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LIGHTNING PROTECTION OF BUILDINGS: ITS TYPES, SOLUTIONS AND CHOICE OPTIONS

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Abstract. Lightning safety in private and public buildings is a seriously evaluated issue that requires an appropriate and safe long-term solution to protect property from destruction during or due to the consequences of a lightning strike. Relatively easy-to-replace home appliances such as a TV-set or a vacuum cleaner, larger and more expensive appliances such as a heat pump, alarm system or antennas can be damaged from a lightning strike. The aim of the study is to explore the ways of lightning protection in buildings and to develop recommendations for its effective use. Lightning protection is part of a set of electrical assembly and fire protection measures of property, which are performed during construction or renovation of property and the installation thereof is determined by the regulatory framework of the Republic of Latvia. Over time, two types of lightning protection systems have been developed: the classic or passive lightning protection system, which, if hit by lightning, captures and drains the electrical charge generated by lightning to the ground, and the active lightning protection system, which attracts the electricity generated by lightning with energy generated by itself and then drains the charge to the ground. Consequently, both lightning protection systems can be considered to have their advantages and disadvantages, so it is necessary to assess the choice of the most appropriate protection system on a case-by-case basis, also taking into account the criteria such as the complexity of the building project, the size and accessibility of the protected area and the cost of each individual site.

***Keywords**: Active lightning protection system, lightning protection, normative enactments, passive lightning protection system.*

INTRODUCTION

Lightning safety in private and public buildings is a seriously evaluated issue that requires an appropriate and safe long-term solution to protect property from destruction during or due to the consequences of a lightning strike, as lightning is one of nature's most powerful and destructive phenomena. Electrical discharge strength during a lightning strike can reach as much as 100 000 A of force, heat the surrounding air to 27 760 °C and cause electrical device damage, fire, as well as severe injuries and even death to humans and animals (Ozoliņš, 2004). Traditionally, in Latvia the storm season started only in May and was particularly active during the summer months. Possibly due to climate change and other factors, now lightning accidents are also experienced in the autumn and winter period. Information compiled by the largest Latvian insurance agency "Balta" shows that the number of lightning accidents is increasing on average by 25 % each year and the most frequent lightning accidents have occurred in the regions of Talsi (10 %), Madona (5 %), Riga (5 %), Tukums (5 %), Garkalne (5 %) and Daugavpils (4 %) (Balta, 2015).

Lightning strike can damage not only a relatively easy-to-replace household appliance such as a TV-set or a vacuum cleaner, but also larger and more expensive appliances such as a heat pump, alarm system or antennas (Standards LVS EN 50468, 2016). To protect oneself and property during a storm, it is primary to take care of lightning-conductors and keep one's home electrical system resistant to power supply disruptions. Latvian construction standards prescribe that every building must be equipped with such a system. As a general rule, it applies already during the preparatory phase of the building design, but protection can also be put up at a later stage (Standards LVS EN 62305-1, 2010). Consequently, the aim of the research is to explore the ways of lightning protection in buildings and to develop recommendations for its effective use.

Lightning protection is part of a set of electrical assembly and property fire protection measures that are taken during the construction or renovation of the property. Lightning protection systems shall be installed in order to prevent the ignition of constructions and their structures thereof in case of lightning discharge. The level of lightning protection and the necessity of installation shall be determined considering the characteristics of the construction and risk criteria. When designing a lightning protection system, it shall be intended to prevent overvoltage of electrical and electronic equipment caused by lightning exposure, as well as the risks caused thereby to parts of the building and human life (Standards LVS EN 62305-4, 2010).

After evaluating the legislation of the Republic of Latvia, in accordance with the current regulatory framework and Latvian national standards, it must be concluded that active lightning protection systems cannot be designed and constructed in Latvia, and these same national standards and regulatory framework restrict the possibility to apply the national standards of other European Union Member States.

1. LIGHTNING AND ITS FORMATION PRINCIPLES

When planning lightning protection, it is necessary to understand the principle of lightning formation. Lightning is usually a temporary electrical discharge between a negatively charged storm cloud and a positively charged ground surface, between two oppositely charged clouds or between individual parts of the same cloud. A typical lightning strike takes about a quarter of a second and consists of 3–4 charges.

There are several types of lightning:

1. Ribbon-like lightning (line lightning), which may also be branched, because discharge occurs not through one channel, but through a whole system of channels;

2. Flash-like lightning, also known in the nation as rust, when parts of the clouds are illuminated with bright electrical discharge;
3. Bead lightning, which is formed when there are separate extensions in the discharge channels, which the observer sees as bright shining knots;
4. Ball-shaped lightning observed as a luminous, ball-shaped 10–100 cm diameter formation that exists from a few tens of seconds to a couple of minutes. Spherical lightning moves relatively slowly, bountifully, accompanied by internal sound, and disappears either without notice or with a powerful explosion (France Paratonneres, 2018).

The average lightning length is 2.5 km, but those that extend to the atmosphere of 20 km have also been observed (Bazelyan & Rayzer, 2001).

Measurements taken in different countries (the USA, Sweden, Russia) show that 80–90 % of all lightning discharges come from a cloud with a negative charge of the lower layer. Lightning discharge from clouds, the bottom half of which is charged positively, is more common in the mountains.

The number of individual pulses in lightning unloads varies across broad boundaries: from 2–4 to several tens. As discharge pulses follow one another in about 30–40 ms, they cannot be observed with the naked eye, it is only in some cases that you can see a flash of lightning. The duration of lightning current pulses is 30–130 s. The entire duration of lightning can be as much as 1.5 s, although it is usually 0.2–0.3 s (Vanzovičs & Želvis, 2006).

Ribbon-like lightning, which is usually what one needs to protect oneself from, is a very outstretched spark that occurs during a storm and is caused by the high voltage between storm clouds and the ground, which is electrically charged. Discharge between clouds and the ground usually begins with a weak line of light branching from cloud to the ground until pulsed electrons begin to move through it at an average speed of 100 to 1000 km/s. In their path, electrons split air atoms, also separating electrons that join the total flow from them, similar to an avalanche of snow (Bazelyan & Rayzer, 2001).

During the process, the air is heated and its conductivity increases with elevated temperatures, so it turns from insulator to conductor. This pre-voltage discharge is called a step leader. The bright streak of light we see during the storm shows the narrow canal that conducts electricity through the air and serves just like an electricity cord for charge movement. When it reaches the surface of the ground, the phase of the main discharge begins, which is visible to the naked eye like lightning – a bright flash of light that also requires lightning protection, as the strength of the electrical discharge during a lightning strike can reach as much as 100 000 A of force, heating the surrounding air to 27 760 °C and causing electrical device damage, fire, as well as severe injuries and even death to humans and animals (Ozoliņš, 2004). Leaders of the next impulse move steadily from cloud to ground along the first impulse's prepared path.

When planning lightning protection, it should be taken into account that the effects of lightning can be devastating directly and indirectly:

– direct lightning forces damage infrastructures, cause fires, the threat of explosion and electric shock. The consequences of direct discharge shall be

visible immediately and it shall be possible to prevent them or to provide assistance to victims without delay;
- indirect lightning forces (lightning discharge takes place at a distance of up to a kilometer or affects power transmission or telephone lines even several kilometres away) cause short-term overvoltages that cause fluctuations in the electrical supply, interfere with essential service provision (energy supply to hospitals and others), resulting in volatility damaging sensitive electronic systems and other serious problems that may be noticed late because they may not be immediately visible.

All household appliances – TV-sets, computers, routers, decoders, refrigerators, washing machines, DVD players and more – are sensitive to surge pulses caused by storms and lightning strikes and can cause irreversible damage, causing significant material damage. Different types of lightning protection systems are used to protect buildings from unwanted lightning discharge effects (Standards LVS EN 62305-2, 2010).

When describing lightning protection systems, a distinction is made between external and internal lightning protection. The external lightning protection system protects buildings and other structures from damage caused by a direct lightning strike. Internal lightning protection includes protection against overvoltage and potential levelling. The functions of the internal lightning protection system are to prevent dangerous sparks in the structure by determining the balance potential connection or by leaving the distance between LPS components and other conductive electrical elements.

The external lightning protection system, which is divided into active and classic or passive lightning protection, will be further explored in depth. Both methods essentially perform the same function: take a lightning strike and lead it through metal leads to the ground depth, where resistance is less than on the surface of the ground. The lightning protection system is designed to protect against direct lightning strikes and, basically, the lightning protection system consists of:

A lightning receiver receiving a direct lightning strike;
- A conductor directing a lightning strike (current) to the ground, thus protecting the building from fire accidents;
- Grounding systems that disperse the lightning charge to the ground to ensure the safe operation of electrical networks;
- Potential levelling systems that eliminate the potential difference between building, electricity and grounding;
- Surge protection protecting ultra-sensitive equipment (TV, hardware, home appliances, etc.) from damage caused by surge during lightning discharge.

Thus, the discharge of lightning strikes takes place along a way with the least resistance. The main system differences are determined by the materials used, the assembly process and the price.

2. COMPARISON OF CLASSIC AND ACTIVE LIGHTNING PROTECTION SYSTEMS

When comparing active and passive lightning protection systems, the following criteria were chosen: operational principle and efficiency, installation costs, maintenance and servicing of the system, legislative requirements, and system security (Table 1).

Table 1. Comparison of Classic and Active Lightning Protection Systems

Lightning protection system	**Operation principle, efficiency**	**Installation costs, construction time**	**Maintenance, servicing**	**Legislation**	**Safety**
1.	2.	3.	4.	5.	6.
Classic	A lightning receiver is installed on the roof of the object, and lightning conductors lead the current to the ground circuit, which conducts the current to the ground. The building itself is also being fitted with internal surge protection as 50% of lightning power through communications goes back to the building. Is able to protect the existing object on which it is installed.	The main cost consists of materials and work, as it is necessary to create network coverage for the entire building, installation of earthing, etc. Depending on the size of the building and the complexity of the planning, it takes several hours to several days.	Maintenance prices depend on connections and groups of quantities (the more connections, the more expensive). The test should be carried out every 10 years, in explosive atmospheres every 2 years, in chemically aggressive atmospheres – once a year.	In accordance with the legislation of the Republic of Latvia, construction is allowed.	The system is valued as very reliable, with a centuries-long history, and has proven itself to be operational.
Active	A lightning receiver, lightning remover and grounding are also used, the difference is that a generator is connected to the tip of the lightning receiver that	The main cost is made by the detector itself and the ion generator, with assembly and installation taking a	The service price depends on the type of receiver. The generator must be maintained every three years.	In accordance with the legislation of the Republic of Latvia, construction is forbidden.	The system is considered partially reliable because there are recorded cases of lightning discharge in a protected

	ionizes air, stimulating direct lightning discharge into the receiver. Capable of protecting a significant area from lightning depending on height.	couple of hours.			area, which raises suspicions about the veracity of the size of the protected area, and there are only 2 lightning conductors.

After examining the criteria of the active and passive lightning protection systems summarised in Table 1, the authors of the article conclude that both lightning protection systems have their own positive and negative characteristics.

The installation of a classic lightning protection system is more time-consuming and complex, especially when the design of a building is non-standard, resulting in higher costs, while being tested over time, so it can be considered safer protection compared to an active lightning protection system.

The active lightning protection system is easier and not so complicated to install, so that the cost of installing can be similar to the cost of installing the classic system; it also looks more aesthetic and conditionally protects a larger area, while in some cases its effectiveness may be lower than the classic lightning protection system.

Consequently, both lightning protection systems can be considered to have their advantages and disadvantages, so it is necessary to assess the choice of the most appropriate protection system individually on a case-by-case basis, also taking into account such criteria as the complexity of the building project, the size and accessibility of the protected area and the cost of each individual site (Merigaud, 2016).

After examining the findings summarised in the chapter, the authors of the research conclude that:

1. Lightning is an uncontrollable expression of natural element, the effect of which is unpredictable and may result in invaluable material and human resource losses, so it is necessary to ensure against it in a timely manner by installing lightning protection systems;
2. Two types of lightning protection systems have been developed over time: a classic or passive lightning protection system which, if struck by lightning, captures and discharges the electricity charge generated by lightning into the ground and an active lightning protection system which attracts the electricity generated by lightning with energy generated by it and then discharges the charge into the ground;
3. Both lightning protection systems have different advantages and disadvantages, so it is necessary to evaluate which lightning protection system to select in each individual object depending on the characteristics of the protected object.

3. LATVIAN AND INTERNATIONAL EXPERIENCE IN THE FIELD OF LIGHTNING PROTECTION

Examining the experience of Latvia and foreign countries in the use of passive and active lightning protection systems, the authors of the research established that two diametrically opposed opinions were found in this matter. Some specialists, who are mostly representatives of manufacturers of active lightning protection systems, say that they are significantly more efficient and economical compared to passive lightning protection systems.

Other specialists say that active lightning protection systems are meaningless and have no advantage over traditional similar-use protective equipment. This is the view expressed by professor Basellian (Bazelyan, 2001) in his publications and seminars.

In their turn, researchers Hartono & Robiah (2009) in their publication, "ESE: The Device for a Modern Patient to Lightning Protection?" compiled a description of dozens of building damage from direct lightning outloads that hit alongside an active lightning protection device (Hartono & Robiah, 2009).

At this point, there are no uniform rules governing the use of the active lightning protection system, either in the world or in the European Union countries. In 1992, the National Fire Safety Association rejected the draft Active Lightning Protection Standard NFPA781 and successfully defended its position in a lawsuit brought by suppliers of such systems (Eybert-Berard et al., 1996).

In the United States, suppliers of active lightning protection systems are now barred from even declaring more coverage of such systems than traditional ones. The authors of the research, taking a closer look at the rules in place in the United States on lightning protection, had to find that there were generally very few requirements for the protection of residential buildings against lightning compared to other countries around the world. There are a number of reasons for this situation, the most significant of which relates to some of the lawsuits that took place a few years ago against the NFPA781 Project by individual manufacturers who wanted to sell questionable quality active lightning protection systems in the US. The opposite is true of the connection of water pipes and other metal parts of buildings to the grounding system. Under the rules, all metal parts must be combined with the ground system and include concrete foundations, an electrical earthing system, water ducts, gas pipes, high-voltage cable supports, swimming pool pumps and other equipment. This is mandatory, similar to every known standard and regulation around the world, for basic electric systems only (E&S blog, 2019).

The opposite is the case in Germany, for example. German directives, standards and legislation are very strict in relation to lightning protection requirements. For example, the Hamburg State Building Code (HbauO Section 17, ABS. 3) states that the building requires the installation of a lightning protection system in cases where lightning can easily be kicked into the building because:

1. It is high;
2. It is long;
3. The lightning may cause significant damage by kicking in.

In fact, this means that a lightning protection system must be set up in the building, even if only one of the requirements is met.

Lightning strikes can have particularly serious consequences for buildings and structures because of their location, design or purpose. It is therefore necessary to lay down legislative requirements for the use of effective lightning protection measures in two cases:

1. In the first case, if buildings and structures are particularly vulnerable to lightning (for example, it is attracted due to its height or location);
2. In the second case when any lightning strike (for example due to the type of structure (wooden buildings) or use (hospitals, kindergartens)) may have particularly severe consequences.

For example, a kindergarten is a building where lightning strikes can have serious consequences due to the purpose of using the building because people are constantly staying there, most of them are children.

For this reason, court decisions such as the Bavarian Administrative Court Decision No. 2 B 84 A.624 of 4 July 1984 requiring local nurseries to install effective lightning protection systems and regulating the minimum fire protection requirements are taken: free-fitting doors preventing the spread of smoke, specially designed staircases and exits. These provisions shall also apply to the residential building as a whole in which the kindergarten is located.

Studying the use of various lightning protection systems, the authors of the research examined how the legislation regulated the design and installation of these systems in the country closest to Latvia – Lithuania. In the Republic of Lithuania, lightning protection of buildings shall be constructed in accordance with technical regulations STR 2.01.06:2009 issued by the Ministry of Environment of the Republic of Lithuania in 2009 laying down requirements for the design, installation and use of external lightning protection in the territory of the Republic of Lithuania. The technical construction regulations shall apply to new buildings, reconstructed or refurbished buildings intended for different operational purposes, taking into account risks in accordance with the provisions of LST EN 62305-2.

As shown in Table 2, in general, these construction regulations are quite similar to the laws and regulations in force in Latvia, with the same division into classes of building lightning protection systems, however, with little nuance in the level of protection (Standards LVS EN 62305-3, 2010).

Table 2. Classes of Lightning Protection Systems of Buildings in the Republic of Lithuania and the Republic of Latvia and their Levels

Protection class	**Protection level in the Republic of Lithuania, %**	**Protection level in the Republic of Latvia, %**
1.	2.	3.
I	99	98
II	97	95
III	91	90
IV	84	80

The design and installation of active lightning protection systems were initially authorised in the Republic of Lithuania, but technical building regulations STR 2.01.06:2009 were revised in 2009 for security reasons. Currently active lightning protection in Lithuania is only allowed as a last means if it is not possible to perform lightning protection by normal means. Moreover, in accordance with Paragraph VI (20) of the Regulations, manufacturers of active lightning protection systems are fully responsible for the conformity of the systems manufactured by them with European Union directives, binding legislative provisions, technical, safety and quality requirements laid down in the relevant laws and regulations (Lietuvas Republikas likums, 2009).

As it has already been concluded, it is not possible to install the active lightning protection in Latvia if the requirements of the General Construction Regulations are complied with. Before the changes were introduced, by 2015, this was possible if:

1. The national standard of one of the European Union Member States was used;
2. Only the national standard of one European Union Member State was used at the site;
3. The construction took place after a co-ordinated building design;
4. The use of the specific national standard was provided for in the construction design contract, the application was co-ordinated with the local government building authority;
5. There was a certification in the building design regarding the conformity of the solutions with the requirements of the construction standards and regulations of Latvia, as well as regarding the correctness of the application of the requirements of a particular national standard.

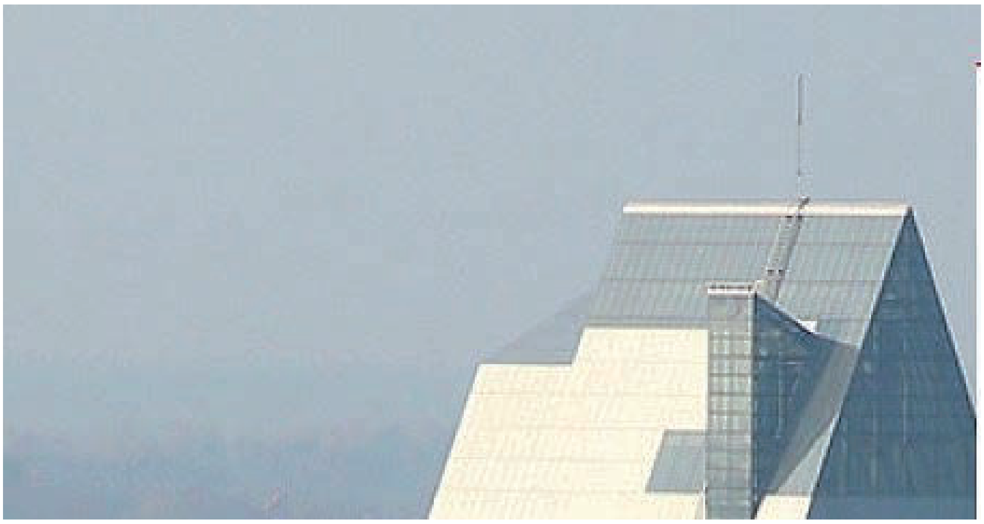

Fig. 1. Active lightning protection system on the roof of the National Library of Latvia (from the authors' archive).

In this way, using the active lightning protection method, the National Library of Latvia, which is the most architecturally complex structure of recent years, and Swedbank central building "Sun Stone" were equipped.

Fig. 1 shows the active lightning protection system on the roof of the National Library building. The lightning conductor on this building is a very visible example of the need for lightning protection to also be built in the light of the technical complexity and design of the building.

CONCLUSIONS

Having conducted the research, the following conclusions have been made:

1. Lightning protection is part of a set of electrical assembly and fire protection measures of property, which are performed during construction or renovation of property and the installation thereof is determined by the regulatory framework of the Republic of Latvia;
2. When designing a lightning protection system, provision should be made for it to prevent the overvoltage of electrical and electronic equipment caused by lightning exposure, as well as the risks it poses to parts of the building and human life.
3. The installation and control of lightning protection systems in the Republic of Latvia shall be determined by Regulations of the Cabinet of Ministers No. 294 approved on 9 June 2015, Latvian Construction Standard LBN 261-15 "Internal Wiring of Buildings" (LR tiesību akti, 2015), Cabinet of Ministers No. 238 of 19 April 2016 "Fire Safety Regulations", as well as lightning protection standards, technical standards of enterprises and other regulatory documents;
4. In accordance with the current regulatory framework and national standards of the Republic of Latvia, the design and installation of active lightning protection systems are not permitted.
5. Lightning is an uncontrollable expression of natural element, the effect of which is unpredictable and may result in invaluable material and human resource losses, so it is necessary to ensure against it in a timely manner by installing lightning protection systems;
6. Two types of lightning protection systems have been developed over time: a classic or passive lightning protection system which, if struck by lightning, captures and discharges the electricity charge generated by lightning into the ground and an active lightning protection system which attracts the electricity generated by lightning with energy generated by it and then discharges the charge into the ground;
7. The two lightning protection systems have different advantages and disadvantages, so it is necessary to evaluate which lightning protection system to select in each individual object depending on the characteristics of the protected object;
8. The effectiveness of the active and passive lightning protection system in the world as a whole is assessed in a contradictory and ambiguous manner;

9. In the Republic of Latvia, using lightning protection standards of other States, active lightning protection systems have been installed for various buildings, including such objects of national significance as the National Library;
10. Active lightning protection systems are effective in technically complex buildings as it is very difficult to deploy passive lightning protection systems on architecturally complex structures;
11. It is very important to use high-quality, relevant materials and to attract specialists when installing lightning protection systems, so that the required quality is achieved and the systems will last long and safe.

Having evaluated the findings regarding the protection of buildings with active and passive lightning protection systems, the authors of the research recommend the following:

1) To carry out thorough calculations and consult a number of specialists, including a certified lightning protection expert, before installing the lightning protection system so that the most economical and safe solution can be chosen;
2) When installing a lightning protection system, it is necessary not to save on materials and choose the materials and services offered by professional firms, as they guarantee security and real protection from lightning strikes on both property and human safety, otherwise if incompatible or inappropriate materials are connected, the lightning protection system may be seriously disturbed and will not be able to fulfil its intended functions;
3) If the building is standard design and the surrounding area is easy to use for technical purposes, it is better to install a passive lightning protection system, as, if high quality materials and specialists are used, the lightning protection system will serve its intended purpose in a sufficiently efficient manner and will be more cost-effective;
4) If the design of the building is architecturally complex, as well as the surrounding area can pose an increased lightning threat to the building and people living there, it is worth investing in and installing an active lightning protection system that will protect against the threat. However, it is imperative to use professional services and high-quality materials for this purpose;
5) When installing lightning protection systems, it is necessary to establish them in accordance with the laws and regulations of the Republic of Latvia, as well as observe the fire safety and other regulations provided for in these enactments in order not to cause problems;
6) Lightning protection without overvoltage protection is a worthless solution that can cause very high losses to electrical equipment inside the home, so there are both to be installed. When perceiving a lightning strike, it is drained thanks to lightning protection, but there is still a chance that the lightning surge generated during the discharge will damage the electrical equipment inside the house – TV-set, computer hardware and other valuable household appliances. Properly installed lightning protection and

surge protection are investments that will protect the building and the rest of the property from possible lightning damage.

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