightning protection engineer works continuously with the architect and can also give practical advices from the beginning of the design process as was introduced in section 2.6[66]. I would like to introduce a very special case about parameter h_z and t_z. The value of input parameter h_z (risk of special hazard) is defined by a number of people inside the building and also by the number of floors. Its values are clearly defined in the standard and cannot be changed. Parameter t_z is the time presence inside (and also outside) of the buildings. Its value clearly represents the time spent in examined area. There was a special situation years ago concerning a planned sugar silo. The crystal sugar was planned to be bulk stored there. Dust is generated during material handling by conveyor belts, so the place has to be considered as a dust-explosive area. The plan also contained some process control so the workers had to check the process personally day-by-day, so due to the lightning protection risk calculation the highest lightning protection (LPS I) would have been required. The American customer did not want to accept this level of protection (LPS I), then an idea was formulated: this planned daily work check was changed from a personal check to remote camera monitoring, so no one had to be in the dangerous areas. Due to this, the R_1 risk (risk of loss of human life) was reduced because the personal presence could be strongly decreased, therefore, the values of h_z and t_z were also strongly reduced. This case drew attention for an opportunity that although the values are strictly defined in the standard, some technological improvement can help to reduce the R_1 risk and this can also reduce the costs, because a lower class lightning protection system (LPS) could be installed.

Based on all data in the Table 16[67], summarizing the results of the theoretical sensitivity analysis, it can be concluded that those input parameters which are shown above the red line (22 , 22 , 25 pieces) are members of the theoretically strong group. All elements of these three theoretically strong groups are examined in the practical sensitivity test. They have a specific effect on the R_1 output so just the practical sensitivity analysis will determine the possible grouping.

2.10 The practical sensitivity test

Several categories of data are required to complete the risk analysis. One is the physical and technical characteristics of the building, which can be extracted from the

[66] **See**: p.61
[67] **See**: p.69

architect's design documentation, the other is the fire protection characteristics, and this can be established from the documentation issued by the fire protection designer.

The various input parameters are determined from the various tables in the standard, based on the properties of the building and their components. Data and calculations are described below. The practical sensitivity test is based on the selected three types of buildings which are widespread in practice, where the recorded parameters have important determining economic roles. The calculations were calculated separately for the three examples. The basic input parameters were determined from the tables in the standard based on the properties of the building. During the calculations, I divided the building into two zones, which means that there is an out-of-building and an in-building zone for which the risk sub-components have to be calculated separately and then aggregated. It is important to note that the calculation method of the standard takes into account the maximum number of people that can be in different zones of the building (e.g.: outside or inside a sports field and changing room), so if there are 160 people in a building, but on average 16 people are outside the building (e.g.: smoking), it shall be 160 for the number of people inside the building and it shall be 16 for number of people outside.The same situation occurs e.g.: also in the case of sporting events, so if 500 people are on the field at a sporting event and 50 go to the locker room after the event, the number of people on the field must be 500 and the number in the locker room must be 50 with time in a separate zone. In each zone, the maximum number of the given number of people must be taken into account, the reason being that it is not known when the lightning will strike, so the worst number must be taken into account because safety is the most important thing. It does not occur in reality but the risk must be calculated for the worst case; outside as well as inside. It is important to highlight that r_{ta} and r_{tu} parameters are changeable items, but in practicality, they are not. The architect defines the materials to be used for the surface of the ground outside and inside the building, and after the building has been constructed, it is very rarely changed. The lightning protection engineer uses the given values and cannot change them arbitrarily because it is an architectural parameter. It means that it is practically irrelevant to test them. In my practical experience there was only one case in the last ten years when the floor material had to be changed due to the lightning protection implementation requirements. In that case the cellar floor material was concrete and had to be covered in tiles for lightning protection reasons. I would like to highlight another case about the location factor parameter.

If a gated community is being built, the first building should be considered as a stand alone building for the location factor, despite the fact that other buildings will surround it at a later date. Legally it is a stand alone building. Sensitivity testing was performed for several parameter sets[68]. This means that after the initial data for the building, a sensitivity test was performed again by changing a parameter that is important in practice (thus creating a new parameter set).

The exact steps of the test are as follows:

Step 1: Entering initial parameters.

Step 2: Running a practical sensitivity test for one input parameter including all values.

Step 3: Copy results to summary file.

Step 4: Go to next input parameter.

Step 5: Repeat steps 2–3–4 automatically until all variations have been examined.

During the test, the following parameters were changed with a certain number of recordable values, for each of which the sensitivity test was performed separately:

- r_f – fire risk (2 pcs. value)
- LPS – Lightning protection class (5 pcs. value)
- r_p – fire protection measures (3 pcs. value)
- h_z – type of special hazard (3 pcs. value)

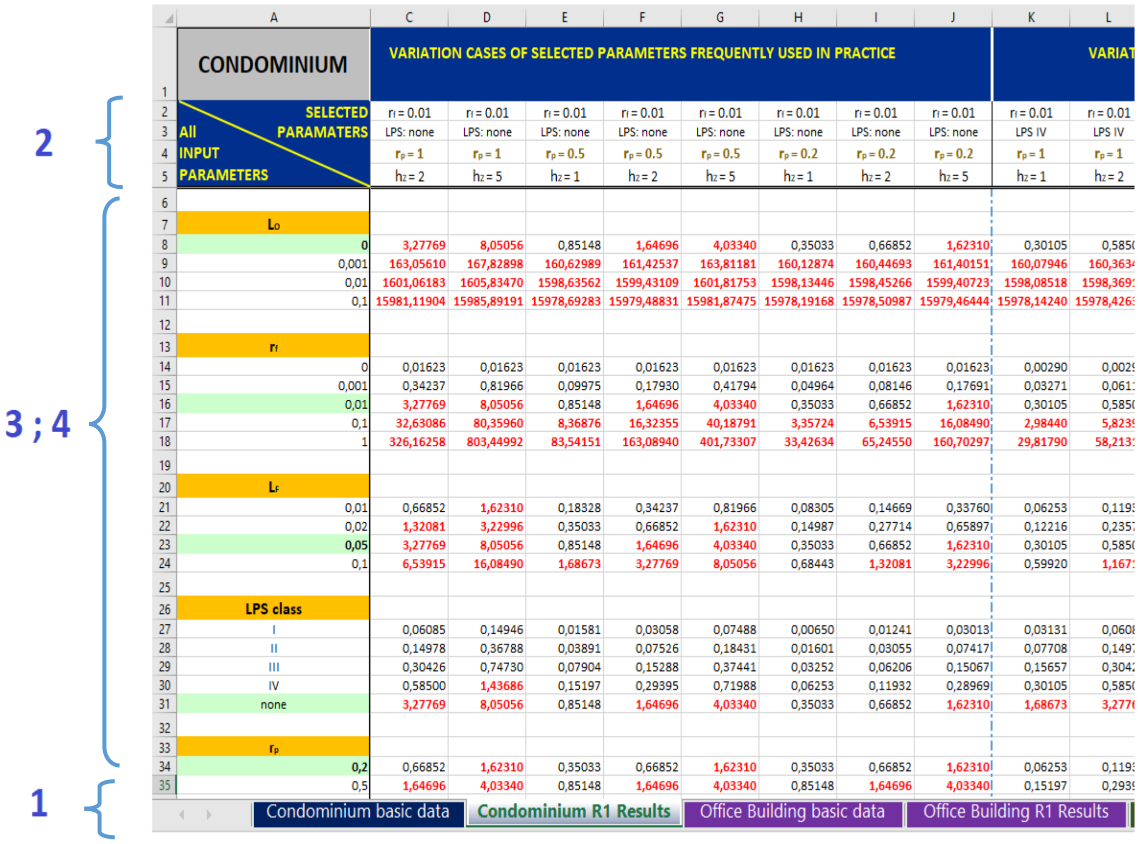
Thus, by changing the selected parameters – $2 \times 5 \times 3 \times 3$ per building = 90 variations – so 90 parameter sets are obtained. These parameter sets are the same for the three buildings, so the total result is $3 \times 90 = 270$ pcs. test result is obtained.

These results are summarized in the Annex III.[69] on attached CD in the common Excel file on different sheets (condominium, office building and assembly plant).

These parameters have been selected by practical reasons of usage.

[68] **Parameter set**: a set of input data for all parameters regarding a selected building.
[69] **See:** Annex III., p.167

The structure and part of content about the Annex III. as follows (Figure 28):



	A	C	D	E	F	G	H	I	J	K	L
1	CONDOMINIUM	VARIATION CASES OF SELECTED PARAMETERS FREQUENTLY USED IN PRACTICE									VARIAT
2	SELECTED	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01	r_f = 0.01
3	All PARAMATERS	LPS: none	LPS: none	LPS: none	LPS: none	LPS: none	LPS: none	LPS: none	LPS: none	LPS IV	LPS IV
4	INPUT	r_p = 1	r_p = 1	r_p = 0.5	r_p = 0.5	r_p = 0.5	r_p = 0.2	r_p = 0.2	r_p = 0.2	r_p = 1	r_p = 1
5	PARAMETERS	h_z = 2	h_z = 5	h_z = 1	h_z = 2	h_z = 5	h_z = 1	h_z = 2	h_z = 5	h_z = 1	h_z = 2
6											
7	L_O										
8	0	3,27769	8,05056	0,85148	1,64696	4,03340	0,35033	0,66852	1,62310	0,30105	0,585
9	0,001	163,05610	167,82898	160,62989	161,42537	163,81181	160,12874	160,44693	161,40151	160,07946	160,363
10	0,01	1601,06183	1605,83470	1598,63562	1599,43109	1601,81753	1598,13446	1598,45266	1599,40723	1598,08518	1598,369
11	0,1	15981,11904	15985,89191	15978,69283	15979,48831	15981,87475	15978,19168	15978,50987	15979,46444	15978,14240	15978,426
12											
13	r_f										
14	0	0,01623	0,01623	0,01623	0,01623	0,01623	0,01623	0,01623	0,01623	0,00290	0,002
15	0,001	0,34237	0,81966	0,09975	0,17930	0,41794	0,04964	0,08146	0,17691	0,03271	0,061
16	0,01	3,27769	8,05056	0,85148	1,64696	4,03340	0,35033	0,66852	1,62310	0,30105	0,585
17	0,1	32,63086	80,35960	8,36876	16,32355	40,18791	3,35724	6,53915	16,08490	2,98440	5,823
18	1	326,16258	803,44992	83,54151	163,08940	401,73307	33,42634	65,24550	160,70297	29,81790	58,213
19											
20	L_F										
21	0,01	0,66852	1,62310	0,18328	0,34237	0,81966	0,08305	0,14669	0,33760	0,06253	0,119
22	0,02	1,32081	3,22996	0,35033	0,66852	1,62310	0,14987	0,27714	0,65897	0,12216	0,235
23	0,05	3,27769	8,05056	0,85148	1,64696	4,03340	0,35033	0,66852	1,62310	0,30105	0,585
24	0,1	6,53915	16,08490	1,68673	3,27769	8,05056	0,68443	1,32081	3,22996	0,59920	1,167
25											
26	LPS class										
27	I	0,06085	0,14946	0,01581	0,03058	0,07488	0,00650	0,01241	0,03013	0,03131	0,060
28	II	0,14978	0,36788	0,03891	0,07526	0,18431	0,01601	0,03055	0,07417	0,07708	0,149
29	III	0,30426	0,74730	0,07904	0,15288	0,37441	0,03252	0,06206	0,15067	0,15657	0,304
30	IV	0,58500	1,43686	0,15197	0,29395	0,71988	0,06253	0,11932	0,28969	0,30105	0,585
31	none	3,27769	8,05056	0,85148	1,64696	4,03340	0,35033	0,66852	1,62310	1,68673	3,277
32											
33	r_p										
34	0,2	0,66852	1,62310	0,35033	0,66852	1,62310	0,35033	0,66852	1,62310	0,06253	0,119
35	0,5	1,64696	4,03340	0,85148	1,64696	4,03340	0,85148	1,64696	4,03340	0,15197	0,293

Condominium basic data | Condominium R1 Results | Office Building basic data | Office Building R1 Results

Figure 28: Part of Annex III. for the condominium
(Edited by author)

LEGEND:

Marked-1: Type of building

Marked-2: Signs and values of changed input parameters (header)

Marked-3: Input data:

- Green background: basic input data of the building
- White background: other possible values for parameter

Marked-4: R_1 output values:

- **Red:** above 1×10^{-5} permissible value
- **Black:** below 1×10^{-5} permissible value,
  structure is protected against this risk

2.10.1 The practical sensitivity test for the condominium[70]

The first building examined is located in a residential area that also occurs in practice (Figure 29).

Figure 29: Picture of a similar building in the real life [57]

It has a flat roof, which will be considered with several types of roofing material during the sensitivity test. The building does not have a cellar. It is a 20-meter-high, 25-apartment condominium without neighbouring buildings, with 100 inhabitants, with different construction parameters.

Outside the building, smokers are present in front of the entrance with 15 people. Strong and low current cables are also connected to the building. These increase the degree of risk because they are conductive and not ground-potential components.

Location of the condominium:

Independent building, not bordered by other buildings in a circle distance of 3H[71] around the building, so the location factor that gives the building's relation to the immediate environment:

$C_D = 1$

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[70] **Concrete details and results** located in Annex III. "**Condominium data & Condominium data base**" in Excel worksheets on CD (attached at end of my dissertation in pocket).

[71] **3H:** three times the height of the building.

Condominium dimensions:

Length, width and height data are required for calculation:

L = 30 m

W = 20 m

H = 20 m

Number of dangerous events per annum per km²

This value is 1.75 in Budapest:

$N_G = 1.75$

Connecting Cables

According to the standard, we have to calculate the data with high-power and low-power (telecommunication) connection wires as follows:

a) data of power-line

Length:	L = 200 m
Type: underground cable	$C_I = 0.5$
Location: suburban environment	$C_E = 0.5$
Transformer factor:	$C_T = 1$
Shielding, grounding:	$C_{LD} = 1$; $C_{LI} = 1$
Surge resistance:	$U_{W/P} = 1.5$ kV

b) data of telecom-line

Length:	L = 100 m
Type: underground cable	$C_I = 0.5$
Location: suburban environment:	$C_E = 0.5$

Transformer factor: $C_T = 1$

Shielding, grounding: $C_{LD} = 1$; $C_{LI} = 1$

Surge resistance: $U_{W/T} = 1$ kV

Fire protection properties

Experience has shown that the fire protection properties of a building strongly influence the lightning protection adequacy of the building.

External soil parameter for grass: $r_{ta} = 0.01$

Internal soil parameter for wood: $r_{tu} = 0.00001$

Fire protection measures: $r_p = 1$

Risk of fire: $r_f = 0.01$

Personal presence

Inside the building:

100 people, 24 hours per day: $n_z = 100$; $t_z = 24 \times 365 = 8760$

Outside the building:

15 people, 8 hours per day: $n_z = 15$; $t_z = 8 \times 365 = 2920$

Losses

Physical damage in a residential building[72]: $L_F = 0.05$

Failure of internal systems: $L_O = 0$

Constant multiplier by standard: $L_T = 0.01$

[72] In this case**, the OTSZ prescribes** a value of 0.05 for L_F.

Other parameters

Lightning protection system (LPS) and its associated parameters (Table 10):

LPS class	P_B	P_{EB}
I	0.02	0.01
II	0.05	0.02
III	0.1	0.05
IV	0.2	0.05
NONE	1	1

Table 10: P_B and P_{EB} values depending on LPS class [53]

(Edited by author based on MSZ EN 62305-2)

Special hazard [73]

Value 2 for maximum 100 people and up to 2 floors, above 100 people in the building or above 2 floors value 5. Due to this, the value is 5 for inside, and 1 for outside of the building.

2.10.1.1 Results of practical sensitivity test for the condominium

After finishing the sensitivity check, it can be anticipated that the input parameters can be grouped into strong and weak parameters, respectively. Strong parameters should be able to identify an extremely important factor that has a decisive influence on the output. If the strong parameters and the 'weak points' of the building are known, the lightning protection engineer can make suggestions to the architect to change or install parts or components, which will no longer be possible once the construction has begun. There are several options to consider before the construction begins. One option is the use of a grounding net, which must be installed in the ground. It is also economically useful to know the parameters beforehand. Another example is the type of the roofing material.

Lightning protection is decisively influenced by the type of roofing material, so it is possible to decide before the construction that the roof will not be made of a combustible material (e.g.: sandwich panel) but rather of a more expensive and non-combustible rock wool.

[73] It is called **'panic danger'** in daily usage in Hungarian slang language.

After finishing the practical sensitivity test, it was found that unit changes for the input parameters do not affect the output R_1 (risk of loss of human life) in the same way. A group of the so-called weak input parameters has a minimal to no effect on the R_1 output, which stays below the tolerated $R_T = 1 \times 10^{-5}$ value. On the other hand, 8 input parameters have been identified whose unit changes have a decisive influence on the R_1 output.

Therefore, based on the practical test the input parameters of strong group as follows:

L_O – Internal System Failure (only hospital and explosion dangerous building)
r_f – Factor reducing loss depending on risk of fire
L_F – Physical damage related to the purpose of the building
LPS – Lightning protection system (class)
r_p – Fire protection measures
C_D – Location factor
N_G – Number of dangerous events
h_Z – Type of special hazard (inside of building)

There are two input parameters which raise the value of R_1 immediately above 1×10^{-5}, removing the lightning protection of the building. **They are L_O and r_f.** The other six input parameters (L_F, LPS, r_p, C_D, N_G and h_Z) either raise R_1 immediately above 1×10^{-5} or already touch the 25% ($0.750 – 1.000 \times 10^{-5}$) security range. It is the task of the lightning protection designer to determine the amount of lightning protection that he/she is considering for certain buildings. Experience has shown that this security range is approx. 20% to 25% before the R_T (100%) limit.

2.10.1.2 Formulation of remarks and lessons based on results of the condominium

The 90 parameter sets – specified for this type of building (condominium) – and their sensitivity analysis draws attention to a number of lessons that can be utilized in the design of lightning protection. From the aggregated results it can be seen which parameters or which parameter combinations affect lightning protection compliance (R_1). Based on this data, a number of lessons can be learned for the building in question.

The examples I consider most important can be divided into two parts in terms of the fire risk of the building.

Fire risk is an indicator, specific to a given building. It can be low, medium and high level. Determination is based on the energy resulting from the combustion per unit floor area (specific fire load[74]) from the expected combustion of the combustible materials of the structural materials of the building; the material of the floor, the material of the roof structure and materials stored in it.

The level is classified as low between 0 and 400 MJ /m^2, medium between 400 and 800 MJ /m^2 and high above 800 MJ /m^2. According to special cases, it can be zero even if there is no fire risk. For example, if the examined building is an iron-goods storage with a metal structure, then there is no fire risk ($r_f = 0$), but if e.g.: the building under test is a paper warehouse, library, archive, rubber warehouse, etc., then this value will be high. The fire risk level of the tested building is determined by the fire protection designer. This value is no longer calculated because it is not required by the OTSZ. If the lightning protection designer does not receive an accurate value for this, a value can be added to this r_f factor based on the guidelines of the electric TvMI.

The flammability of the roof also affects the level of fire risk. This is an important influencing factor in the fire rating of the building because during the event of a lightning strike, the roof can catch fire. In general, the building tested should be considered high risk if the claim is met for 60% of the roof that if its material is fire protection class B, C, D, E, F. Practice shows that in the case of residential houses, wall materials and the materials of the internal devices and goods stored in different rooms require the factoring in of a normal fire risk, but the roof is an important influencing factor so the level of fire risk is determined by the roof alone. Accordingly, I divided my remarks and lessons into two parts:

- lessons from cases about non-combustible roofs
- lessons from cases about combustible roofs.

[74] **Specific fire load:** Determination is based on the expected energy resulting from the expected combustion of the combustible materials stored in it, on structural materials of the building, on the material of the floor, the material of the roof structure etc. calculated for unit of base area.

Buildings with non-combustible roofs (r_f = 0.01, column B – AT)

Non-combustible roofs are rarely built, but e.g.: in the case of a flat roof, occurs when special materials (e.g.: rock wool) are used. It can be seen from the different results that the building becomes protected, if fire protection measures are applied. In the case of this 20 m high condominium without protection measures, lightning protection is required because the output R_T value is always above 1×10^{-5} (column C). If in the fire protection plan there are e.g.: protected escape routes, using the value of the protection measure r_p= 0.5 (placement of fire-fighting equipment, provision of sheltered escape routes, etc.) the building becomes protected (column F) if it is only 10 m high (which is not typical for a 25-apartment residential building) or be surrounded by buildings of the same height or higher (C_D = 0.5 or 0.25). The construction of lightning protection can only be neglected in these two cases. In all other cases, lightning protection is required even if the roof is not combustible.

Applying any LPS class will reduce the risk sufficiently. It is also important to note that recording the r_p with a value of 0.2 is not viable because in this case the protection measure means an automatic fire alarm, which in the case of a 25-apartment house practically does not happen that such equipment would be installed just for lightning protection. Based on these observations, two lessons can be drawn, one is that the widespread belief that lightning protection is not necessary in this case does not hold true, and the other is that in addition to the aforementioned protection measures (r_p = 0.5), the lowest LPS class (LPS IV) may also be sufficient to protect the condominium.

Since according to the old MSZ 274 it was not necessary to install lightning protection for such a building, my experience is that many employees of general construction companies still have the mistaken idea that the mentioned building under study does not need lightning protection in case of new construction, but the calculated results confirm in the Annex III. that, with the exception of the few cases mentioned, it is always necessary to install lightning protection according to the new standard since 2011.

The LPS III and r_p value of 1 and 0.5 (columns T and Y) it is clear that in many cases the building already has a protected status. This means that the mentioned building under test can be practically protected with LPS III with a non-combustible roof, respectively, or in some cases already with LPS IV.

Cases with combustible roofs (high risk of fire, r_f = 0.1, column AU – CM)

Cases with a combustible roof are located beginning of column AU to right side in the Annex III. on CD again.

The collected data show that nearly all values up to the LPS II are above the allowable 1×10^{-5} value. In vain there are fire protection measures (e.g.: $r_p = 0.5$). For a combination of LPS IV and $r_p = 0.5$, a value below 1×10^{-5} first appears in a case where the building would be surrounded by taller buildings ($C_D = 0.25$) in cell BH39 ($R_1 = 0.81618$). My experience shows that if a building is built up "newly", the customer will plan/order his new building with the same height of the surrounding buildings.

For LPS III (columns BM and BR) it can be seen that a value below 1×10^{-5} appears only when there is a high environment (C_D = 0.5 or 0.25) but it can be said that practically LPS III is not enough generally to protect the condominium because, except in the two cases mentioned, all values are non-compliant (red). It can be seen from LPS II that more and more values are already below 1×10^{-5}. Here, e.g.: a building with a fire protection measure of 0.5 (column BZ) can also be made protected.

However, LPS II and I have an economically significant disadvantage. In such a case, it is advisable to break down the building into additional zones because there is a good chance that the resulting risk can be reduced to a level where LPS III protection can be adequate instead of LPS II. In this case, if the level divider between the floors consists only of reinforced concrete, it is enough to consider only the top level in contact with the roof as a high fire risk level.

The other levels are no longer necessary, provided that the air space between the levels is not permeable. In practice, it is expected that this type of building would not have a stronger degree of lightning protection than LPS III because LPS II is already difficult to have it accepted and approved by the customer.

If any value of the input parameter changed due to new needs/questions, the calculations for the concrete building or for an entire practical sensitivity test would be needed in cooperation with the fire protection designers.

2.10.2 The practical sensitivity test for the office building[75]

The second tested building is a 20 m high, 5-floor office building with 176 employees and workers inside (Figure 30). 16 people stay in front of the building on average in the smoking area. High power-line and telecom-line are connecting to this building.

Figure 30: Similar planned office building [58]

Location of the office building:

Independent building, partly bordered by other buildings in a circle distance of 3H[76] around the building, so the location factor gives the building's relation to the immediate environment:

$C_D = 1$

Office building dimensions:

Length, width and height data are required for calculation:

L = 20 m

W = 40 m

H = 20 m

[75] **Concrete details and results** located in Annex III."**Office Building data & Office Building data base**" in Excel worksheets on CD (attached at end of my dissertation in pocket).
[76] **3H:** three times the height of the building.

Number of dangerous events per annum per km²

This value is 1.75 in Budapest:

$N_G = 1.75$

Connecting cables

According to the standard, we have to calculate the data with high-power and low-power (telecommunication) connection wires as follows:

a) data of power-line

Length:	L = 200 m
Type: power line	$C_I = 1$
Location: urban environment	$C_E = 0.1$
Transformer factor:	$C_T = 1$
Shielding, grounding:	$C_{LD} = 1$; $C_{LI} = 1$
Surge resistance:	$U_{W/P} = 1.5$ kV

b) data of telecom-line

Length:	L = 1000 m
Type: underground cable	$C_I = 0.5$
Location: urban environment	$C_E = 0.1$
Transformer factor:	$C_T = 1$
Shielding, grounding:	$C_{LD} = 1$; $C_{LI} = 1$
Surge resistance:	$U_{W/T} = 1$ kV

Fire protection properties

Experience has shown that the fire protection properties of a building strongly influence the lightning protection adequacy of the building.

External soil parameter for grass: $r_{ta} = 0.01$

Internal soil parameter for wood: $r_{tu} = 0.00001$

Fire protection measures: $r_p = 0.2$

Risk of fire: $r_f = 0.01$

Personal and time presence

Inside the building:

176 people, 12 hours per day: $n_z = 176$

$t_z = 12 \times 365 = 4380$

Outside the building: 16 people, 2 hours per day

16 people, 2 hours per day: $n_z = 16$

$t_z = 2 \times 365 = 730$

Losses

Physical damage in an office building[77]**:** $L_F = 0.1$

Failure of internal systems: $L_O = 0$

Constant multiplier by standard: $L_T = 0.01$

[77] In this case, **the OTSZ prescribes** a value of 0.1 for L_F.

Other parameters

Lightning protection system (LPS) and its associated parameters (Table 10):

LPS class	P_B	P_{EB}
I	0.02	0.01
II	0.05	0.02
III	0.1	0.05
IV	0.2	0.05
NONE	1	1

Table 10: P_B and P_{EB} values depending on LPS class [53]
(Edited by author based on MSZ EN 62305-2:2012)

Special hazard [78]

Value 2 for maximum 100 people and up to 2 floors, above 100 people in the building or above 2 floors value 5. Due to this, the value is 5 for inside, and 1 for outside of the building.

2.10.2.1 Result of practical sensitivity test for the office building

Similar to testing an office building, the test here showed that not all parameters affect the output equally. The research shed light on the conjecture that grouping is feasible here as well. Here, too, the input parameters can be divided into strong and weak groups. Strong parameters have a decisive influence on output. After the strong parameters have been identified, the lightning protection engineer is able to help the architect to install some components in order to reduce risk, before the construction would begin.

Therefore, based on the practical test the input parameters of strong group as follows:

- **L_O** – Internal System Failure (only hospital and explosion dangerous building)
- **r_f** – Factor reducing loss depending on risk of fire
- **L_F** – Physical damage related to the purpose of the building
- **LPS** – Lightning protection system (class)

[78] It is called **‘panic danger**’ in daily usage in Hungarian slang language.

r_P – Fire protection measures

C_D – Location factor

N_G – Number of dangerous events

h_Z – Type of special hazard (inside of building)

2.10.2.2 Formulation of remarks and lessons based on results of the office building

The sensitivity tests here were performed also for 90 parameter sets. The results – in the Annex III. on the office building sheet– have been divided into two main groups. One such group is the case with a non-combustible roof (columns B to AT) and the other is the case with a combustible roof (columns AU to CM). These two groups were established for practical reasons because this is one of the strongest parameters in terms of lightning protection design. Lessons learned and comments were also detailed according to these two groups.

Cases with non-combustible roofs (r_f = 0.01, column B – AT)

Very few office buildings have non-combustible roofs and it is not common for architects to think about non-combustible roofs for office buildings, it is rare in practice. According to the measurement results in the Annex III. - with the exception of a few special cases - only those columns should be taken into account where the value of h_z is 5, because the number of occupants and the number of storeys entail this mandatory value. There is no external lightning protection for the examples between columns B–J, it is already present for the examples at the beginning of column K on the right. In this section (column B–J) it can be clearly seen that if there is no external lightning protection in the building, it occurs only in a few cases that the building can be considered protected. In practice (column J) this would be the case with a height of 10 m instead of 20 m, or if the building would be surrounded by taller buildings (C_D = 0.25), but this is only a theoretical approach, in practice this does not occur because the customer will not plan to have a lower building than the surrounding buildings in a given place.

History shows that the customer will design a building of the same height. It would be an uneconomical “waste,” and for many other reasons, it is virtually non-existent, it may never eventuate.

If as a protection concept, we choose to have an automatic fire alarm device in the building (r_p = 0.2), then the building becomes protected (column J) in several versions and lightning protection is not required. It is important to note that in this case the protection of the building has only a legally protected status but not a technical one. This means that in the event of a lightning strike, the automatic fire alarm will be activated and it is likely that the people present will start extinguishing the fire, saving human life.

Experience shows that in such cases the fire causes great damage because if the roof catches fire, extinguishing it can be a difficult task even for the fire brigade. In many cases only the spread of flames can be influenced or prevented, the parts already on fire will have a high chance to burn down. Firefighters often comment that in such cases, by cooling the roof elements, they can only control the further spread of the flames and because of this, the parts exposed to the flame practically always burn down.

So, legally the building can be considered protected and thus we physically protect human life but at the same time not the building, because technically the building does not have any external lightning protection. It can be stated based on the values between columns B–J that although the building can be legally protected in some cases, in practice it is not recommended to choose these options, taking into account technical and mainly economic aspects, so it is very rare for this type of building not to have external lightning protection. The cost of repairing a burnt roof is already in most cases comparable to the cost of installing the lowest level of lightning protection (LPS IV) - following a precautionary mind set - the message to the lightning protection engineer in practice is to recommend the construction of lightning protection, thus protecting this building.

For the reasons mentioned above, another practical reason for setting up lightning protection is to reach hard-to-reach areas (and buildings), e.g.: in the narrow area of an old town and thus in the case of repairs that are difficult to carry out, or in the case of cultural and historical buildings (e.g.: monuments) where the fire can cause irrecoverable and irreparable damage to these structures.

The analysis of cultural heritage (R_3) is done separately from R_1. As starting from column K and moving to the right, we can already see cases of buildings with external lightning protection. Even in the case of the lowest class of lightning protection (column K–S), it can be seen that in several cases the building can already be considered protected. In practical life, the cases in columns P and S occur. It can be clearly seen that while in cases without external lightning protection only the highest fire protection measure (r_p = 0.2) could be used to achieve protection in a special cases (column J). However, with the lowest external lightning protection (LPS IV, column S), the building is protected in almost all cases. The message to the lightning protection designer is to use the lowest lightning protection level (e.g.: LPS IV, r_p = 0.2, column S) instead of the case without the previously mentioned lightning protection (column J, r_p = 0.2).

In almost all cases when the building has the lowest lightning protection level, it can be made not only legally but also technically protected. So the lowest lightning protection level (LPS IV) and the automatic fire alarm system (r_p = 0.2) can handle almost any case. It is important to mention that while of the only cases without external lightning protection the building can be protected by an automatic fire alarm system, by applying the lowest lightning protection level (LPS IV), one level lower fire protection measure (r_p = 0.5) also provides protection (P73 cell, R_1 = 0.80542 ≈ 80.6%). If the legislation does not prescribe the installation of an automatic fire alarm, then the installation of an automatic fire alarm as a part of lightning protection acts as a risk reducing factor. In this case, it must be decided as an economic comparison whether to choose this or a higher class of lightning protection.

If the installation of an automatic fire alarm system (r_p = 0.2, column S) was deemed too expensive, by switching to one higher lightning protection level (LPS III) and in parallel, using one lower fire protection measure (r_p = 0.5, column Y), in virtually for all cases, the building can be classified as protected. It is then necessary to compare the price of the class of the higher lightning protection system with the price of an automatic fire alarm system, i.e. whether a combination with an LPS IV automatic fire alarm or without an LPS III automatic fire alarm is more economically advantageous. Practice shows that there is little difference in price between LPS IV and LPS III, but the installation of an automatic fire alarm can make the investment very expensive because it is mandatory to install the system in every room. If the OTSZ does not prescribe the installation of an automatic fire alarm system, then it must be considered together with the fire protection designer whether it makes economic sense to prescribe an automatic fire alarm instead of using one class higher lightning protection. Technically, of course, the use of a higher level external lightning protection system is recommended.

Based on these calculations, I would like to highlight three main observations for this office building with a non-combustible roof:

- It is not recommended to avoid lightning protection despite the fact that this office building can be legally protected.
- In some cases, (if there is an automatic fire alarm system) LPS IV is already sufficient to achieve adequate protection.
- Except for a few special cases, it is practically not necessary to use LPS II-I classes, so using LPS IV-III classes are almost always enough.

Cases with combustible roofs (high risk of fire, r_f = 0.1, column AU – CM)

Based on the given results, it can be clearly seen that the first practical case when a building can be protected is the use of LPS III with an automatic fire alarm (r_p = 0.2, column BU), which requires building with at least the same height around the building (C_D = 0.5). If the building is to be considered as stand-alone, a minimum of LPS II (column CD) or even LPS I (column CJ, CM) will be justified.

Other lightning protection design solutions allow the use of LPS III. One such solution is zoning concept (dividing the building into zones), which avoids the use of LPS I or even LPS II, but requires a very well thought out model that requires a lot of experience. In practice, this means breaking down a building into a separate zone for each level.

Then there are people on the top level under the combustible roof only in the space under the combustible roof, no longer on the levels below it. From this reason it is worthwhile to place or install into this level e.g.: server rooms, boiler rooms, ventilation machine houses etc. This minimizes the number of people at the top level (which is directly below the combustible roof structure), thus reducing the R_1 output risk for office building.

If any value of the input parameter changed due to new needs/questions, the calculations for the concrete building or for an entire practical sensitivity test would be needed in cooperation with the fire protection designers.

2.10.3 The practical sensitivity test for the assembly plant[79]

The third examined building is a 20-meter-high assembly plant with 250 employees, of which an average of 30 people is in the designated smoking area in front of the building 24 hours a day due to shifts (Figure 31). High power-lines and telecom-lines are connected to this building.

Figure 31: Indoor picture of a similar assembly plant in the real life [59]

Location of the assembly plant:

It is an independent building, not bordered by any other buildings with a circle distance of 3H[80] around the building, so the location factor that gives the building's relation to the immediate environment is:

$C_D = 1$

Assembly plant dimensions:

Length, width and height data are required for calculation:

L = 80 m ; W = 40 m ; H = 20 m

Connecting Wires

According to the standard, we have to calculate with the data of high-power and low-power (telecommunication) connection wires as follows:

[79] **Concrete details and results** located in Annex III. " **Assembly plant data & Assembly plant data base**" in Excel worksheets on CD (attached at end of my dissertation in pocket).
[80] **3H**: three times the height of the building.

a) data of power-line:

Length:	L = 500 m
Type: underground cable	C_I = 0.5
Location: suburban environment	C_E = 0.5
Transformer factor:	C_T = 1
Shielding, grounding:	C_{LD} = 1 ; C_{LI} = 1
Surge resistance:	$U_{W/P}$ = 1.5 kV

b) data of telecom-line:

Length:	L = 1000 m
Type: underground cable	C_I = 0.5
Location: suburban environment:	C_E = 0.5
Transformer factor:	C_T = 1
Shielding, grounding:	C_{LD} = 1 ; C_{LI} = 1
Surge resistance:	$U_{W/T}$ = 1 kV

Fire protection properties

Experience has shown that the fire protection properties of a building strongly influence the lightning protection adequacy of the building.

External soil parameter for grass:	r_{ta} = 0.01
Internal soil parameter for parquet floor:	r_{tu} = 0.001
Fire protection measures:	r_p = 1
Risk of fire:	r_f = 0.1

Personal presence

Inside the building:

250 people, 24 hours per day: $n_z = 250$

$t_z = 24 \times 365 = 8760$

Outside the building:

30 people, 24 hours per day: $n_z = 30$

$t_z = 24 \times 365 = 8760$

Number of dangerous events per annum per km²

This value is 1.75 in Budapest:

$N_G = 1.75$

Losses

Physical damage in assembly plant[81]: $L_F = 0.02$

Failure of internal systems: $L_O = 0$

Constant multiplier by standard: $L_T = 0.01$

Other parameters

Lightning protection system (LPS) and its associated parameters (Table 10):

LPS class	P_B	P_{EB}
I	0.02	0.01
II	0.05	0.02
III	0.1	0.05
IV	0.2	0.05
NONE	1	1

Table 10: P_B and P_{EB} values depending on LPS class [53]
(Edited by author based on MSZ EN 62305-2:2012)

[81] In this case, **the OTSZ prescribes** a value of 0.02 for L_F.

Special hazard **[82]**

For a maximum of 100 people in the building, or for 2 floors belong to $h_Z = 2$, but in this case, the number of persons is 250 which is above 100, $h_Z = 5$ must be used for the calculation.

2.10.3.1 Results of practical sensitivity test for the assembly plant

The practical sensitivity test about assembly plant proved that input parameters can be grouped into strong a non-strong group. The members of the strong group have also a decisive effect on the output similar to other examples mentioned above.

Therefore, based on the practical test the input parameters of strong group as follows:

L_O – Internal System Failure (only hospital and explosion dangerous building)
r_f – Factor reducing loss depending on risk of fire
L_F – Physical damage related to the purpose of the building
LPS – Lightning protection system (class)
r_p – Fire protection measures
C_D – Location factor
N_G – Number of dangerous events
h_Z – Type of special hazard (inside of building)

2.10.3.2 Formulation of remarks and lessons based on results for the assembly plant

In relation to the assembly plant, the sensitivity tests here were performed also with 90 parameter sets. Using the same structure with the previous examples in the Annex III. (condominium and office building), the results have been separated into buildings with non-combustible roofs (column B – AT) and with combustible roof (column AU – CN). Due to the number of workers (250) the h_z input parameter is set to 5 by default. So the columns containing this value exist in practical life, so these must be taken into account.

[82] It is called **'panic danger'** in daily usage in Hungarian slang language.

Cases with non-combustible roofs (r_f = 0.01, column B – AT)

The examples with no lightning protection are in column B–J. It can be seen that the first example when the building is protected appears in column J. One case is when the lightning density would be 1 per km^2 per annum (N_G = 1). This is specified in Eastern Hungary. The other case is when the building would be surrounded by higher buildings (C_D = 0.25). This is not a common example because production sites need space, so they are built up in large open areas. These two examples an automatic fire alarm system (r_p = 0.2). Cases with LPS IV are in column K–S. The results show that there is a good chance to protect this assembly with this class (LPS IV), so this level may be enough. Fire protection regulations require fire protection measures (r_P < 1) so the results are better in column P and S (r_p = 0.5 and 0.2). If lightning density is 3, as in Western Hungary, the building would be also protected.

This confirms the statement that LPS IV may be enough usually for assembly plants. Due to this, there is no need to check the cases beginning from LPS III.

Cases with combustible roofs (high risk of fire, r_f = 0.1, column AU – CN)

The examples with combustible roofs are in column AU – CN. If the roof is combustible, the situation is worse than with non-combustible roofs. It means that higher protection will be needed. All risks are higher than the allowed limit (1×10^{-5}) when there is no protection (column AU – BC). In the LPS IV section (column BD – BL) the only case when the building would be protected is when it would have an automatic fire alarm system (r_p = 0.2) and would be surrounded by higher buildings (column BL). This is not an everyday situation. In most circumstances, large assembly plants are not surrounded by higher buildings. The primary consideration for companies who have assembly plant is that they may need other production plants in the future, so they build their assembly plants in open areas, in order to be able to expand with other new production plants in the future.

As an example, Mercedes in Hungary purchased land in the middle of the plough land (in the country) as a green field investment to enable the company to expand in all ‘directions’. So, the question arises - is LPS III adequate or not (column BM – BV)?

It can be seen in column BV that the only protected case would be, if the building would have higher buildings or buildings with the same height around it. As mentioned above, it is not a life-like situation. So, if this is a stand-alone building on the land, LPS III is not sufficient. It is important to note that in the future, more and more robot automation production processes will be used in these kinds of buildings so the personnel numbers and presence will be much lower, reducing the R_1 output risk, so LPS III may be appropriate in the future. A theoretical case has been set up in column BU. This assembly plant with a robot assisted production plant has a reduced worker number (100 instead of 250) has also been tested. It turned out that in this combination nearly all cases have protected status. I would like to highlight some technical information about the plants. These assembly plants represent a lot of value, so owners are not just protecting human life but also the technical goods. It means that in nearly all cases an automatic alarm system is installed. This defines the value for r_p to 0.2, so the only columns which contain this value must be taken into account during the different examples.

2.10.3.3 The lightning protection challenges for some halls in the future

The present assembly hall is a classic building with many workers. Due to technological advances and development, the use of robots in various stages of production will become more widespread. For example, at the Audi plant in Győr, at the production line for electric car propulsion engines – it employs human labour in only one phase during the entire process. All the other phases of production are carried out by robots. According to one of the guidelines of Industry 4.0[83], the use of robots is expected to increase dramatically. This will also have an impact on the design and construction of lightning protection. Due to the expected very low or even zero number of employees, the risk of R_1 will no longer be critical, but will be replaced by the risk of economic damage to R_4, as the machines in production will become increasingly sensitive to the effects of lightning. Technically, the task will be to prevent lightning current entering the building. One of the probable solutions for this will be the insulated drainage of the lightning current. If the lightning current enters the building, it will easily destroy any sensitive devices that it reaches. Another task is to design adequate over-voltage protection. This is an expensive system which requires a high level of expertise and experience.

[83] **Industry 4.0**, in Hungarian: Ipar 4.0

2.11 Summary of my theoretical and practical tests results

The sensitivity test found that unit changes in different input parameters do not equally affect output R_1 (risk of loss of human life). A group of input parameters has a very minimal effect on the value of the output so that R_1 value remains below 1×10^{-5}, so the R_1 output for lightning protection of the building does not change. On the other hand, some parameters have decisive influence on the output. I identified the strong input parameters whose unit changes decisively influence the R_1 output. Theoretical test result has some strong members of input parameters, but in my point of view the practical sensitivity test can validate them because some parameters look like as strong members, but in practical life they don't have decisive effect on the output. Some members look like constants but in practical life they may change. They are L_O , L_F , C_D , $N_{G.}$ and h_Z. The L_O is the overvoltage damage, L_F is a multiplier according to the purpose of the building. So, if the purpose of the building changes, these input parameters change with decisive effect on the output. C_D and N_G are theoretically constants but if the buildings among the observed building are demolished, the value of C_D input parameter also changes. The situation about N_G is very similar. Theoretically it is constant, but for example if the building would be designed at a different location in any country, the number of dangerous events may have a different value than the original location, so R_1 will decisively change. I would like to highlight a very important case regarding this mentioned example. The new version of the MSZ EN 62305 standard may calculate with double value of N_G, if this will be introduced, it will have a very significant raise in R_1 output for the same attributes of the buildings. LPS is an exception because although it is an input parameter, the goal is to determine the proper LPS class for the building. Generally, the theoretical and practical results match which is confirmed from the practical life of design. It can be said that these parameters have to be taken into account when designing a building. The h_Z input parameter also looks like constant but in some special cases the value of it may be changed. One example was introduced in section 2.9[84] as well. The H input parameter based on the theoretical test looked like strong input parameter because it is a quadratic member in the calculation, but the practical sensitivity test proved that its effect on the R_1 output is low. This is because of the other input parameters "flatten" the parabolic curve of value set of the function.

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[84] **See:** p.66-72

The concrete results of the sensitivity tests are shown in the Table 17 as below:

RESULTS OF SENSITIVITY TESTS					
Theoretical test			Practical test		
Condominium	Office Building	Assembly Plant	Condominium	Office Building	Assembly Plant
L_O	L_O	L_O	L_O	L_O	L_O
r_f	r_f	L_F	r_f	r_f	r_f
L_F	L_F	r_f	L_F	L_F	L_F
r_{tu} (inside of bld)	r_{tu} (inside of bld)	LPS	LPS	LPS	LPS
LPS	LPS	r_P	r_P	r_P	r_P
r_P	r_P	r_{tu} (inside of bld)	C_D	C_D	C_D
C_D	$C_{E/T}$	C_D	N_G	N_G	N_G
N_G	C_D	N_G	h_Z (inside of bld)	h_Z (inside of bld)	h_Z (inside of bld)
h_Z (inside of bld)	N_G	$C_{E/T}$			
r_{ta} (outside of bld)	$C_{E/P}$	$C_{I/T}$			
$C_{E/P}$	h_Z (inside of bld)	$C_{E/P}$			
$C_{I/P}$	$C_{I/T}$	$C_{I/P}$			
$C_{E/T}$	$C_{LD/T}$	$C_{LD/T}$			
$C_{I/T}$	$C_{T/T}$	$C_{T/T}$			
$C_{LD/P}$	$P_{LD/T}$	$P_{LD/T}$			
$C_{T/P}$	t_Z (inside of bld.)	h_Z (inside of bld)			
$P_{LD/P}$	H (height)	r_{ta} (outside of bld)			
H (height)	$C_{I/P}$	$C_{LD/P}$			
$C_{LD/T}$	$C_{LD/P}$	$C_{T/P}$			
$C_{T/T}$	$C_{T/P}$	$P_{LD/P}$			
$P_{LD/T}$	$P_{LD/P}$	H (height)			
t_Z (inside of bld.)	r_{ta} (outside of bld)	t_Z (inside of bld.)			
-----	-----	h_Z (outside of bld)			
-----	-----	W (width)			
-----	-----	L (lenght)			

Table 17: Results of sensitivity tests in common table
(Edited by author)

These input parameters are a kind of help and will be assistance to the designers. The lightning protection engineer and also the architect should work together using these data list for developing the lightning protection. Two of the 8 input parameters (L_O and r_f) nearly immediately raise the value of R_1 above 1×10^{-5}, eliminating the lightning protection of the building. This is a very rare case when parameter L_O has a different value than zero.

2.12 Expected use of results for areas

In many cases, there is an obligation to build lightning protection at the end of a buildings construction. By this time, the construction is in such a phase that in most cases it is not possible to install simpler, cheaper or less destructive components of the lightning protection system. In common language, it remains as an "ugly lightning rod" solution. As a practical benefit in exploring strong parameters, if an engineer designing a lightning protection system already foresees the "weak points" of a building, he can make a suggestion before the construction to install components that will no longer be possible after construction begins. One such element may be, for example, a grounding net which must be installed in the ground. It is useful from an economic point of view to know the parameters in advance. The lightning protection is decisively influenced by the type of roofing material, so it is possible to decide before construction that the roof is not made of combustible material (e.g.: sandwich panel) but rather expensive but not combustible rock wool. But, in this case, installing cheaper lightning protection equipment is sufficient to provide adequate lightning protection. Another option is to use the building's natural invisible guides as lightning arrestors before starting construction, which means we can leave out the visible lightning conductors, which are not aesthetically pleasing. It is essential that the architect and the lightning protection designer work together from the design phase prior to the commencement of construction to find, use and execute similar technical solutions. Such engineering and technical issues require a degree of vision from the parties involved. If any value of the input parameter changed due to new needs/questions, the calculations for the concrete building or for an entire practical sensitivity test would be needed in cooperation with the fire protection designers.

2.13 Chapter summary

The concept defined by the standards is an extremely complex topic in terms of lightning protection risk calculation. In a general sense, when approached with a mathematical vision, danger and vulnerability are inversely proportional to safety. This means that a low level of vulnerability is coupled with a high level of security, while a high level of vulnerability is coupled with a low level of security. Therefore, we can conclude that in the technical sense, there is no absolute safety, only in the case of the object concerned, a decision legally identified with a specific level of risk, on the basis of which the safe operation and operation accepted according to the basic purpose can be realized. In the case of specific objects, these input parameters individually interact to determine the lightning protection risk of the buildings. Based on this, I consider it warranted to develop a lightning protection system, based on an early comprehensive risk analysis, running in conjunction with the planning phase of any building or in the case of a previously built object. The knowledge of the strong parameters revealed in the research, facilitate and speed up the design of lightning protection, because with this knowledge, it is possible to plan in advance the construction solutions important for lightning protection, which would no longer be feasible after the building is constructed.

Another help can be my risk analysis self-developed IT program I have created which is able to perform the (practical) sensitivity test. In practice, this means that for a given specific building (and its recorded parameters), in addition to calculating the R_1 output risk, it is also able to perform sensitivity testing of input parameters which are important and useful information for designers for lightning protection design of a building.

In the course of my present research, according to my calculations, the 40 examined input parameters do not affect the output to the same extent, so some statements can be made based on my results of the practical sensitivity tests:

- The number (22, 22 and 25 pieces) of the input parameters of the theoretical strong group reduced to 8 pieces.
- The input parameters can be grouped into both strong input parameters (8 pieces) and to non-strong input parameters (49 pieces).
- Two input parameters of grouped input parameters can be identified as a priority.

In the group of strong parameters with their small change they have decisively effect on the output and the result. I discovered 8 input parameters, which I presented and explained in detail in section 2.11[85]**.** Two of these 8 input parameters can even be considered as a priority in the strong group. Therefore, I identified two extremely strong parameter from in this group (L_O and r_f) which in each case, increases the risk value of the three examined buildings immediately above the permissible R_T limit by a unit change. These large output changes are related to the fact that these input parameters can take discrete values, which values are defined by the standard. In my opinion, the results, based on my calculations, provide useful assistance to both the architect and the lightning protection designer, both in the design phase of new buildings and also in the modernization phase of lightning protection systems for existing buildings, in order to achieve easier, faster and in some cases cheaper solutions, including the attainment of an even better visual image. As I mentioned earlier, the H (height of building) input parameter based on the theoretical test looked like strong input parameter. But my practical sensitivity test proved that the other input parameters “flatten” the parabolic curve of value set of the function. Based on my research, this makes it possible to use the natural elements of the building as receptors on the design table, to build invisible lightning protection, as well as creating a visual image that fits well into the environment.

[85] **See**: p.98-99

Looking to the future, I would like to draw the attention to the change that is likely to be introduced, if the third edition of the lightning protection standard (Edition 3) would be passed into law[86]**.** There will be a very important change, according to which the value of N_G will be taken into account with double the value. The consequence of this in practice will be - as the examples presented in my dissertation - in the case of buildings that can be found in reality, the situation will be shown that the LPS class used by the profession will no longer be sufficient to protect structures, in all probability only one higher LPS class will provide protection for buildings.

In this chapter my research process was introduced. I showed my different research methods, my ideas about the research method and my self-developed IT program in MS Excel was introduced (Annex I.). The calculation method was also presented and based on that the basic steps of my self-developed IT program was also introduced. My research was separated into a theoretical and a practical test. I have concluded and presented a theoretical and a practical test about my research. In case of changes in the parts, elements of the given buildings and structures, the previously obtained data must be recalculated. By comparative analysis I determined the dominant input parameters, which are named as a group of strong and extremely strong input parameters based on set of 8 input parameters of the practical sensitivity test. Assigning some input parameters to all variation cases of the values and degrees of the input parameters included in this group - considering the others constant until then - I calculated the value of the risk of loss of human life (R_1)[87] for the three chosen building types about the research. The research needed 51 840 calculations for the condominium, for the office building and for the assembly plant together. In the case of the structures under research, the specific values of my variation calculations for the risk of loss of human life (R_1) are included in the CD data carrier attached at the end of my doctoral dissertation (Annex III). If any value of the input parameter is changed due to new needs/questions, the calculations for the concrete building or for an entire practical sensitivity test would be needed in cooperation with the fire protection designers.

My set-up hypotheses (H1 and H2) were proved which are listed at the end of my dissertation[88] based on MSZ EN 62305-2:2012 standard.

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[86] **Giving** to national consultation and debate **again in Jan 2021**.
[87] **Marked as R_1** in MSZ EN 62305-2:2012.
[88] **See**: in the Table 19, p.138

3. STANDARD IEC 62305 ED3[89] DRAFT IN GENERAL

A standard is a published description containing definitions, concepts, physical quantities, and applicable calculations. After our accession to the European Union (EU) in 2004, there application in Hungary is no longer mandatory and only voluntary. The purpose of the standard is to facilitate validation of the needs of the national economy, the implementation of international and European standardization activities and the protection of life, health and the environment. Its precise definition is set out in Act XXVIII of 1995 about "The Law on National Standardization." There are several types of standards, such as e.g.: the basic standard, product standard, test standard, etc. The MSZ EN 62305 family of standards is a methodological standard. In Hungary, a standard can only be issued by the MSZT[90].

3.1 Standardization procedure in general

There are several levels of standards as e.g.: international (IEC[91]), and European (EN[92]) and national. National standards in Hungary can only be issued by the MSZT. The highest standards and international standards are created and issued by the IEC. If the European Union wants to nationalize a standard, it will be voted on in its appropriate organization. If it is about e.g.: a technical standard (such as 62305), the responsible organization is the CENELEC[93] for European technical standards. The members will vote on it and it can be introduced or not.

The voting committee consists of permanent (P) and observer (O) members. Voting is valid if at the same time at least 66% of the permanent members vote in favour ($P >= 66\%$) and less than 25% of the permanent + observer members give no votes at all ($P + O < 25\%$). There is an obligation in Hungary from our membership in the European Union in CEN[94] CENELEC that our Hungarian national standards should be introduced till a given deadline. There are even harmonization documents that are actually standards, but due to national specifications, comments and explanations can be added to the documents

[89] **FDIS: F**inal **D**raft **I**nternational **S**tandard, used version: IEC FDIS 62305-2:2018; 81/607/FDIS.
[90] **MSZT**: **H**ungarian **S**tandards **B**oard, in Hungarian: **M**agyar **Sz**abványügyi **T**estület.
[91] **IEC**: **I**nternational **E**lectrotechnical **C**ommission
[92] **EN**: **E**uropean **N**orm, **E**uropean **S**tandard (EN) [60]
[93] **CENELEC** (abbrev. in French): European Committee for Electrotechnical Standardization in English.
[94] **CEN** (abbreviation in French): European Committee for Standardization in English.

without changing the content. Standards of this type are marked MSZ HD[95]. Standards can also be issued at a national level by the Member States of the European Union, in which case the rule is that they cannot conflict with any international standard. Member States can also adopt standards directly from e.g.: the IEC, omitting the European Union. When a standard is introduced, the IEC or EN type standard becomes the national standard for the given country during localization. In Hungary, this is denoted by MSZ.

Based on this, from 01.01.2018 the markings of the technical standards are as follows:

- **IEC:** international standard
- **EN:** A standard issued by the European Union or a standard adopted from IEC in which an amendment has been made.
- **MSZ:** Hungarian Standard

- **EN IEC:** Standard adopted by the European Union from the IEC organization without amendment.
- **MSZ EN:** Standard issued by and adopted from the European Union
- **MSZ IEC:** a standard adopted directly from the IEC

- **MSZ EN IEC:** A standard adopted by the European Union that the EU has adopted in advance from the IEC.
- **MSZ EN HD:** harmonized standard-like documents, e.g.: MSZ HD 60364-4-443 or MSZ HD 60364-5-534, where there are also alternatives to the specifics of each nation.

An additional rule is that if there are more standards should be used then stricter ones should be applied.

The relationship among the different types of standards is shown in Figure 32[96] as follows:

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[95] **MSZ HD**: **h**armonized standard-like **d**ocuments, not harmonized standard.
[96] **See:** p.105 (next page)

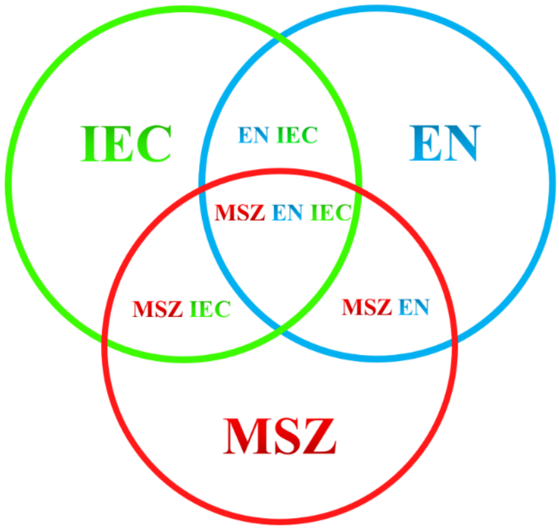

Figure 32: The relationship of standards
(Edited by author)

3.2 About IEC 62305 Edition 3, version 81/607/FDIS

The MSZ EN 62305 standard family was introduced in Hungary on the basis of IEC 62305. The first edition was published in 2006 by IEC and introduced in Hungary in 2011 as MSZ EN standard. In recent years, another updated version has also been released called Edition 2. The IEC 62305 Edition 3 was voted down in September 2018, so the industry still has to wait for this version. According to my research, there was no consensus on some technical issues that, due to national positions, require further investigation. The finalization of the draft and its later national codification[97] will be further both enhanced in this time and also the process as well. This Edition 3 contains a number of new features and changes compared to the current (valid) Edition 2. At the beginning of my current studies, one of my research tasks was to compare current and future drafts of the standard.

After the vote on the new draft standard in 2018, this task lost its relevance because the draft was returned to basic drafting status. There were a number of new features in the draft that will presumably be included in the newer version. I present a few of these main changes to be mentioned in section 3.3[98] of my dissertation.

[97] **codification**: transposition into national law
[98] **See:** p.106-108 (from next page)

3.3 Planned news and changes

There are some planned changes for the draft version of the standard which may be introduced in the future, this chapter introduces some of them.

3.3.1 Planned change in risk components

The current standard calculates the value of R_1 from 8 components:

$$\mathbf{R_1} = R_A + R_B + R_C + R_M + R_U + R_V + R_W + R_Z$$

The draft splits the R_A component into R_{AT} and R_{AD} components, where:

$\mathbf{R_{AT}}$ – Damage related to electric shock, caused by electric shock (touch and step voltages)

$\mathbf{R_{AD}}$ – Damage caused by a flash to living beings exposed on a structure.

3.3.2 N_G and N_{SG} – lightning strikes per km^2 per annum

The future version of the standard counts twice the number of lightning strikes per square kilometer per year in risk management. The reason for this can be explained by the physical phenomenon that the main discharge is always followed by an auxiliary discharge, so the new version already counts twice the value on the lightning density map. Sign of the new method N_{SG}. The N_G parameter remains as the value read from the lightning density map.

$$\mathbf{N_{SG}} = 2 \times N_G$$

In places where lightning density data provided by an instrumental lightning detection system is not available, to determine the value of N_G is the quarter of the visually detected value (N_t).

$N_G = 0.25 \times N_t$

Multiplied by two:

$2 \times N_G = 2 \times (0.25 \times N_t)$, so:

$$\mathbf{N_{SG}} = 0.5 \times N_t$$

I would like to draw attention to a very important matter of the future. During the lighting protection design (and during risk assessment) this parameter is fix, it is used from the lightning density map. Although this parameter is fix, the theoretical test showed it has a decisive effect on the output. If the planned method will be voted in the future (to calculate with double value as mentioned above) it will have a very important effect on the design. **Probably one-level higher LPS class will be proper** for the same buildings which has also an economical aspect as well.

3.3.3 F_X - frequency of damage events

The Edition 3 draft introduced a new concept, the frequency of damage events (F). This variable shows the number of potential adverse events per year. Its value consists of F_C , F_M , F_W , F_Z components:

The Edition 3 draft introduced a new concept, the frequency of damage events (F). This variable shows the number of potential harmful events per year. Its value consists of F_C , F_M , F_W , F_Z components (Table 18).

$$\mathbf{F} = F_C + F_M + F_W + F_Z, \text{ where these are:}$$

Frequency symbol	Description
F_c	Frequency of damage due to flashes to the structure (source S1)
F_M	Frequency of damage due to flashes near the structure (source S2)
F_w	Frequency of damage due to flashes to the line (source S3)
F_z	Frequency of damage due to flashes near the line (source S4)

Table 18: Types of frequency of damages
(Edited by author based on IEC 62305 Edition 3 draft version)

3.3.4 Collection area

The collection area calculation presented in section 2.5.1[99], according to the current version, the collection area determined for the immediate vicinity of a rectangular building has been determined according to the following formula:

$$\mathbf{A_M} = 500 \times 2 \times (L + W) + \pi \times 500^2$$

The planned version now counts only with 350 meters:

$$\mathbf{A_M} = 350 \times 2 \times (L_S + W_S) + \pi \times 350^2$$

[99] **See**: p.54-59

Reducing the distance to 350 m from 500 m also reduces the risk. The reason may be that the calculation used high number (500 m) so the risk might be unreasonably high.

3.3.5 Other parameters used for risk calculation

P_P *– Probability that a person will be in a dangerous place*

Shows the presence time in the dangerous place in percentage. It is calculated:

Time presence in dangerous place in hours for a year / 8760.

$$\mathbf{P_P} = t_z / 8760$$

P_O *– Probability factor according to position of person in the exposed area*

This is related to the case that person is near the exposed area. The limit is 3 m, so below 3 m the person is “close”, beyond 3 m the person is “far away”.

3.4 My discovered error in draft (Edition 3)

The calculation introduces the discovered error through the example of a 25 meters high office building with a green roof on the top.

The green roof top operates like a park, people can stay in that area having some breaks, talks, having kind of meetings or doing a little jogging etc. (Figure 33). It is important to notice that this is not a working area of the company, just a relaxing place of it. Not all parts are introduced, only its main steps.

Figure 33: The different types of green roofs [61]

3.4.1 Calculation method of FDIS draft standard

The error occurred in the 'flash to building' risk. Calculation method of R_{AD} in the planned standard is:

$$\mathbf{R_{AD}} = N_D \times P_{AD} \times P_P \times L_{AD}$$ where these are named:

N_D – Number of suspected lightning strike

P_{AD} – Sensitivity of a building or part of a building (zone)

P_P – The probability that a person will be in a dangerous location

L_{AD} – Losses

The concrete example with main steps:

$N_D = 0.21977164$

$P_{AD} = 0.9$

P_P[100] $= 2/3$

$L_{AD} = 0.1$

$R_{AD} = 0.21977164 \times 0.9 \times 2/3 \times 0.1$

$R_{AD} = 0.0131862 = 1318.62 \times 10^{-5} \approx 1319 \times 10^{-5}$

$\mathbf{R_{AD} = 1319 \times 10^{-5}}$

$R_T = 1 \times 10^{-5}$

Result: $R_{AD} >> R_T$ → **NOT PROTECTED**

It can be seen that the resulting risk (R_{AD}) exceeds the permissible risk (R_T). The problem lies in the P_P parameter. This is a value of time presence of the people. Due to the fact that this is not a working place with a calculable time presence, the time cannot be measured or calculated. For this reason, it has been set to[100] 2/3. In real life it is unlikely that people will stay there when it begins to rain.

[100] **For example**, if a skybar is open from 12:00 – 04:00 or the resident uses his open area of the loft apartment for not-sleep period, then the time presence is 16 hours a day, which is 16/24 = 2/3. This mathes the practical experiences about skybar, loft apartment rooftop areas. Due to this the risk will be high.

This situation is similar to these people would wait in the rain to get struck by the lightning. But on the other hand, a situation can happen about some tourist attractions that people will need to stay in the rain because they want to walk around the place if they had travelled from far to visit it. So, the definition of the values of this parameters is not easy and unequivocal.

My proposal is to check the possibilities for protection measures usage in order to reduce human grouping in different cases. It has some methods, for example organized measure to draw people out of the place/area or placement of boards about the danger or operating company can get a warning so it can notify the people to leave. There is a tool (TWS) [101] which detects the storm approaching so its mandatory usage can be also an option. This draft does not include the protection measures which could reduce the human grouping (e.g.: a signboards on the walls). Calculations show that the risk is very high with three orders of magnitude so protection measures are needed. Draft accepts as reduction factors the external lightning protection and the warning system (TWS). In my point of view, it would be worth considering additional protection options which would reduce the human grouping. Placing boards are not acceptable because experiences show that they are get rid of soon in the buildings. If an apartment is sold, they are not replaced back to the original place (wall) so the new owner won't have any information about this danger. It's not a coincidence that the draft did not contain this "board" option because the working committee does not accept this solution.

Experiences show that these buildings which have this kind of open rooftop are open for lot of hours a day (e.g.: shopping malls, skybars) or for example retired people who own a loft apartment can also spend a lot of time there. The lightning protection planning and installation of a building is carried out in order to protect both human life and the economic value of the structure. In my research plan, based on the previously detailed goals I set the objective to define a so far unapplied priority order for the input parameters for the lightning protection risk management of buildings, in the case of standardized buildings, housing a considerable number of people (e.g.: hospitals, condos, schools, etc.).

I performed this activity based on my self-developed informatics program that I have created. This showed immediately that the result exceeded the permissible value by three

[101] **TWS**: **T**hunder **W**arning **S**ystem

magnitudes. This program compares and demonstrates the differences in the content, and in some cases the calculation methods of the actual and the draft standard. The more complex the building the more parameters are taken into consideration during the risk assessment calculation. The high number of input parameters makes the planning and installation of any lightning protection system of a building much more difficult, so the availability of a priority order of parameters, typical for a given building, may decrease its complexity. A practical benefit of my research results will be that these points will be already visible at the building design's lightning protection planning phase, the specific focus on which it will make it possible to implement lightning protection solutions irreplaceable afterwards.

3.5 Chapter summary

The future version of the standard is currently being developed. There will be some novelties in its content. At the beginning of the research, my task was also to check the calculation method of this planned version. In this chapter, some parts of the planned version of the standard were introduced. I have extended my self-developed IT program with the planned content of the standard to be able to compare the differences. During my research, I have noticed an error in the draft version of the planned content (Edition 3).

I have made a proposal for correction and made a presentation in abroad **[P9]**[102]

During my research I performed the calculations for my hypothesis 3 (H3) and **published my results [P3]**[103] **[P9]**[102] but since the draft standard was not published, I cannot formulate a thesis in this regard. Therefore, the research of my hypothesis 4 (H4) which was derived from it has also become obsolete.

[102] **See:** p.154
[103] **See:** p.153

4. THOUGHTS ABOUT THE LIGHTNING PROTECTION OF SOME ELECTRIC VEHICLES

4.1 Some thoughts about electric vehicles

Continuous advances in networked digital technologies based on scientific results nowadays enable the design and organization of not only smaller communities and condominiums, but also the operation of entire villages, towns, community functions and services for citizens, through the integrated use of ICTs[104] and tools, and support for enforcement. If the above activities are implemented in practice, we can usually speak of a smart city, which, regardless of its size, has the same public tasks that can be clearly identified and grouped. These may include, but are not limited to, e.g.: public transport and emergency public tasks involving several different types of vehicles. As technology advances, different types of electric vehicles are becoming more common on the road. Manufacturers are planning to make the bodywork elements of these vehicles from various plastics and composite materials in order to achieve lighter weight. This type of technology has long been present in racing cars, but due to their high cost it has not yet moved into the field of the domestic motor car. The automotive industry is already experimenting with cheap composites to replace the metal bodywork.

In Hungary various components of buses were manufactured from composite elements and then shipped to the USA. UV resistance is achieved by UV-resistant painting of the surface and also meets the refraction test requirements by placing parts underneath this element. The Boeing Company, as a large aircraft manufacturer has already been involved in the development of this material and in 2016 their Composite Wing Center research center was started [62].

These vehicles can unexpectedly or knowingly, exit the lightning-protected area during their traffic manoeuvres. Nowadays, natural phenomena suggest that global warming caused by human infrastructural activities, increases the number of lightning strikes. As much as 1% temperature rise will increase the number of lightning strikes by 6% per annum [63]. Parameters of strikes are also increasing (e.g.: lightning density, peak value).

[104] **ICT: I**nformation and **C**ommunications **T**echnology

With the advancement of technology, electric vehicles are becoming more widespread on the road. Manufacturers are planning to make the body parts of these vehicles from different plastics or composite materials in the future to achieve lighter weight.

Therefore, in my opinion, the lightning protection not only for buildings but also for these electric vehicles can be a priority research area with regards smart cities in the future as well **[P4]**[105] **[P12]**[106]**.**

4.2 The effects of lightning strike

The source of damage is considered to be that point where the lightning may strike (one example in Figure 34). In case of vehicles it may be two different points, a strike to the vehicle (primary effect) and a strike near a vehicle (secondary effect). Contrary to popular belief, harmful events may not only occur if lightning strikes directly on the automobile, but also when it strikes in close proximity to it. In the latter case, the overvoltage induced in the vehicle's electric systems may cause significant damage.

Figure 34: Direct strike to car [64]

A lightning strike may directly and indirectly cause very severe damage. In order to avoid these harmful effects, automobiles need to be provided with appropriate protection. In the case of direct lightning strikes, not only the vehicle may be in danger, but also its electric devices and systems (secondary effect). Metal bodywork gives protection against it.

[105] **See:** p.153
[106] **See:** p.154

In the case of indirect (or secondary) effect damage, it is not done by a direct lightning strike, but overvoltage induced by it. It is very difficult to protect against it.

4.3 Electric vehicles today

Automobiles with alternative drives are becoming more and more popular [65]. Their popularity is well represented by the fact that during the Olympic Games in Beijing in 2008 and during the 2018 winter Olympics as well, contestants were transported to different locations by a significant number of electric buses [66].

One of the main reasons behind their popularity and spread is the operating costs and the different tax allowances [67]. From the perspective of utilization, these vehicles are quiet and have a zero point of emission, therefore, result in cleaner air, which will be most advantageous in major cities when they become widespread. Their disadvantage is their range and charging time. Their maximum range is a fraction of the internal combustion engine equivalents, and their "refuelling" (recharging) time is longer by many orders of magnitude, compared to vehicles running on conventional fuel. There is continuous research and there are already some solutions for rapid charging [68], so exceptionally long charging times will not be an obstacle to their spread in the future.

It is important to note that for the charging of these automobiles, electricity is coming from the burning of hydrocarbons, so even if they have zero emissions locally, at the site of energy production (power plants) they trigger pollution - but to a smaller extent compared to internal combustion engines. An exception is the charging provided with entirely renewable energy.

4.4 The problem of the non-metallic body vehicles

Because electric cars are becoming more and more popular, charging stations are expected to spread around countries. This technical field is new so there are no standards for these types of stations. There are only recommendations like VdS 3471[69] or DKE/AK EMOBILITY.60 [70]. Standard IEC 61851 relates to electric vehicle conductive charging systems, parts of which are under development. These recommendations are drawing attention to the fact that lightning strike protection is important for electric charging stations.

There are some guidelines for protecting the electric charging stations e.g.: overvoltage protection (Figure 35.) but there are no guidelines for direct lightning strike to cars.

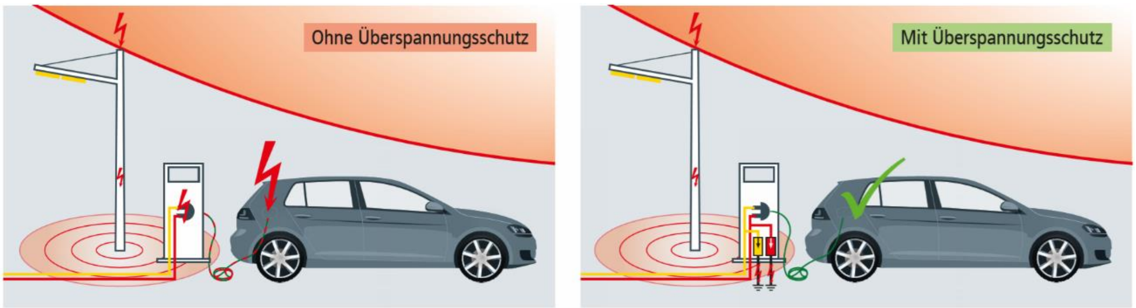

Figure 35: The lightning protection for poles at charging station [71]

In the case of a direct lightning strike, the lightning current flows through the car body and partly through the suspension, then finally exits through the wheel disk (rim) and is discharged in the air towards the ground (Figure 36). The metal body protects the passengers of the vehicle. In order to increase maximum range, manufacturers are planning to produce the bodywork of electric vehicles out of non-metallic materials (plastics, composite materials). These materials are not conductive, having electrically insulating properties. Currently, due to their short range, electric vehicles (automobiles and buses) are mostly used in populated areas, particularly in cities.

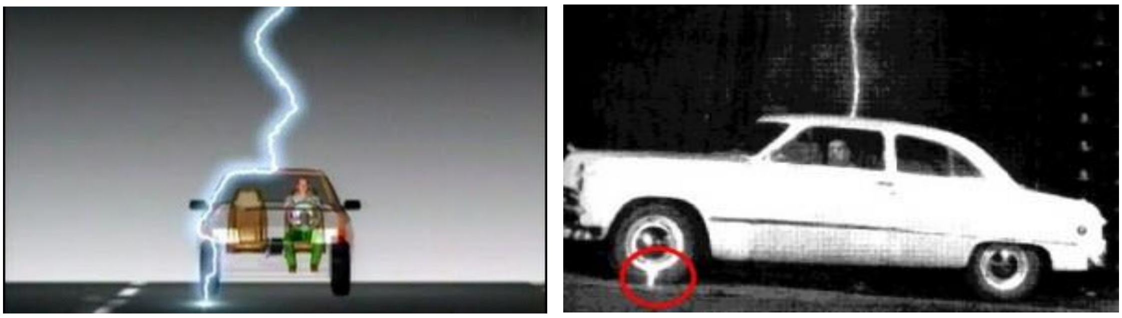

Figure 36: The lightning current route in schematic diagram and in reality [72] [73]

This gives protection against bolts of lightning. Buildings, due to their height, and thanks to lightning arrestors built on them, give safety in the case of lightning strikes.

One might wonder what happens if an electric vehicle exits this protected area and what happens during a lightning strike? Are the passengers in danger? Is there lightning protection?

4.5 Possible solution for non-metal framed vehicles

Technically, the aim is to capture the lightning and conduct it towards the ground. To find the position of the lightning arrestors, we should use the rolling sphere method. This is a procedure in designing the lightning arrestors, according to which protection is appropriate, if a rolling sphere of given radius cannot come in contact from the outside of the protected surface without touching the lightning arrestor. In practice, this means that we are moving a sphere of given radius in the space around the protected object (building, vehicle, etc.) and where the sphere touches an object that will be the touchpoint of the bolt. With this design method the given object can be protected, because the protected surface will be part of the protected space, since the sphere reaches the end point of the protective conductor (better known as lightning arrestor) first. For this design method there are different kinds of 3D software available on the market. As a result, we get a blanket-like surface around the examined object, behind which the protected space is located (Figure 37).

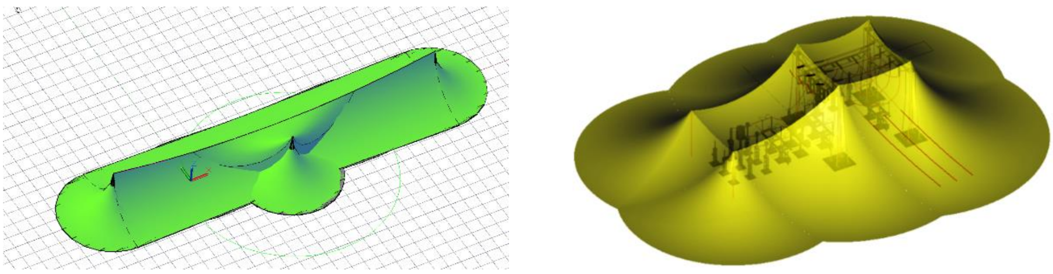

Figure 37: Types of 3D diagram of the rolling sphere design [74][75]

Nowadays, the technology (Figure 38) is available for a device to laser scan an object in 3D and design its rolling spherical editing in 3D to make the protected areas. Its great advantage is that it’s not necessary to draw the examined object separately in advance.

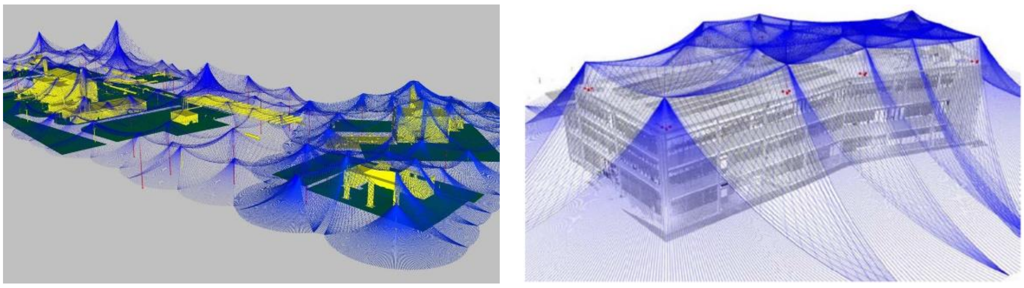

Figure 38: 3D rolling sphere design for buildings in real life with 3D scan [76] [77]

According to the above-mentioned method, the lightning is most easily "captured" by a well placed metal body which therefore is protecting the surfaces. In the case of electric vehicles, for this purpose, a mechanically fixed radio antenna (mast) is partially suitable. It is important that the any strong wind should not bend the antenna in any direction, because this is protecting part of the body. For this, adequate mechanical placement is a must. Moreover, the vehicle must be provided with arrestors on several other points as well.

Figure 39: Rolling sphere design for a commercially available car (Edited by author)

The Figure 39 shows us an electric vehicle available on the commercial market, currently manufactured with a metal body. On the left side, the actual, original condition of the vehicle is visible, on the right side the rolling sphere design with the planned arrestors (red markings) is detailed. We should notice that thanks to the arrestors, the sphere is not contacting the vehicle surfaces, therefore, they are protecting not only the automobile, but the passengers inside the car. The Figure 39 shows us one variation of the theoretical design and placement of arrestors. Of course, in the case of the vehicle's complete design, the full three-dimensional protection of the body should be compiled and completed. For the implementation of lightning protection, not only capturing, but conducting the lightning current is also a problem to solve. When we can speak about designing, the largest stress must be considered as engineering idea, in this case this means a situation when only one arrestor and one conductor would conduct the lightning current. The system should be designed to be capable of conducting even 200 kA of current impulse without any damage and warming. For this, a 50 mm^2 cross-section conductor is perfect. The lightning current must be conducted to the ground from the body. A solution to this might be a movable conductor that automatically reaches the ground in different intervals when the car is stopped/parked. To avoid excessive and unnecessary requisition (opening of this device at every stop, then closing at start), in practice the movement of this device should be controlled by an electric field strength gauge or by storm warning system (TWS). This means that the mobile conductor would be automatically activated when clouds start to develop in the sky and therefore the electric field strength changes measurably. A further task is the protection of electric appliances against the induced overvoltage that may appear in such cases. Electric devices in different automobiles are very sensitive to overvoltage. Protection of such appliances can be solved by installing them into metal housings, and electric cables may be threaded through protective tubes or provided with electric shielding.

4.6 Chapter summary

Technology is continuously developing. Our tools are becoming faster and smarter. Some tools and vehicles etc. may be connected to a common system in the future, forming a kind of community. If the above activities are implemented in practice, we can usually speak of a smart city, which, regardless of its size, has the same public tasks that can be clearly identified and grouped. As technology advances, different types of electric vehicles are becoming more common on the roads. To achieve lighter weight for the vehicles, the frame will be produced from some kind of non-metal material. The frame is not protecting the passengers and also the electric parts of the vehicle during the lightning. In this chapter this kind of problem and my recommended solution were introduced.

I made a theoretical engineering opinion and recommendation on the specific lightning protection requirements of non-metal (e.g.: composite) body electric cars as a possible area of theoretical research and practical implementation in the future **[P4]**[107] **[P12]**[108]**[P13]**[108]

Nowadays, it is not in the standardization process at the moment, the performance of sensitivity tests based on model experimentation may be an area of engineering and standardization field of research in the future.

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[107] **See:** p.153
[108] **See:** p.154

5. SOME ASPECTS ABOUT LIGHTNING PROTECTION ISSUES FOR DIFFERENT BUILDINGS AND EDIFICES

The importance of protecting any structures has been highlighted after a number of dangerous incidents. Modern societies are highly depending on technical and virtual infrastructure systems (e.g.: energy supply, drinking water supply, IT networks, etc.), whose complex system is also interdependent. Malfunctions of these systems or the temporary loss or destruction of some of their components have a significant impact on our daily lives and on the efficient functioning of the economy and government. It is the expectation of the general public and also from the government that these critical infrastructures operate with the highest degree of security. It is imperative to protect both critical infrastructure elements from terrorist attacks, industrial and natural disasters and accidents. Recent natural disasters (e.g.: the Asian tsunamis, earthquakes) have highlighted the vulnerability of such infrastructures. One of the natural threats is the lightning strike. My thesis does not cover lightning protection solutions for different infrastructures or for critical infrastructure, I merely want to draw attention to some potential dangers and I will suggest some solutions for protection.

5.1 About infrastructures in general

Infrastructure (Figure 40) is the basic building block of the economy, of production and of the business world. Generally speaking, balanced and sustainable economic growth can only be achieved if the infrastructure as a whole is developed proportionally to production and service, ensuring nearly the same level of development, technical quality and condition of its components.

Figure 40: Different structures under the lightning strike [78]

There are several conceptual definitions for defining infrastructure:

„*Ember alkotta rendszerek és eljárások hálózata, amelyek szinergikusan együttműködve arra törekszenek, hogy folyamatosan alapvető termékeket és szolgáltatásokat állítsanak elő és terjesszenek"* [79]

In translation: A network of man-made systems and processes working together in synergy to continuously produce and distribute essential products and services.

According to another literature, infrastructure is:

„Olyan állandó helyű vagy mobil építmények, eszközök, rendszerek, hálózatok, az általuk nyújtott szolgáltatások, és működési feltételek összességét kell érteni, amelyek valamilyen társadalmi, gazdasági vagy akár katonai funkciók és rendszerek feladatorientált, zavartalan és hatékony működését teszik lehetővé." [80]

In translation: It is to be understood as a set of fixed or mobile structures, devices, systems, networks, the services they provide and the operating conditions that enable the task-oriented, smooth and efficient operation of some social, economic or even military functions and systems.

5.2 About critical infrastructure in general

If the infrastructure is examined with the point of view of challenges and dangers then we can distinguish between critical and vulnerable infrastructure. The operation of these infrastructures is very important and indispensable for the country and also for society. In the situation of their ceasing operating, the consequences can be unforeseeable for the country's economy and defence.

Attributes of critical infrastructures [81]:

“ *1, egymással összekapcsolódó, interaktív*

2, egymástól kölcsönös függésben lévő infrastruktúra elemek, létesítmények, szolgáltatások, rendszerek és folyamatok hálózata

3, az ország működése szempontjából létfontosságúak és érdemi szerepük van egy társadalmilag elvárt minimális szintű biztonság, gazdasági működőképesség, közegészségügyi és környezeti állapot fenntartásában.” [81]

In translation:

1, interconnected, interactive

2, a network of interdependent infrastructure elements, facilities, services, systems and processes

3, they are vital for the functioning of the country and play a significant role in maintaining a socially required minimum level of security, economic viability, public health and the environment

Disaster Management[109] defines the critical infrastructure as follows:

„*létfontosságú infrastruktúrákhoz azok a fizikai és információs-technológiai berendezések és hálózatok, szolgáltatások és eszközök tartoznak, amelyek összeomlása vagy megsemmisítése súlyos következményekkel járhat a polgárok egészsége, védelme, biztonsága és gazdasági jóléte, illetve a tagállamok kormányainak hatékony működése szempontjából.*” [82]

In translation: The critical infrastructures include physical and information technology equipment and networks, services and facilities, the collapse or destruction of which could have serious consequences for the health, safety, security and economic well-being of citizens and for the effective functioning of Member State governments.

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[109] **Disaster Management**, in Hungarian: Katasztrófavédelem

5.3 Dangers of different structures and infrastructures and some protection options in practice

Infrastructures can be distinguished or categorized according to the nature of the threat. In the 21st century, traditional war events and armed conflicts are no longer significant, but new methods of warfare will arise from difficult to identify sources of danger and these will present a high security level challenge in developed countries of the world today and in the future. One such danger relates to natural disasters (e.g.: Japan). It is not just human neglect. We must be prepared not only for the dangers of deliberate damage but also from natural disasters.

The lightning strikes are becoming more common nowadays [63], and the associated risks are increasing. The lightning strikes have two effects. One is the direct lightning strike itself and the other is a secondary effect. As a secondary effect, the lightning current-induced overvoltages produce smart damage. We need to be prepared for both threats. To prepare for lightning strikes, we must understand where the lightning is pointing to strike. Every lightning strike has an orientation point. It means we must imagine a sphere with a radius with this point in the center. What this theoretical sphere can touch will be the strike-point. The radius of this sphere is proportional to the flowing current. The connection between the lightning current and the radius[110] as follows:

$$\mathbf{r} = 10\,\frac{\mathrm{m}}{\mathrm{kA}} \times \mathrm{I}^{0.65}\ \ \mathrm{kA}\quad [\mathrm{m}]$$

It can be seen that the greater energy in the lightning-strike, the bigger the radius. It means that the lightning will touch more distant points. If there is less energy, the radius is smaller. In means that under planning that we must consider closer points to bolt. At the highest protection level (LPS I), the lowest considered current is 3 kA and the highest is 200 kA. The radius is defined as between 20 m – 313 m. The lightning protection engineer calculates using the lowest value (20 m) for identifying the crucial strike points, because a sphere of 20 m radius can touch more points.

Structures including critical infrastructures are also exposed to lightning strikes. In this chapter, I would like to draw attention through some practical examples to illustrate this danger.

[110] IEC 62305-1:2010 Edition 2, its p.35

5.3.1 Protection of transmission lines

The purpose of the electricity transmission network is to transport large amounts of electricity over long distances. Electricity must be supplied from the producer to the consumer. This type of transmission makes it possible to connect remote energy sources to consumers. Electricity is often transported long distances over high, overhead lines. The high-voltage transmission lines stand out from their surroundings and are therefore at an increased risk of lightning strikes. In the past, in order to preserve the stability of the electricity system it was less and less permissible to disconnect a high-voltage transmission line from the grid.

Nowadays, due to the growing use of renewable energy sources in Western Europe, this is already changing, because the electricity produced by renewable energy only needs to be transported to distances closer to the producer. Hungary is currently an energy importer [83] which means that the loss of a high-voltage transmission line in the electricity network is currently not allowed. The core network is constantly needed.

The solution is to use the protective conductor higher than the phase conductors on the transmission line column (Figure 41).

Figure 41: Phase protector in reality [84]

This conductor extends at the highest point of the transmission line pole and is in metallic contact with the grounded pole structure, so the lightning strike first reaches his conductor, protecting the phase conductors.

Protective angle editing method is generally used to place protective conductors (Figure 42). This means that a sphere is formed with the theoretical smallest radius belonging to the given degree of lightning protection system (e.g.: in the case of LPS I class by r = 20 m) and moved in space. Where the surface of the sphere reaches the object under study (in this case the conduit column or pylon), there will be the expected point of impact. Spaces that fall outside this sphere are called protected spaces.

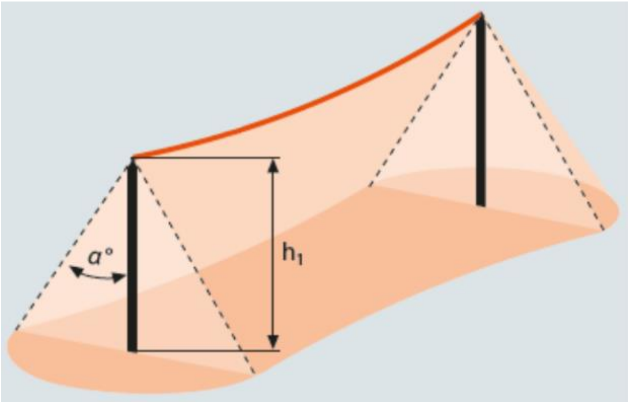

Figure 42: 3D protective angle method[111] [85]

In the event of a lightning strike, the lightning current continues in two directions in the line. At each column, a portion of the lightning current is conducted through the column toward the ground, but another portion proceeds to the next column where this phenomenon is repeated again, going "column by column" (Figure 43). This means that part of the lightning current is conducted through the column to the ground and another part continues toward the next column.

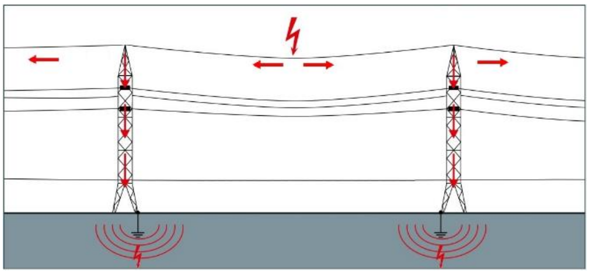

Figure 43: Schematic drawing of the protective conductor
(Edited by author of catalogue picture) [86]

In addition, there are many other problems that can occur during transmission. One is the induction effect. This means that lightning current flowing through the protective

[111] **α:** Value of the protecting angle regard to **building height (h_1)**

conductor can trigger a firing wave in the phase conductors running in parallel with it. Some cloud-to-cloud discharges can have the same effect. The induced overvoltage then reaches the power plant, substation or associated transformer as well. The appropriate protection devices, in performing their function, limit the pushing stresses and thus most likely should protect the expensive equipment. When purchasing electricity, in cases where the transformer is in the possession of the consumer, it is advisable for the owner to ensure its protection. For example, in Hungary, the Audi and Mercedes factories purchase electricity at KÖF[112]**,** and they take care of their own protection. It is important that the columns are properly grounded. Another problem is the possibility of punctures in the insulators. In the event of a lightning strike on a column, the potential difference rises to such a level that an overhang occurs on the insulator which mechanically destroys the device. Another problem is the direct lightning strike on the phase conductor. The lightning then reaches the phase conductor directly. Operators are responsible for preparing for various emergencies, protective equipment, repairs, troubleshooting and maintaining operational safety. These protection measures do not provide 100% protection, it is also necessary to build proper protection for consumers, in order to ensure safe operation and protection of human life and property.

These examples show that the transmission line is a highly exposed source of danger from lightning strikes, which must be protected in order to maintain continuous operational safety and to protect human life.

5.3.2 The pipeline protection

The purpose of pipeline transportation is to transport a gaseous or liquid substance over long distances. Such materials can be varied energy carriers or e.g.: water for district heating. During corrosion protection, the pipeline is insulated and cathodic protection is applied to the metal part. This means that 50-70 V DC is connected to the metal body of the insulated pipeline. For above-ground, underground connections (Figure 44)[113] and at the point where the pipe protrudes from the ground, there is an insulating pipe flange.

[112]**KÖF:** Medium voltage. In Hungarian: **Kö**zepes **f**eszültség. Networks of 1 to 35 kV AC are commonly referred to in practical parlance as medium voltage networks.
[113] **See:** p.126 (next page)

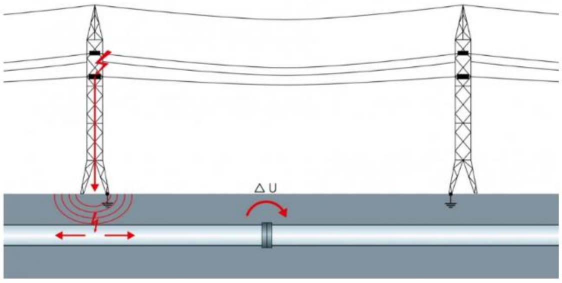

Figure 44: Underground connection for pipes [86]

Some of the return current may enter the metal elements running parallel to the rail. In this case, it causes a potential increase and corrosion in the parallel elements running in the ground. In the event of a lightning strike near the pipeline to the surface transmission line, the current flowing into the ground can create a potential funnel that induces current in the metal part of the pipeline (Figure 45). This raises the electrical potential of the insulated pipeline relative to the ground potential. This can even result in an electric shock to maintenance personnel. Another problem may be the electric rail network running near the pipeline, where the return branch of the electricity supplied on the overhead line is the rail itself at the "ground potential". Some of the return current may enter the metal elements in the ground, running parallel to the rail, causing a potential increase and corrosion.

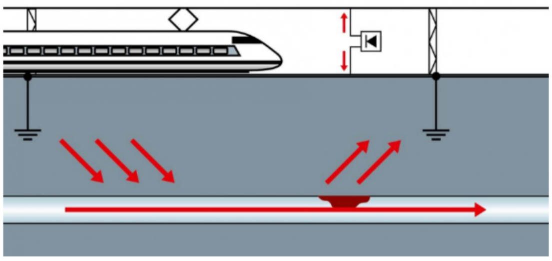

Figure 45: Current reaching and entering underground pipes [86]

Solution is e.g.: use of VCSD[114] devices. As the pipeline voltage rises, this device begins to become conductive and limits the amount of voltage – thus protecting maintenance personnel. It is possible to set a protection value below 50 V on this device. On the AC[115] side, the 50 V would be the maximum permissible voltage level.

[114] **VCSD: V**oltage-**c**ontrolled **s**mart decoupling **d**evice
[115] **AC**: **Al**terning **C**urrent

Impact to insulation materials can be avoided at the flange of the insulation pipe, both above and below ground level, with a controlled spark gap (Figure 46).

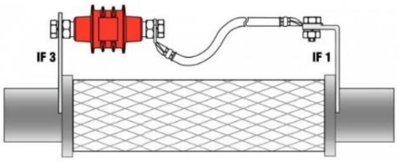

Figure 46: Types of controlled spark gaps [87] [88]

As a further rule, in the case of pipelines carrying above-ground explosive substances, clamps must be installed on the pipeline. This is not necessary for the transport of non-explosive substances, and inversely, if the pipeline transports explosive substances, only classified protective equipment can be used. The spark gaps shown in Figure 47 are of Rb[116] design. The building has also a lightning protection on it [89].

Figure 47: VCSD device in daily usage [89].

5.3.3 The protection of Data Centers

Different data centers are designed for the specific purpose of storing large amounts of data for some specific purpose, even for decades (Figure 48)[117]. Critical infrastructure participants also store large amounts of data in such data centers (e.g.: Government at Budapest and at Göd [90]).

[116] **Rb design**: a product approved for that explosive zone. In Hungarian: Az adott robbanásveszélyes zónára jóváhagyott termék.
[117] **See**: p.128 (next page)

Figure 48: TIER III[118] class servers [91] [92] [93]

These servers must operate securely. In addition to the direct impact of lightning, protection must be installed against any secondary effects of lightning. The lightning strike in the wires triggers a surge wave towards the equipment of the building which, when reached, damages the various electrical equipment. While the "lightning rod" solution protects against direct lightning strikes, overvoltage protection protects against induced (over) voltages (Figure 49). Such devices limit the voltage to a level that these devices can withstand or to some extent, the surge current is diverted to protect sensitive and important-performing devices. For this reason, the protection is built in several stages by installing several protection devices. It is important to note that overvoltages can be induced in both high-current (power cord) and low-current (communication) cables, so both networks need to be adequately protected.

Figure 49: Installed overvoltage protection devices in use.

On the left is a T3 device that can be placed behind a socket, and **on the right** is a combined device used on a desktop computer, which, in addition to power, also provides protection for the information transmission signal line. [94] [95]

[118] **TIER III**: It has multiple independent network connections. Each computing device is powered by two independent power sources. Infrastructure that can be maintained in operation with an expected availability of 99.982%.

There is a common anecdote in the industry that in Africa, a 1 meter grid can give protection against elephants, but it no longer provides protection against lions. A 10 cm grid is adequate for lions, but it does not protect against mosquitoes. The mosquito net is right for that. And the mosquito net does not provide any protection against elephants. Due to similar principles in lightning protection, it is necessary to build several levels of protection in both high-current and low-current networks. In reality, this means 3-level protection. The high energy is conducted by the T1 equipment of the first stage, the medium energy by the T2 equipment and the low energy by the T3 devices, located next to the equipment to be protected. Devices are commercially available that include all three grades. Figure 50 shows types of commercial available T1 + T2 devices.

Figure 50: T1 + T2 surge protection devices with similar properties on the market [96] [97] [98]

It is also important to mention that it is necessary to “grate” the different places. A grid or metal mesh in the wall, on the wall or even outdoors is then installed around the devices to be protected. It has two functions. One is the spatial shielding which reduces the electromagnetic field. The other is eavesdropping protection. The smaller the division of a given grid, it protects against higher the frequency. In special cases, the rooms to be protected are surrounded by finer nets than mosquito nets, and special filters are used in the various electrical wires. Where the power line crosses this grid surface, the lightning protection equipotential bonding shall be applied. Interception protection is dealt with in a separate area. Interception protection is a different technical area the electrical profession.

5.3.4 The lightning protection of tall buildings (height over 60 m)

During our travels, we usually see a water tower, a radio tower and various chimneys as tall non-residential buildings. In this section, some thoughts on lightning protection of these structures are presented.

In the example of tall buildings – as in the case of tall transmission line poles – side lightning strikes must also be taken into account. According to the MSZ EN 62305-3 standard, in the case of tall buildings the upper 20% of the height only needs to be taken into account for protection.

In Hungary, too several cases prove that in the case of tall buildings, it is also necessary to prepare for a side lightning strike. As recently mentioned in the news, one such case occurred with the Szeged Cathedral in 2018. Three lightning bolts struck the 81-meter high building, one of which was captured by a passer. The Figure 51 shows that the lightning did not strike the top, but the roof section below the top.

Figure 51: The lightning strike to roof-side of Szeged Cathedral in 2018 [99]

I would like to highlight the importance of cultural heritage lightning protection. In order to protect the cultural heritage, lightning protection is more important than the aesthetic experience/outlook of the building.

By the other hand, although the Castel Sant'Angelo[119] in Rome does not reach the height of 60 m (just 48 m in reality), its lightning protection has concrete priority against aesthetic sight (Figure 52)[120]. It can be seen that this castle has a lot of arrestors and conductors not only on the top but also on the walls. The conductor shown in Figure 52[120] is very dangerous because the conductors are too close to the visitor stairs.

[119] **Castel Sant'Angelo**, Rome, Italy (in Hungarian: Angyalvár)
[120] **See:** p.131 (next page)

Figure 52: Lightning protection parts of cultural heritage building (Picture by author, 2017)

Another interesting issue is the lightning protection issues of so-called supertall[121] and megatall[122] buildings [100] higher than 300 and 600 meters. We find them in many countries and states, and it is expected that such buildings will be built in the future at even greater heights [101].

In these cases, the natural elements of the building must be used as lightning protection traps and arrestors. E.g.: facade elements or steel structures, where continuity must be ensured (Figure 53). In these examples, lightning protection design, starting with the architect, begins at the design stage in the initial phase of building design.

Figure 53: Two pictures of the Burj Khalifa [102] [103]
On the left: metal parts of forefront, ***on the right***: during lightning

[121] **Supertall:** higher than 300 m, defined by The Council on Tall Buildings and Urban Habitat [100]
[122] **Megatall:** higher than 600 m, defined by The Council on Tall Buildings and Urban Habitat [100]

5.3.5 Some other special lightning protection solutions in practice

Certain areas and situations do not belong to the topic of critical infrastructure. Due to the technical topic of my dissertation and my personal interest, I consider it important to present examples that come under the special topic of lightning protection. The examples presented in this chapter of my dissertation are not always related to lightning protection of buildings, but rather only to lightning protection. There are buildings and situations when lightning protection already requires special solutions. These special cases are not included in the MSZ EN 62305 standard. These cases include lightning protection of bridges, boats, inflated tents, festival tents and other temporary structures. As a rule, for example, if a tent remains erected between April and October, it already requires lightning protection, or if the temporary structure stands for more than a year, it is already considered a permanent facility and requires lightning protection on it[123]. Such a tent structure (Figure 54) can be e.g.: tents set up at airports for various storage functions.

Figure 54: Inflatable tent for hundreds of people [104]

The protection of bridges is also a special situation. There are so many types of bridges, so they cannot be generalized (Figure 55)[124]. As many bridges as there are, there are also many kinds of problems, but a few general technical solutions can be formulated. One is that the earthing conductors should be placed in the pillars because e.g.: earthing wires cannot be hung in the water. Another technical solution could be to use the bridge elements as a natural drain if the bridge has a metal structure. The galvanic connection must also be solved at the different sections of the bridge at the expansion (moving) connections for equipotential bonding. For example, in the case of a pedestrian bridge, it may be necessary to create a protected area with the arrestors, or there may be a step voltage problem when the bridge reaches a different potential than the ground, so

[123] OTSZ 54/2014 (XII.05.), according to **BM decree**.
[124] **See:** p.133 (next page)

insulation must be applied when leaving the bridge, e.g.: on the lowest stairs. Another interesting situation is the case of different pedestrian bridges (overpasses) used in stadiums and arenas hosting various sporting events.

Figure 55: Széchenyi Chain Bridge[125] in Budapest in 2019, before renovation [105]

Another interesting situation is the lightning protection of ships. Ships are exposed to the risk of lightning strikes on open water, in ports and on land as well, therefore the protection of the lives of passengers and crew is very important. The number of lightning strikes is higher on land than on open water, therefore, different calculations for harbours and land values should be applied. The water is an excellent conductor, so fishing rods and masts act as arrestors. With inadequate protection, lightning will find its way towards the ship's body, and as a result a hole might be burnt into the ship's frame. On open water this is usually detectable, but with vessels left in the harbour over winter, this could result in an unnoticed sinking. For the lightning protection of ships, we should protect against the secondary effects [20] of lightning as well, which saves the sensitive equipment (e.g.: navigation, communication equipment, etc.) on board. With a ship out on open water, far away from land, the protection of navigation and communication equipment is highly important. Not only ensuring this equipment from been jeopardised is important but also the protection of stored data should be safeguarded [106]. If the body of the ship is made of metal, which is directly connected to the metal structure, there are no further actions needed for the spread of the lightning current. If lightning hits the mast, then the greater part of the lightning current and partial lightning currents will travel toward the water through the mast, the poles, the hull and the keel. If the ship's body is made of non-metallic material (wood, plastic, composite), then lightning protection measures are required. If the mast is non-conductive, then a lightning arrestor of at least 12 mm diameter should span at least 300 mm beyond the mast, and the cross-section of the

[125] **In Hungarian**: Széchenyi Lánchíd, in common parlance: Chainbridge, in Hungarian: Lánchíd

lightning conductor should be at least 70 mm^2. All connections of the lightning current should be securely bolted, riveted or welded. It is worthwhile to apply arrestors on the bends of the vessel’s body (Figure 56) and ground them in the direction of the water. If this is not possible, portable grounding may be used (Figure 56). In harbours, during anchorage, ship bodies are usually connected to ground potential with portable grounding.

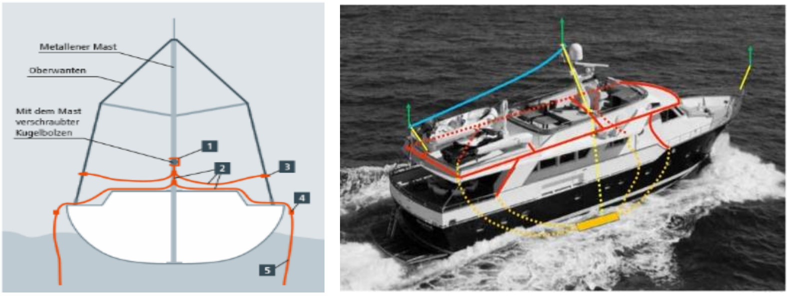

Figure 56: Arrestor plans in design and in real life for ships [107] [108]

Although it is not related to lightning protection of buildings, I would like to close my dissertation by presenting two cases of a topic I find very interesting related to lightning protection. The lightning protection covers not only the protection of buildings and vehicles but it also covers various life situations (e.g.: outdoor sports) and other devices. In my concluding example, I present two cases related to space travel.

The first topic is about spacecrafts. The first introduced incident concerns the Russian Soyuz rocket in 2019.

After the rocket was launched and it was in the air, lightning struck the rocket’s nose cone (Figure 57)[126], went through the third stage and travelled to the ground (Figure 57)[126] through the steam, which came out from the power units (engines). Initially, we would think that the rocket was harmed, but the rocket continued to travel through the air into outer space without any further problems as anticipated, because lightning protection aspects were applied during the rocket design phase.

„*A villámcsapás azután történt, hogy a rakéta sikeresen elhagyta a startállást, de nem tett kárt a Szojuzban, annak minden berendezése normálisan működött tovább és sikeresen pályára is állította a műholdat, nyilatozta Nyikolaj Nesztecsuk őrnagy, az űrkikötő főnöke*” [109]

[126] **See:** p.135 (next page)

In translation: “It was said by Major Nyikolaj Nesztecsuk, commander of the spaceport that lightning struck the rocket, but all of the equipment continued to function normally and also successfully in order to put the satellite into orbit”.

Figure 57: The lightning strike to the Soyuz rocket [109]

Another case occurred on November 14, 1969 (Figure 58). Two lightning bolts struck an American spacecraft. The first, 36 and half seconds after Apollo-12 was launched and the second, 16 seconds after that, 5.6 km high in the air. These events had critical side effects: all the existing instruments and displays went wild.

„Fogalmam sincs mi történt. Amink csak van, tönkrement”

– Report to Houston by Pete Conrad, commander of mission

In translation:

“I have no idea what happened. Whatever we have is ruined”.

Figure 58: Start of Apollo-12, 14th of November 1969 [110]

Probably, a lot of people have watched the Back to the future movie trilogy [111] [112] [113]. In this movie the actor Michael J. Fox and Christopher Lloyd are using an iconic time machine to travel through time. After they have arrived to past, they are facing with a technical problem with this machine and they need 1.21 GW [114] power to come back to present. In the past (in the movie at 1955) they don’t have any tool to provide this kind of level of power. Then comes the iconic solution: they will know when and where one (known) lightning will strike (because they are from the future) so they will catch it to get this level of power (Figure 59). So, the second topic as a closing thought – as I hear it so often – relates to some common questions:

- What is the energy delivered by the lightnings? What it could be used for?

Figure 59: Fantasy drawing of the car catching the lightning in the movie [115]

To answer this question, it must be stated that energy (E[127]) and power (P)[128] are absolutely not the same. Energy is an ability to perform work and power is the created energy or finished work in time unit. The connection between them is the time:

$$\mathbf{W} = \mathbf{E} = P \times t \rightarrow \mathbf{P} = \Delta W / \Delta t$$

As an example, we would like to heat up ‘m’ weight of water with Δt temperature, it needs a defined E energy to achieve. This can be done with a low-power machine -for example- in 10 minutes, but with a high-power machine -for example- in 30 seconds. The energy is the same, but the power of the tools is not. The power of the lightning is gigawatts [116] [117] but the elapsed time is between microseconds (!) and half second [118] and the time course of current is not linear therefore the multiplication can be divided by 2, so this gives a result of some MJ energy only which is much less than a burnout of 1 liter petrol which gives an energy of 33.6 MJ. If we turn back to the question in the movie, yes, the lightning can provide 1.21 GW power.

[127] **E means:** energy from performed work.
[128] **P means:** work performed per unit time.

5.4 Chapter summary

This chapter described the danger of lightning strikes around critical infrastructure and also considering different structures. The lightning strikes can cause a lot of damage. It is essential to protect both human life and also structures and a special infrastructures as well, so we must be prepared for this kind of danger. The chapter drew attention to the lightning protection required in these special cases. In our daily life, we do not even pay attention to lightning, only when the trouble happens. I also highlighted the importance of cultural heritage lightning protection. In order to protect the cultural heritage, lightning protection is more important than the aesthetic experience/outlook of the building.

In this chapter, I collected some examples from our daily life and highlighted the weak points of the structures and proposed some technical solution options.

Due to this, the examples were collected from this point of view.

The lightning protection of the critical infrastructures in connection with human and his built environment is top priority. The lightning protection designer should regularly pay special attention to the results of theoretical and practical sensitivity tests. Not only for the input parameters I have proven to be strong input parameter, but also for the weak input parameters that may “delegate” itself from the weak group into the strong group (e.g.: non-standard building parameters like height, explosive places, pure metal structures etc.).

In my opinion, one of the keys to success is the initiating cooperation among the lightning protection designer, the fire protection designer and the architectural team which is an essential necessity during the design process for structures.

SUMMARY OF DISSERTATION CONCLUSIONS

Checking my hypotheses

Checking my formulated hypotheses during my full research process harmonising both my research questions and goals added to results which are supported by my calculations based on my self-developed IT Excel program too, I am able to confirm two of them and I had to discard two due to loss of relevance.

The assessments regarding my introduced hypotheses are provided in Table 19 as follows:

HYPOTHESES	RESULTS
H1: During lightning protection risk management of MSZ EN 62305-2:2012, **not all input parameters may affect the output equally**, therefore they **may be grouped** into strong and non-strong categories.	**Proven**
H2: Within the strong parameters group, **some extremely strong parameters may be identified**.	**Proven**
H3: Final Draft IEC (FDIS) 62305-2:2018 **incorrectly takes into account** the time spent on the type of roofs where persons can stay any time, but not all protection measures have been taken into account in order to reduce human grouping in different cases.	**Had to reject**
H4: The input parameters of the Final Draft IEC (FDIS) 62305-2:2018 **may also be grouped into strong and non-strong categories.**	**Had to reject**

Table 19: My hypotheses (Edited by author)

My new scientific results in general

The topic of my research was to examine the changes in the output value resulting from the elemental changes of the input variables within the lightning protection risk analysis of buildings. Based on the MSZ EN 62305-2:2012 standard containing lightning protection risk analysis which contains the calculation methods I have created a self-developed IT program with MS Office Excel circumstances with which I was able to carry out my research. I investigated the effect of changing the values of the input parameters on the output lightning protection adequacy and the pre-construction lightning protection measures that make it possible to build the appropriate lightning protection faster, simpler and in some cases more economically. My experience in practice has confirmed my idea that certain lightning protection measures can only be carried out on a “design table” in the planning phase before the start of construction and that these solutions cannot be replaced afterwards. Prior to the different lightning protection risk management of the already constructed buildings, I assumed that not all input parameters affect the output equally, so strong and weak input parameters can be identified. Knowing such detected parameters, which was also confirmed by practical experience, it was possible to implement preliminary lightning protection measures. The design engineers involved in the profession welcomed both the input parameter grouping list and my self-developed IT program which I created that can perform the sensitivity test in a few seconds.

Therefore, my new scientific results as follows:

T1: *I proved with scientific methods that in the case of risk management according to the MSZ EN 62305-2:2012 standard,* ***not all input parameters affect the output equally****. Therefore,* ***they can be grouped*** *into strong and non-strong categories.*

I calculated the slopes about the value sets of function for the 40 input parameters of the currently valid standard of MSZ EN 62305-2:2012. Both during my comparative analysis of the common results of the theoretical and practical sensitivity tests and focused on their common effects on the output, **8 pieces of input parameters are dominant based on the practical sensitivity test** (Table 20[129]). These input parameters are the members of the strong group of input parameters.

[129] **See:** p.140 (next page)

RESULTS OF SENSITIVITY TESTS					
Theoretical test			Practical test		
Condominium	Office Building	Assembly Plant	Condominium	Office Building	Assembly Plant
L_O	L_O	L_O	L_O	L_O	L_O
r_f	r_f	L_F	r_f	r_f	r_f
L_F	L_F	r_f	L_F	L_F	L_F
r_{tu} (inside of bld)	r_{tu} (inside of bld)	LPS	LPS	LPS	LPS
LPS	LPS	r_P	r_P	r_P	r_P
r_P	r_P	r_{tu} (inside of bld)	C_D	C_D	C_D
C_D	$C_{E/T}$	C_D	N_G	N_G	N_G
N_G	C_D	N_G	h_Z (inside of bld)	h_Z (inside of bld)	h_Z (inside of bld)
h_Z (inside of bld)	N_G	$C_{E/T}$			
r_{ta} (outside of bld)	$C_{E/P}$	$C_{I/T}$			
$C_{E/P}$	h_Z (inside of bld)	$C_{E/P}$			
$C_{I/P}$	$C_{I/T}$	$C_{I/P}$			
$C_{E/T}$	$C_{LD/T}$	$C_{LD/T}$			
$C_{I/T}$	$C_{T/T}$	$C_{T/T}$			
$C_{LD/P}$	$P_{LD/T}$	$P_{LD/T}$			
$C_{T/P}$	t_Z (inside of bld.)	h_Z (inside of bld)			
$P_{LD/P}$	H (height)	r_{ta} (outside of bld)			
H (height)	$C_{I/P}$	$C_{LD/P}$			
$C_{LD/T}$	$C_{LD/P}$	$C_{T/P}$			
$C_{T/T}$	$C_{T/P}$	$P_{LD/P}$			
$P_{LD/T}$	$P_{LD/P}$	H (height)			
t_Z (inside of bld.)	r_{ta} (outside of bld)	t_Z (inside of bld.)			
		h_Z (outside of bld)			
		W (width)			
		L (lenght)			

Table 20: Final results of sensitivity tests (Edited by author)

L_O – Internal System Failure (only hospital and explosion dangerous building)

r_f – Factor reducing loss depending on risk of fire

L_F – Physical damage related to the purpose of the building

LPS– Lightning protection system (class)

r_P – Fire protection measures

C_D – Location factor

N_G – Number of dangerous events

h_Z – Type of special hazard (inside of building)

The another input parameters are forming the group (set) of non-strong input parameters. Their impact is virtually negligible but their control during the design process may be warranted continuously. During my research, this was only minimally practically necessary in the case of the three examined structures. However, when construction and design take place roughly simultaneously and practical solutions generate new design needs, it is possible that even a continuous change in the value of a previously weak input parameter (e.g.: H = building height) "delegates" itself into the strong input parameters group, possibly into extremely strong input parameters group as well. This happened several times during the construction of the Burj Khalifa[130] when the practical solution of an architectural or technical problem made it possible to reach another significant height.

Therefore, **my T1 thesis is proved** by my results of my scientific research process, **which is supported by my [P3][131] [P7][131] publications.**

T2: *I proved with scientific methods and supported by the results of my calculations that* ***two extremely strong input parameters can be identified*** *within the group of strong input parameters designed by me (*L_O[132]*,* r_f[133]*).*

The theoretical and practical sensitivity testing required 17 280 pieces of each calculations for the selected three building types with variation cases of some selected strong input parameters. I proved by a mathematical method and confirmed by performing the 51 840 pieces common calculations that in the case of all three building types the **L_O and r_f** input parameters **are the extremely strong input parameters**. This means that their changes must be given special attention in the human decision-making process during the controlling of the design because their unit change has a decisive effect on the output, so they immediately result an "inadequate" rating for lightning protection of the examined building. I theoretically proved and substantiated the fact applied in practice that it is expedient to intervene in the design process of buildings. In order to ensure the "adequacy" of the lightning protection of the building, **the initiating cooperation** among the lightning protection designer, the fire protection designer and the architectural team is an **essential necessity**. Both the changes of the integrated technical and architectural solutions of the lightning and fire protection and the applied tools, materials, procedures may have economic consequences during their co-operation of the common human decision process.

Therefore, **my T2 thesis is proved by** my results of my scientific research process, which is **supported by my [P3][131][P7][131] publications.** During my research process, I performed calculations for my hypothesis 3 (H3), and **published my results**, in which I also pointed out a specific calculation error **[P3][131] [P9][134]**. In the standardization process, based on the results of consultations between national and international professional

[130] **Burj Khalifa**: Dubai, United Arabic Emirates. Height: 828 m, the tallest building in the world, 2020.
[131] **See:** p.153
[132] **L_O**: internal system failure (only hospital and explosion dangerous building).
[133] **r_f**: factor reducing loss depending on risk of fire.
[134] **See:** p.154

working groups, a number of problems arose up, so the new draft version of the standard was voted down at the end of 2018, so it was not issued[135]. Unfortunately, the research of my hypothesis 4 (H4) which was derived from it has also become obsolete. **In the absence of a national codification of the standard, I could not formulate a scientific thesis regarding my H3 and H4 hypotheses.**

My new scientific results (in Hungarian) as follows:

T1: *Tudományos módszerekkel igazoltam, hogy MSZ EN 62305-2:2012 szabvány szerinti kockázatkezelés esetében* ***nem minden bemeneti paraméter hat egyformán a kimenetre****, ezért* ***lehet őket csoportosítani erős és nem erős kategóriákba****.*

Ezt követően tovább vizsgáltam az erős paraméterek csoportját és megállapítottam, hogy ezen csoport paraméterei tovább csoportosíthatóak erős és kiemelten erős paraméterekre.

T2: *Tudományos módszerekkel igazoltam és a számításaim eredményeivel alátámasztottam, hogy az általam kialakított erős bemeneti paraméterek csoportján* ***belül azonosítható további két kiemelten erős*** *bemeneti paraméter* ***(Lo[136], r_f[137]*** *).*

A kutatási tevékenységem során a **H3 hipotézisemre vonatkozó számításokat elvégeztem, eredményeimet publikáltam,** amelyben egy konkrét számítási hibára is rámutattam **[P3]**[138]. Szabványosítási folyamat során a nemzeti és nemzetközi szakmai munkacsoportok egyeztetéseinek eredményei alapján számos probléma merült fel, ezért **a szabvány új tervezete** a bizottságokban **leszavazásra került** 2018 végén, így az nem került kiadásra[135]. Ebből adódóan az addig elért eredményeim a disszertációm szempontjából okafogyottá váltak és sajnos aktualitását vesztette az ebből származtatott H4 hipotézisem is. **A szabvány nemzeti kodifikációjának hiányában tudományos tézist nem fogalmazhattam meg a H3 és H4 hipotéziseimre vonatkozóan.**

[135] **Giving** to national consultation and debate **again in Jan 2021**.
[136] **Lo**: internal system failure (only hospital and explosion dangerous building).
[137] **r_f**: factor reducing loss depending on risk of fire.
[138] **See:** p.153

Recommendations for future usage

In our accelerated world, there is also less and less time to create technical structures. The technical requirements are becoming more complex and appearing at an ever higher technical level that must be met in terms of protection of life and property. This makes the design and implementation phase slower and more complex. The continuous use of continuously researched results in practical life is essential. Both my achievements and my theses can be used in the industry and in the standardization process as well as in further research related to lightning protection and in the fields of education.

In light of this, my recommendation can be formulated as follows:

- In the controlling processes already used in the design of buildings **in the industry**, the design process can be optimized by grouping the input parameters belonging to the legal and competence of the lightning and fire protection designers. By possibly changing the input parameters, the design process can be optimized too which on one hand reduces design time and on the other hand can ensure cost-effective simultaneous compliance with safety, the lightning and fire protection in the human decision-making system of the applicable engineering solutions for infrastructures as well. Encourage the members of the industry to invest into innovative developments and also for production of **high-quality** lightning protection equipment. Encourage them to take into account the requirements of standards, electrical directives, industrial regulations as mandatory requirements in their documentation on compliance with work, accident, fire, and safety regulations [122].

- My results can support the **standardization process** to be easier, more transparent, and more efficient by focusing on detected and grouped strong / extremely strong input parameters. It guides thinking in the theoretical and practical use of the requirements of the standard in force at any time, in the creation of new standards, thus supporting the dynamic system of national and international standardization processes. Dissemination presentations at national and international standardization conferences, professional events and in standardization bodies, committees[139], as well as in their sub-committees & working groups[140], can expand the knowledge and horizons of registered participants, and can contribute to the effective and efficient professional work of lightning protection standardization working groups [123].

- Both in the **national and international research process**, my results can inspire the researchers to explore new connections with the risk-based approach to lightning protection of structures, to research optimal material-technical solutions and their economic implications due to the simultaneous impact assessment of the input and output parameters defined in the standards. My publications in the database of the Hungarian Science Bibliography (HSB)[141] also contributes to the use and expansion of the domestic and international standardization knowledge base [124].

- **In the fields of education**, my results can be incorporated into the basic professional topics of domestic [125] and international university education during institutional training, on one hand, also into the order of retraining, and on the other hand, further training in the course system as well. Due to the individual needs (e.g.: multinational companies, large industrial companies, etc.), specific planning controlling processes of lightning protection design can be optimized on site by using mobile training groups.

- By any other parts, the calculations should be performed with a computer program developed for this purpose, and the results should be recorded and collected in a **reachable database**.

[139] **e.g.**: **IEC/TC 81**: **I**nternational **E**lectrotechnical **C**ommittee/**T**echnical **C**ommittee-81: Lightning Protection; **MSZT/MB 841**: **M**agyar **Sz**abványügyi **T**estület / **M**űszaki **B**izottság-841
[140] **e.g.**: **MT-**21:**M**aintennance **T**eam- 21, sub-committee of TC 81
[141] **HSB:** **H**ungarian **S**cience **B**ibliography, in Hungarian: **M**agyar **T**udományos **M**űvek **T**ára (MTMT)

In Europe, there is no public awareness how dangerous a lightning strike is, our built (urban) environment gives people a false security and a false feeling about it. This modern society anesthetized the sense of danger and in my point of view, this kind of danger will come to the fore again due to the popularity of e.g.: loft apartments and skybars. This presumed popularity will continue in the future about this new kind of construction will draw attention to the danger of lightning. It would be important to be in the public consciousness that lightning strike can make a serious danger source among us in our everyday life.

As closing thoughts of my dissertation, I would like to highlight three matters as follows:

Firstly, as mentioned above, the places with open rooftops will be more popular in our daily lives, so danger of lightning should be in the public consciousness in order to protect the human lives.

Secondly, as mentioned in section 3.3.2[142], the draft version of standard calculates with the double value of number of lightning strikes ($N_{SG} = N_G \times 2$). If it will be introduced, it will have a huge impact for the designers. Unlike usual current practice, it is likely that one-level higher LPS class will be required for the same type of buildings which will have both economical and technical effects for the lightning protection solutions.

Finally, in my point of view I think that the importance of the topic justifies that the lightning protection is a very important part of our human life in connection with our natural environment. Based on all this, it can be stated that my achievements in the field of protection of human life and property can be widely used, they are closely related to the presented areas which simultaneously and mutually intersect each other, generating further new theoretical and practical solutions and research opportunities regarding technical interdisciplinary relationship in relation to man and his built environment which are also embodied not only in the lightning protection of structures but also in the standardization with regard to the safety of human life and property.

[142] **See:** p.106-107

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All of my publications and presentations are listed in MTMT (HSB) system.

ABBREVIATIONS

AC	Alterning Current
AFDD	Arc fault detection device
AFDD+ tool	Tools which includes the overcurrent protection, circuit breaker and arc fault protection
ÁNTSZ	Public Health Authority = Állami Népegészségügyi és Tisztiorvosi Szolgálat
BM	Ministry of the Interior = Belügyminisztérium
CCTV	Closed-circuit television

CEN European Committee for Standardization (abbreviation in French)

CENELEC European Committee for Electrical Standardization (abbrev. in French)

CWC Composite Wing Center

DC Direct Current

DIN Deutsches Institut für Normung

DKE/AK Deutsche Kommission Elektrotechnik

DKE/AK EMOBILITY.60 Ladeinfrastruktur Elektromobilität

DM Disaster Management

EN European Norm

EN IEC Standard adopted by the European Union from the IEC without amendment

FDIS Final Draft International Standard

GDV Gesamtverband der Deutschen Versicherungswirtschaft

ICT Information and communications technology

IT Information technology

IEC International Electrotechnical Commission

IEC/TC Technical committees of IEC

KÖF Medium voltage = középfeszültség

LPS Lightning Protection System

MABISZ Association of Hungarian Insurance Companies = Magyar Biztosítók Szövetsége

MSZ Hungarian Standard = Magyar Szabvány

MSZ EN Standard issued by and adopted from the European Union

MSZ IEC A standard adopted directly from the IEC

MSZ EN IEC A standard adopted by the European Union that the EU has adopted in advance from the IEC

MSZ EN HD Harmonized documents (standard), e.g.: MSZ HD 60364-4-443 or MSZ HD 60364-5-534

MSZT Magyar Szabványügyi Testület

MSZT/MB 841 Magyar Szabványügyi Testület 841-s számú műszaki bizottsága

MTMT Magyar Tudományos Művek Tára in Hungarian (HSB: Hungarian Science Bibliography in English)

NASA National Aeronautics and Space Administration, Nemzeti Repülési és Űrhajózási Hivatal (Amerika)

NV Lightning protection according to the norm = Norma szerinti villámvédelem

OKF Országos Katasztrófavédelmi Főfelügyelőség, National Disaster Management Inspectorate (NDMI in English)

OTSZ Országos Tűzvédelmi Szabályzat, National Fire Protection Regulations

ÖTM Önkormányzati és Területfejlesztési Minisztérium, Ministry of Local Government and Regional Development

PVC Polyvinyl chloride

TvMI Tűzvédelmi és Műszaki Irányelvek, Fire and Technical Guidelines

TWS Thunder Warning System

UV Ultraviolet

VCSD Voltage-controlled smart decoupling device

VdS Vertrauen durch Sicherheit

VIKOP Villámvédelmi kockázatkezelő program

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ANNEXES

ANNEX I. – STRUCTURE OF MY SELF-DEVELOPED IT PROGRAM

My self-developed IT program is MS Excel based on featuring with Visual Basic for Applications (VBA). It contains a sheet where the input data needs to be entered.

For example, the details of power and telecom lines are entered in Table I.:

Input	Comment			Value
		Power line		
Lengh (m)			L_L	200
Installation factor			C_I	0,5
Environmental factor			C_E	0,5
Transformator factor			C_T	1
Cable shielding			R_S	
Shielding, grounding, isolaton			C_{LD}	1
			C_{LI}	1
		Telecom line		
Lengh			L_L	100
Installation factor			C_I	0,5
Environmental factor			C_E	0,5
Transformator factor			C_T	1
Cable shielding			R_S	
Shielding, grounding, isolaton			C_{LD}	1
			C_{LI}	1

Table I: Entering data into input fields in my self-developed IT program
(Edited by author)

Some data can be entered manually but others can be selected by a dropdown box, shown in Figure I. The contents of the dropdown boxes were set by me due to the specification of the MSZ EN 62305-2:2012 standard. E.g.: values of input parameter r_p are stored in dedicated fields in my Excel file then a dropdown box is using only these values for selection. On one hand, it makes the selection much faster and more comfortable, and on the other hand, only specified data can be selected avoiding the intake of false data.

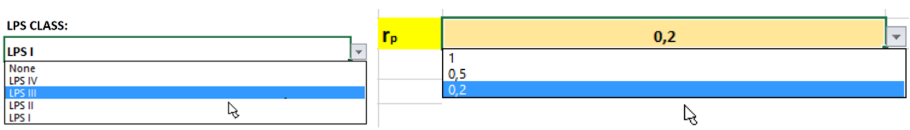

Figure I: Some dropdown boxes in my Excel file
(Edited by author)

The order of input parameters was setup due to the methology of DehnSupport software so the input data order is nearly the same (Table II.).

	Input		Value
Épület	**Environment and structure charasteristics**		
	Structure lengh (m)	L	20
	Structure width (m)	W	40
	Structure height (m)	H	10
	Thunderstrom days per year	T_D	
	Lightning ground flash density	N_G	1,75
	Location factor	C_D	1
	Adjacent structure lengh (m)- Power Line	L_J	
	Adjacent structure width (m)- Power Line	W_J	
	Adjacent structure height (m)- Power Line	H_J	
	Adjacent structure lengh (m) - Telecom Line	L_J	
	Adjacent structure width (m) - Telecom Line	W_J	
	Adjacent structure height (m) - Telecom Line	H_J	
	Thunderstrom days per year in adjacent structure	T_{DJ}	
	Lightning ground flash density in adjacent area	N_{GJ}	
Csatl. vezetékek	**Line parameters**		
	Internal systems connected to power and telecom lines?		No
	Power line		
	Lengh (m)	L_L	200
	Installation factor	C_I	1
	Environmental factor	C_E	0,1
	Transformator factor	C_T	1
	Cable shielding	R_S	
	Shielding, grounding, isolaton	C_{LD}	1
		C_{LI}	1
	Telecom line		
	Lengh	L_L	1000

Table II: Order of input parameters (Edited by author)

After all data have been entered, the practical sensitivity test starts. It is done by my self-developed macros (Figure II.).

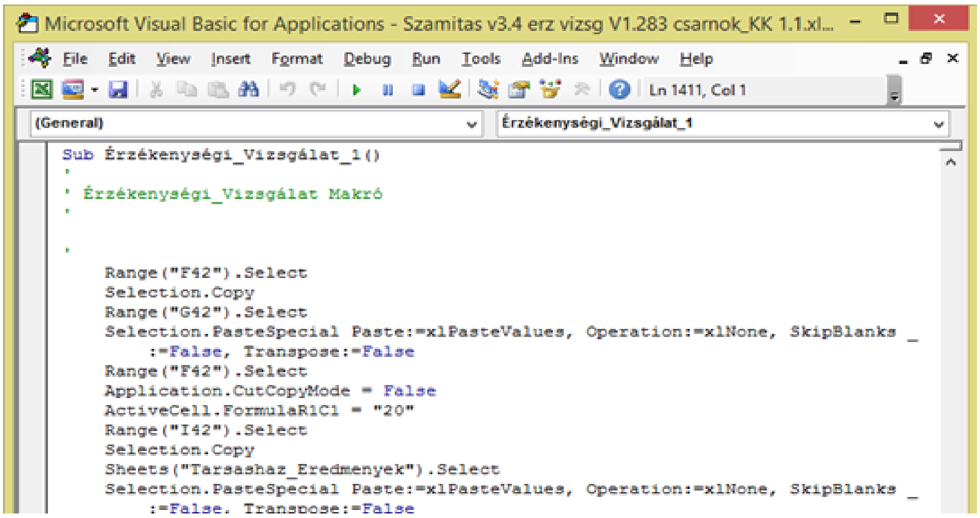

Figure II: Part of code of my macro "Érzékenységi_Vizsgálat_1" (Edited by author)

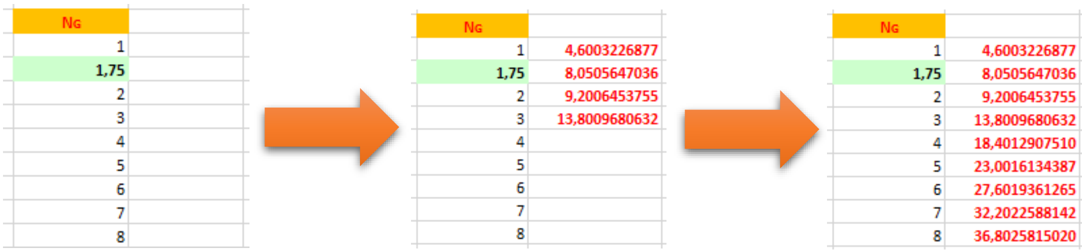

Figure III: My macros calculating the R_1 data with different input parameter **In left columns:** Input parameter values**, in the right columns**: calculated R_1 values.
(Edited by author)

After executing the macro(s), my macro enters a desired value into the input field of a parameter and copies the calculated R_1 output into the collection sheet (Figure III).Then it enters the **next** value of the parameter into the input field and copies the newly calculated R_1 output into the collection sheet, below the previous output value step-by-step in order. After finishing the calculation of the R_1 output based on all input values, it replaces back the original value of the parameter (as shown with green background in Figure III.) and continues this process with the next parameter with its all values. This is going till the last selected input parameter for its all values. After finishing this, all data is copied to a common sheet forming the result of the selected observed building. These activities needed 51 840 pieces variated calculations. The new variation of input parameters (parameter set) needs new calculations.

My Annex III. has been created with this method, containing three sheets of results of my selected buildings (condominium, office building and assembly plant).

These common sheets are collected in one Excel file forming the Annex III.[143]

[143] The Annex III. contains six sheets in one MS Excel file which is stored on CD attached at the end of the dissertation in the pocket.

ANNEX II. – RESULTS OF THE THEORETICAL SENSITIVITY TEST

The Annex II. contains the slopes about value sets of function for different input parameters starting from the “no LPS” column to “LPS I” column for the three chosen buildings (Table III-IV-V) as follows:

Condominium Parameters	Degrees at no LPS	Degrees at LPS IV	Degrees at LPS III	Degrees at LPS II	Degrees at LPS I
L_O	89,99	89,99	89,99	89,99	89,99
r_f	89,92	89,60	89,23	88,43	86,16
L_F	89,64	88,00	86,16	82,24	71,46
r_{tu} (inside of building)	88,19	80,01	71,29	55,48	30,57
LPS	83,10	81,74	82,49	82,17	-----
r_P	82,90	55,10	36,71	20,15	8,48
C_D	81,74	54,05	34,58	19,02	7,85
N_G	77,73	39,38	23,12	11,87	4,88
h_Z (inside of building)	57,84	15,85	8,40	4,15	1,69
r_{ta} (outside of building)	57,84	15,85	8,40	4,15	1,69
$C_{E/P}$	57,00	4,40	4,40	1,76	0,88
$C_{I/P}$	57,00	4,40	4,40	1,76	0,88
$C_{E/T}$	37,59	2,20	2,20	0,88	0,44
$C_{I/T}$	37,59	2,20	2,20	0,88	0,44
$C_{LD/P}$	37,59	2,20	2,20	0,88	0,44
$C_{T/P}$	37,59	2,20	2,20	0,88	0,44
$P_{LD/P}$	37,59	2,20	2,20	0,88	0,44
H (height)	28,85	6,28	3,15	1,57	0,63
$C_{LD/T}$	21,05	1,10	1,10	0,44	0,22
$C_{T/T}$	21,05	1,10	1,10	0,44	0,22
$P_{LD/T}$	21,05	1,10	1,10	0,44	0,22
t_Z (inside of bld.)	18,33	3,38	1,76	0,86	0,35
h_Z (outside of building)	4,54	0,81	0,42	0,20	0,08
W (width)	3,30	0,66	0,33	0,16	0,06
L (lenght)	3,08	0,61	0,30	0,15	0,06
P_{TA}	1,00	0,17	0,09	0,04	0,01
n_Z - num. of persons in bld.	0,29	0,05	0,02	0,01	0,00
Power line lenght	0,22	0,01	0,01	0,00	0,00
Telecom line lenght	0,22	0,01	0,01	0,00	0,00
P_{TU}	0,01	0,00	0,00	0,00	0,00
$C_{LI/P}$	0,00	0,00	0,00	0,00	0,00
$C_{LI/T}$	0,00	0,00	0,00	0,00	0,00
$K_{S3/P}$	0,00	0,00	0,00	0,00	0,00
$K_{S3/T}$	0,00	0,00	0,00	0,00	0,00
$P_{LI/P}$	0,00	0,00	0,00	0,00	0,00
$P_{LI/T}$	0,00	0,00	0,00	0,00	0,00
$P_{/SPD/P}$	0,00	0,00	0,00	0,00	0,00
$P_{/SPD/T}$	0,00	0,00	0,00	0,00	0,00
$U_{W/P}$	0,00	0,00	0,00	0,00	0,00
$U_{W/T}$	0,00	0,00	0,00	0,00	0,00

Table III: Slopes about value sets of function of input parameters for the Condominium in degrees (°) (Edited by author)

Office Building Parameters	Degrees at no LPS	Degrees at LPS IV	Degrees at LPS III	Degrees at LPS II	Degrees at LPS I
L_O	89,99	89,99	89,99	89,99	89,99
r_f	89,93	89,64	89,31	88,60	86,56
L_F	89,35	86,44	83,15	76,32	59,02
r_{tu} (inside of building)	86,77	72,69	58,95	39,32	18,37
LPS	83,73	82,66	83,24	83,00	-----
r_P	83,58	58,15	39,79	22,33	9,45
$C_{E/T}$	82,91	21,91	21,91	9,14	4,60
C_D	82,66	57,23	37,84	21,23	8,83
N_G	78,87	42,61	25,46	13,21	5,44
$C_{E/P}$	72,74	9,14	9,14	0,36	0,18
h_Z (inside of building)	60,58	17,79	9,43	4,68	1,90
$C_{I/T}$	58,14	4,60	4,60	1,84	0,92
$C_{LD/T}$	38,82	2,30	2,30	0,92	0,46
$C_{T/T}$	38,82	2,30	2,30	0,92	0,46
$P_{LD/T}$	38,82	2,30	2,30	0,92	0,46
t_Z (inside of bld.)	36,46	7,61	3,95	1,95	0,79
H (height)	30,96	6,84	3,43	1,71	0,68
$C_{I/P}$	17,84	0,92	0,92	0,36	0,18
$C_{LD/P}$	17,84	0,92	0,92	0,36	0,18
$C_{T/P}$	17,84	0,92	0,92	0,36	0,18
$P_{LD/P}$	17,84	0,92	0,92	0,36	0,18
r_{ta} (outside of building)	15,03	2,78	1,44	0,71	0,28
L (lenght)	3,68	0,73	0,36	0,18	0,07
W (width)	3,22	0,64	0,32	0,16	0,06
h_Z (outside of building)	1,53	0,27	0,14	0,07	0,02
P_{TA}	0,16	0,03	0,01	0,00	0,00
n_Z - num. of persons in bld.	0,12	0,02	0,01	0,00	0,00
Power line lenght	0,09	0,01	0,01	0,00	0,00
Telecom line lenght	0,04	0,01	0,01	0,00	0,00
P_{TU}	0,01	0,00	0,00	0,00	0,00
$C_{LI/P}$	0,00	0,00	0,00	0,00	0,00
$C_{LI/T}$	0,00	0,00	0,00	0,00	0,00
$K_{S3/P}$	0,00	0,00	0,00	0,00	0,00
$K_{S3/T}$	0,00	0,00	0,00	0,00	0,00
$P_{LI/P}$	0,00	0,00	0,00	0,00	0,00
$P_{LI/T}$	0,00	0,00	0,00	0,00	0,00
$P_{/SPD/P}$	0,00	0,00	0,00	0,00	0,00
$P_{/SPD/T}$	0,00	0,00	0,00	0,00	0,00
$U_{W/P}$	0,00	0,00	0,00	0,00	0,00
$U_{W/T}$	0,00	0,00	0,00	0,00	0,00

Table IV: Slopes about value sets of function of input parameters for the Office Building in degrees (°)

Assembly Plant Parameters	Degrees at no LPS	Degrees at LPS IV	Degrees at LPS III	Degrees at LPS II	Degrees at LPS I
L_O	89,99	89,99	89,99	89,99	89,99
L_F	89,98	89,89	89,80	89,58	89,01
r_f	89,91	89,45	89,01	87,94	85,09
LPS	89,23	88,76	89,05	88,94	-----
r_P	89,18	84,53	80,25	70,29	49,36
r_{tu} (inside of building)	89,16	84,40	80,03	69,86	48,68
C_D	88,76	83,84	77,82	66,66	42,83
N_G	88,57	80,51	73,31	57,98	33,71
$C_{E/T}$	88,21	58,04	58,04	32,62	17,78
$C_{I/T}$	88,21	58,04	58,04	32,62	17,78
$C_{E/P}$	86,43	38,71	38,71	17,78	9,10
$C_{I/P}$	86,43	38,71	38,71	17,78	9,10
$C_{LD/T}$	86,43	38,71	38,71	17,78	9,10
$C_{T/T}$	86,43	38,71	38,71	17,78	9,10
$P_{LD/T}$	86,43	38,71	38,71	17,78	9,10
h_Z (inside of building)	85,83	63,89	48,68	28,61	12,81
r_{ta} (outside of building)	83,07	50,76	34,32	18,12	7,77
$C_{LD/P}$	82,89	21,84	21,84	9,10	4,58
$C_{T/P}$	82,89	21,84	21,84	9,10	4,58
$P_{LD/P}$	82,89	21,84	21,84	9,10	4,58
H (height)	71,37	30,69	16,53	8,44	3,39
t_Z (inside of bld.)	70,73	23,05	13,34	1,47	1,16
h_Z (outside of building)	58,72	13,76	7,77	3,74	1,56
W (width)	17,78	3,66	1,83	0,91	0,36
L (lenght)	14,38	2,93	1,46	0,73	0,29
P_{TA}	5,17	0,77	0,43	0,20	0,08
P_{TU}	3,92	0,58	0,32	0,15	0,06
Power line lenght	0,91	0,04	0,04	0,01	0,00
Telecom line lenght	0,91	0,04	0,04	0,01	0,00
n_Z - num. of persons in bld.	0,70	0,10	0,05	0,20	0,10
$C_{LI/P}$	0,00	0,00	0,00	0,00	0,00
$C_{LI/T}$	0,00	0,00	0,00	0,00	0,00
$K_{S3/P}$	0,00	0,00	0,00	0,00	0,00
$K_{S3/T}$	0,00	0,00	0,00	0,00	0,00
$P_{LI/P}$	0,00	0,00	0,00	0,00	0,00
$P_{LI/T}$	0,00	0,00	0,00	0,00	0,00
$P_{/SPD/P}$	0,00	0,00	0,00	0,00	0,00
$P_{/SPD/T}$	0,00	0,00	0,00	0,00	0,00
$U_{W/P}$	0,00	0,00	0,00	0,00	0,00
$U_{W/T}$	0,00	0,00	0,00	0,00	0,00

Table V: Slopes about value sets of function of input parameters for the Assembly Plant in degrees (°) (Edited by author)

ANNEX III. – SUMMARY FILE OF MY RESULTS ABOUT THE PRACTICAL SENSITIVITY TEST FOR SELECTED BUILDINGS

The Annex III. contains six sheets in one MS Excel file which is stored on CD attached at the end of the dissertation in the pocket.

The first pair of sheets contain the results about the condominium, the second pair of sheets contain the results about the office building and the third pair of sheets about the assembly plant as well. Sheets are tagged with different colours as well.

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I dedicate my doctoral dissertation and
my work to my parents and to my former teachers
who continuously inspired and orinted me for my studies as well.

The Author

Budapest, 20th of March, 2021

(doctoral student, author of dissertation)

Óbudai Egyetem

N Y I L A T K O Z A T

A MUNKA ÖNÁLLÓSÁGÁRÓL,

AZ IRODALMI FORRÁSOK, MEGFELELŐ MÓDON TÖRTÉNT IDÉZÉSÉRŐL

Alulírott **Kasza Zoltán** kijelentem, hogy a

LIGHTNING PROTECTION RISK ANALYSIS FOR STRUCTURES

című benyújtott doktori értekezést **magam készítettem**, és abban csak az irodalmi hivatkozások listáján megadott forrásokat használtam fel. Minden olyan részt, amelyet szó szerint, vagy azonos tartalomban, de átfogalmazva más forrásból átvettem, a forrás megadásával egyértelműen megjelöltem.

Budapest, 2021. március 20 -n.

(Kasza Zoltán)
szerző

20th March 2021, Budapest

Óbuda University

<u>S T A T E M E N T</u>

FOR THE INDEPENDENCE OF WORK, LITERATURE RESOURCES

OF THE QUOTE IN AN APPROPRIATE WAY

<u>As the author, **Mr. Zoltan KASZA** takes an official statement as follows:</u>

a) **Firstly**, this ”**Lightning protection risk analysis for structures**” doctoral dissertation is my own fully exclusive work;

b) **Secondly**, both the used sources and references are marked and listed correctly. All parts that I have taken from another source, either verbatim or in the same content but reworded are clearly marked with the source;

c) **Finally**, all my scientific results and theses of my resource process are the results of my own work.

written by:

…………………………………..
(Mr. Zoltán KASZA)
author