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A Study on the Current Status and Reduction Method Caused by Lightning at Educational Facilities

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Abstract: This study was aimed at identifying the causes of continuous failures, fires, and explosions of electrical and electronic systems in educational facilities that result from lightning, which occurs frequently during the summer. The study is also aimed at suggesting prevention measures for such damage. The installation status and problems of lightning protection systems (LPSs) were examined by analyzing the damage compensation data of the Korea Institute of Educational Facility Safety, a questionnaire and field survey, and related laws. A total of 49,989 educational facilities responded to the questionnaire. The survey indicated that out of all the educational facilities, 21% had external LPSs, 6.2% had internal LPSs, 4% had both internal and external LPSs, and only 2.5% had installed bonding in addition to internal and external LPSs. The LPSs were not installed properly because the heights of most educational facilities are less than 20 m although the Building Act stipulates that LPSs should be installed in buildings with a height of 20 m or more. Furthermore, periodic inspections and checkups were not performed because the Electric Utility Act does not apply to LPSs. However, starting in January 2021, the installation and management of LPSs will be conducted in accordance with the Korean Electric Equipment Regulation, which includes the standards for LPSs. A design using a field survey must be performed prior to the installation of LPSs. Based on the survey, an estimate should be calculated, and the design, construction, and supervision should be performed.

Keywords: lightning protection system; surge protection system; lightning protection level; lightning protection zone

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Citation: Kang, S.-D.; Kim, S.-C.; Park, K.-B.; Kim, J.-H. A Study on the Current Status and Reduction Method Caused by Lightning at Educational Facilities. *Energies* **2021**, *14*, 3015. https://doi.org/10.3390/en14113015

Academic Editor: Renato Procopio

Received: 7 April 2021
Accepted: 18 May 2021
Published: 23 May 2021

1. Introduction

The frequency of lightning and the resulting damage have increased due to climate change and increased atmospheric instability caused by global warming. According to the 2019 Lightning Yearbook of the Korea Meteorological Administration, on average, 127,420 lightning events have been observed annually in South Korea over the last 10 years [1]. According to the National Fire Data System at the National Fire Agency, the total number of fires and the total number of deaths caused by lightning over the last 10 years was 190 and 8, respectively [2]. Lightning mainly occurs during the summer when ascending air currents form easily due to the electric energy discharge. Energy accumulates through the electrification of the water droplets and ice crystals in thunderclouds. Lightning is an electrical discharge that occurs between clouds, between clouds and air, and between clouds and the earth. The International Electrotechnical Commission (IEC) 62305 (protection against lightning) defines lightning as an electrical discharge of atmospheric origin between clouds and the earth consisting of one or more strokes [3]. The voltage generated by lightning amounts to tens of millions of volts or more, the peak discharge currents range from several thousand amperes to 200,000 A or more, the temperature of lightning is approximately 30,000 K [4]. However, these values can vary depending on the thundercloud's size and its distance away from the earth. The potential damage that can be caused by lightning includes destruction of structures by direct lightning strikes and flashover due to the lack of a minimum separation distance, fire, explosions, and electric shock. Furthermore, even if there are no direct lightning strikes, electrical and electronic systems can be broken by a rise or surge in ground potential due to indirect lightning strikes, and other damage can be caused by step potential, touch potential, and side flashes [5–9]. According to the damage compensation data of the Korea Institute of Educational Facility Safety, most of the damage that occurs in educational facilities consists of damage to electrical and electronic equipment due to indirect lightning strikes and accidents caused by fire [10]. In educational facilities, these accidents are likely to cause not only panic but also damage because a large number of young students occupy a limited amount of space. Moreover, as the electrical and electronic systems used in educational facilities are being modernized and diversified, malfunctions constantly occur due to surges caused by indirect lightning strikes [3]. Thus, it is necessary to analyze the lightning protection systems (LPSs) currently installed in educational facilities and to propose a plan to reduce damage. This study targets elementary, middle, and high schools in which there are large ripple effects in the event of an accident. The installation status of LPSs, the presence or absence of lightning damage, facilities subject to lightning damage, incorrect installations through field investigations, and related laws and regulations are examined. In addition, measures to reduce damage to educational facilities caused by lightning are suggested. The research method was to investigate the installation of lightning protection systems and thereby to identify problems and present solutions with regard to erroneous installations and related legal standards. Field investigation allowed for the identification of equipment subject to lightning damage and of the existence or absence of lightning damage.

2. Lightning Protection System

The LPSs of buildings are subject to Article 20 of the Regulation for Facility in Buildings. This regulation stipulates that external and internal LPSs should be installed in buildings prone to lightning or buildings with a height of 20 m or more [11]. Furthermore, the Korea Electrotechnical Code, which was enforced from 1 January 2021, also requires the installation of low-voltage electrical and electronic systems, high and extra-high voltage electrical equipment, and external and internal LPSs as suggested in the IEC 62305 standard for facilities that need to be protected from lightning or have a height of 20 m or more [12]. IEC 62305 is a design standard for the protection of structures, service entering facilities, humans, and animals from lightning and is composed of four parts. IEC 62305-1 (part 1: general principles) classifies the causes of the damage to structures and service entering facilities into four types as shown in Figure 1: S1 for lightning flashes to the structure; S2 for lightning flashes near the structure; S3 for lightning flashes to the lines connected to the structure; and S4 for lightning flashes near the lines connected to the structure. The data types are classified into D1 for injury to living beings by electric shock; D2 for physical damage (fire, explosion, mechanical destruction, and chemical release) due to the direct effects of lightning, including sparking; and D3 for failure of internal systems due to lightning electromagnetic impulse (LEMP). The losses are classified into L1 for loss of human life; L2 for loss of service to the public, L3 for loss of cultural heritage, and L4 for loss of economic value. Consequently, appropriate protective measures should be established depending on the cause, type of damage, and type of loss. There are four lightning protection levels (LPLs): I, II, III, and IV [3]. The maximum and minimum lightning currents according to the LPLs are listed in Table 1. These currents can be selected by the architect or official (owner) according to the type and importance of the building being protected. In addition, IEC 62305-2 (part 2: risk management) stipulates that the LPL should be determined using risk assessment software, and the appropriate LPSs for this purpose should be installed. To establish the most appropriate protection measures, lightning protection zones (LPZs) are identified, and the protective measures for LPZs, such as LPSs, shielding wires, magnetic shields, and surge protection devices (SPDs), are determined. LPZs are classified as LPZ 0A, LPZ 0B, LPZ 1, LPZ 2, . . . LPZn. LPZ 0 (A and B) indicates an external zone and LPZ 1 (1, 2, 3, . . . *n*) indicates an internal zone [13].

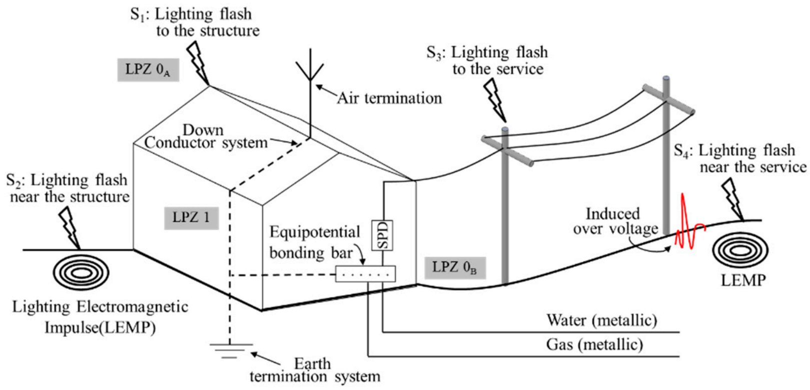


Figure 1. Types of lightning damage type and appropriate LPSs.

Table 1. Lightning current for each LPL based on a 10/350 us waveform.

LPL	I	II	III	IV
Maximum current(kA)	200	150	100	100
Minimum current(kA)	3	5	10	16

IEC 62305-2 is a standard on risk analysis regarding the selection of lightning damage risks and protective measures. This standard stipulates that the need for lightning protection for structures and service entering facilities should be determined first, and the lightning frequency, damage probability, and the impact, size, and degree of the damage should be considered to choose the optimal technical and economic protective measures. Since the risks of educational facilities are calculated according to diverse variables (e.g., the number of people in school zones, economic value of facilities, types of structures, spaces, lightning reception areas, expected number and probability of dangerous events per year), it is difficult to install the same LPL for every school. IEC 62305-3 (part 3: physical damage to structures and life hazard) deals with the protection of structures from physical damage due to direct lightning strikes and the protection of humans and animals from injuries due to the touch potential and step potential around LPSs. The main contents include the design of air termination systems, down conductor systems, earth termination systems, lightning equipotential bonding, testing, and maintenance [14]. IEC 62305-4 (part 4: electrical and electronic systems within structures) deals with the design, installation, maintenance, and testing of surge protection measures (SPMs) to reduce the failure risks of electrical and electronic systems due to LEMP in structures [15].

2.1. External LPSs

External LPSs are installed to protect structures from damage due to direct lightning strikes and people from electric shock. As shown in Figure 1, an external LPS is composed of an air termination system, a down conductor system, and an earth termination system. In an external LPS, the air termination system captures lightning and safely discharges lightning current to the ground through the down conductor and earth termination systems. In an external LPS, the air termination system captures lightning and safely discharges lightning current to the ground through the down conductor and earth termination systems. The air termination system can be composed of rods (including free-standing masts), catenary wires, and a meshed conductor, which can be mixed (combined) as needed. Special care should be paid to the corner protection of the structure when determining the location of the air termination system of the LPS. The arrangement and position of the air termination system can be determined using the rolling sphere method, mesh method, or protective angle method [16–19]. The down conductor system secures multiple parallel current paths for discharge to the earth without damaging the lightning current flowing through the LPSs, minimizing the length of the current paths, or performing equipotential bonding to the conductive parts of the structure. The role of the earth termination system is to minimize overvoltage by dispersing the lightning current to the earth. It is installed, based on its shape and size, to maintain a low earth resistance (10 ohm or lower). The earth electrodes in the earth termination system are composed of type A and B layouts. The type A earth electrode is built by installing the individual horizontal or vertical earth electrodes outside the structure to be protected, and there must be two or more earth electrodes. The type B mesh-type earth electrode is composed of a ring conductor or foundation earth electrode, and 80% of its total length is installed underground outside the structure to be protected.

2.2. Internal LPSs

With the modernization of educational facilities, the use of electrical and electronic systems, such as computers, electronic boards, fire extinguishing equipment, and cooling and heating equipment, is increasing. In addition, incidents of damage due to surges flowing into buildings are growing following the increasing frequency of lightning [1,11], and it is becoming increasingly important to establish protective measures for buildings. Surges are pulses characterized by sharp, instantaneous increases in the current or voltage caused by an LEMP. They usually flow into the building during the switching operation and lightning discharge and cause failures, fires, and explosion of electrical and electronic systems. The internal LPS is a protective system for LEMP that applies grounding and lightning equipotential bonding, SPDs, zone setting for magnetic shielding and minimization of loops, and the separation distance from air-termination. In addition, lightning equipotential bonding serves to electrically connect conductive parts, cables, and metal parts of the internal systems as well as conductive services entering these systems. It is used to minimize potential difference, suppress sparks, and reduce the magnetic field. SPDs are one of the most effective methods used to protect the load devices by limiting transient voltage in the power and communication lines and discharging surge current. SPDs usually have high impedance when the surge voltage is not applied, using a metal oxide varistor (MOV) device [17]. SPDs maintain open states, and when a surge voltage is applied, the impedance drops rapidly and changes to a short circuit state. SPDs are categorized into three classes and must be installed for protective coordination depending on the location.

3. Results and Discussion

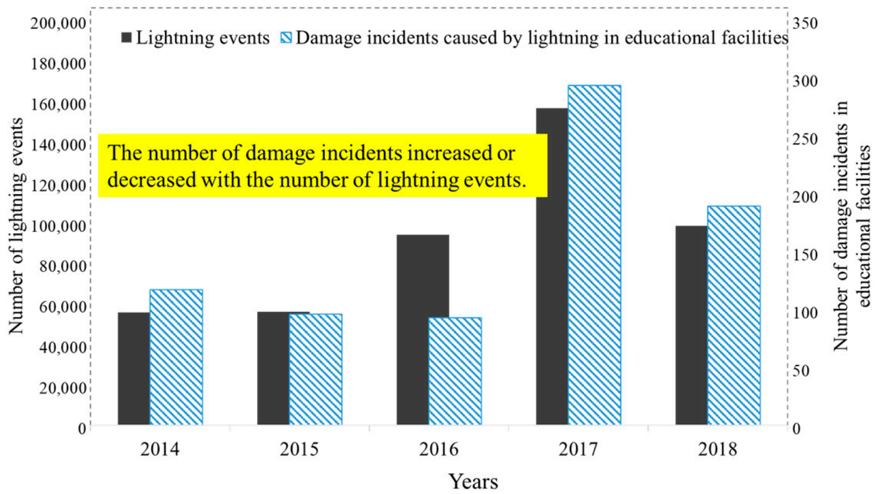
3.1. Analysis of the Current Status of LPSs

To analyze the damage to educational facilities caused by lightning and the installation status of LPSs, the damage compensation data of the Educational Facilities Disaster Relief Society was collected, and questionnaire surveys were conducted in 49,989 schools nationwide. The fundamental surveys dataset is shown Table 2. The frequency of lightning damage was analyzed using a statistical analysis program (IBM SPSS statistics program version 25). Elementary schools accounted for 49.5% (24,754) of these schools; middle schools, 22.5%; high schools, 25.9%; special schools, 1%; and others, 1.1%. In addition, field surveys were conducted by visiting the schools (five schools in which lightning damage occurred more than twice) that experienced damage due to lightning to analyze problems and suggest methods to avoid such damage.

Table 2. Fundamental surveys dataset of educational facilities.

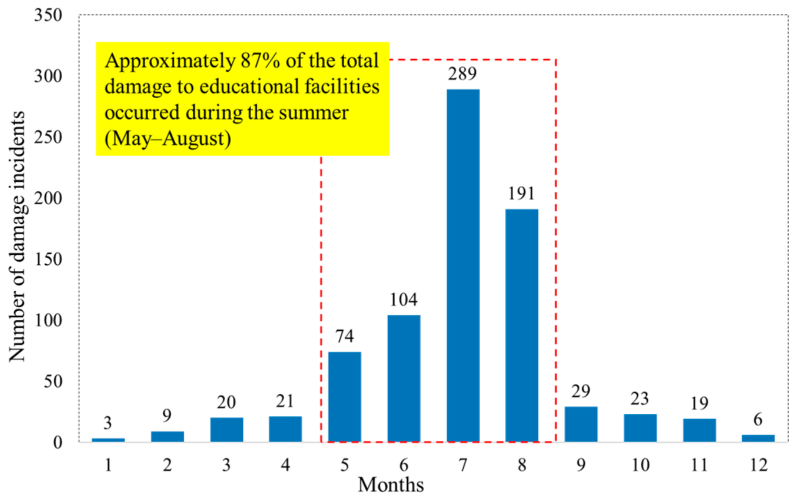
No.	Variable identifier	Parameters
1	School	Elementary, middle, high, special education, etc.
2	Number of damage incidents	Once, twice, more than three times
3	When the damage occurred	January to December
4	Building height	Three stories or less, four stories, fifth stories, sixth stories or higher
5	Installation of LPSs(external)	Installed, not installed
6	Air-termination type	Rods, catenary wire, etc.
7	Installation of LPSs (SPD)	Installed, not installed
8	Equipotential bonding	Installed, not installed
9	Damaged system	Cooling and heating system, firefighting system, broadcasting system, elevators, solar power system, CCTVs, other systems
10	Earthing resistance of LPSs	Less than 10 ohm, less than 30 ohm, less than 50 ohm, less than 100 ohm, more than 100 ohm

Figure 2 shows the results of analyzing the damage compensation data of the Educational Facilities Disaster Relief Society between 2014 and 2018. Figure 2a shows the number of lightning events and the number of damage incidents caused by lightning in educational facilities. The number of damage incidents increased or decreased with the number of lightning events. This means that the LPSs were not installed properly. Figure 2b shows the monthly lightning damage status. According to the yearbooks of the Korea Meteorological Administration, approximately 88% of the total number of lightning events occurred between May and August. Thus, it can be seen that approximately 87% of the total damage to educational facilities occurred during the summer (May–August), which has a high lightning frequency. In other words, damage incidents due to lightning are concentrated in a season with unstable weather, and LPSs should be installed to prevent such damage.



(a)

Figure 2. *Cont*.



(b)

Figure 2. Results of analyzing the lightning damage compensation data of the Educational Facilities Disaster Relief Society: (**a**) Number of lightning events and the number of damage incidents due to lightning in educational facilities, (**b**) Monthly lightning damage status.

Figure 3 shows the results of the questionnaire survey on the installation status of LPSs in educational facilities and the lightning damage ratios by type of installation. As shown in Figure 3a, external LPSs were installed in 10,509 facilities (21.1%) to prevent damage due to direct lightning strikes. Bonding, which is an internal LPS for preventing damage due to indirect lightning strikes or induced lightning, was installed in 7652 facilities (15.8%). SPDs were installed in 2995 facilities (6.2%). Approximately 4% (1901) of educational facilities had both external and internal LPSs (SPDs) installed and 1196 or approximately 2.5% had external LPSs, SPDs, and bonding installed. This confirmed that the LPSs are lacking. Figure 3b shows the lightning damage status by type of LPSs. A total of 982 educational facilities had lightning damage over the last five years. Lightning damage occurred in 405 educational facilities that had only external LPSs installed, in 87 education facilities where only SPDs were installed, in 54 educational facilities where external LPSs and SPDs were installed together, and in 31 educational facilities where external LPSs, SPDs, and bonding were installed. Lightning damage also occurred in 400 educational facilities where internal and external LPSs were not installed. The damage was the least when the internal and external LPSs and bonding were installed as suggested in the standard, and the most when only the external LPSs were installed. This result confirmed that lightning damage can be reduced by the installation of both external and internal LPSs as suggested in the standard. Figure 3c shows the major systems that were damaged by lightning. The largest number of cases of damage (385) occurred in cooling and heating systems (outdoor units) installed outdoors and on the roof, followed by 351 cases in firefighting systems, 300 cases in CCTVs, 188 cases in broadcasting systems, 91 cases in elevators, 15 cases in solar power systems, and 410 cases in other systems (computers and communication systems). In other words, most of the damage occurred in electrical and electronic systems due to surges flowing indoors by indirect lightning strikes or induced lightning rather than direct lightning strikes. Therefore, damage incidents can be significantly reduced by installing only internal LPSs.

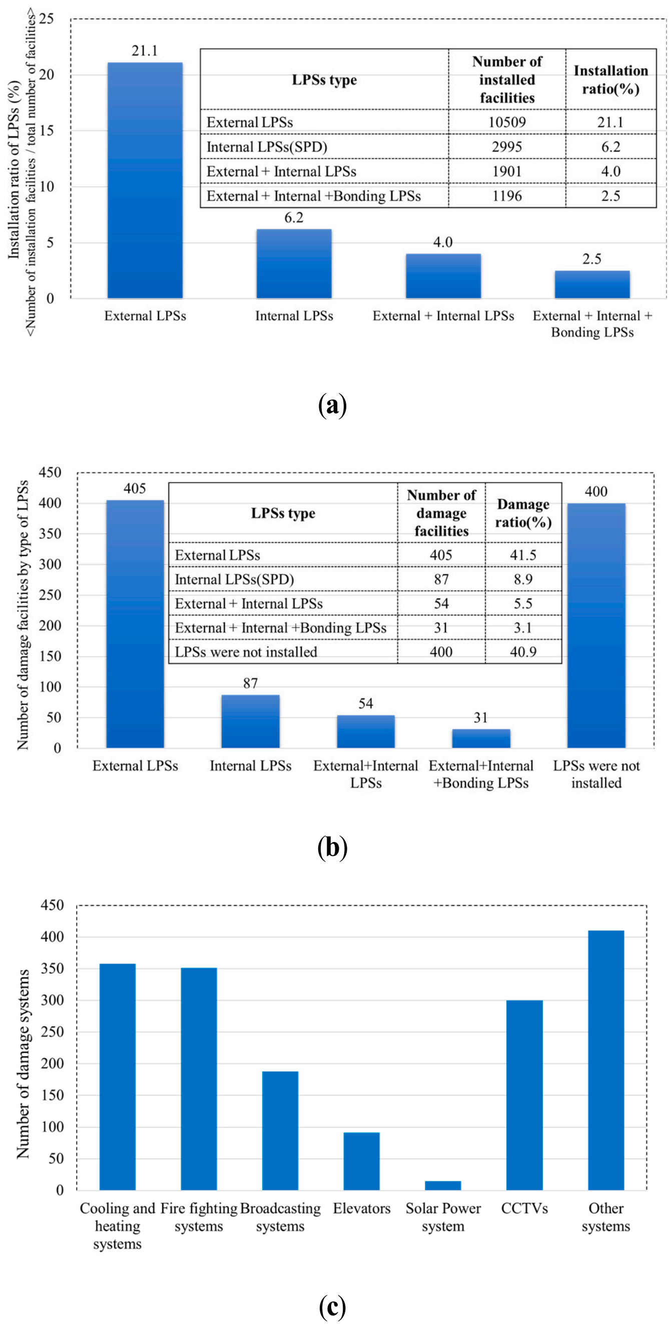
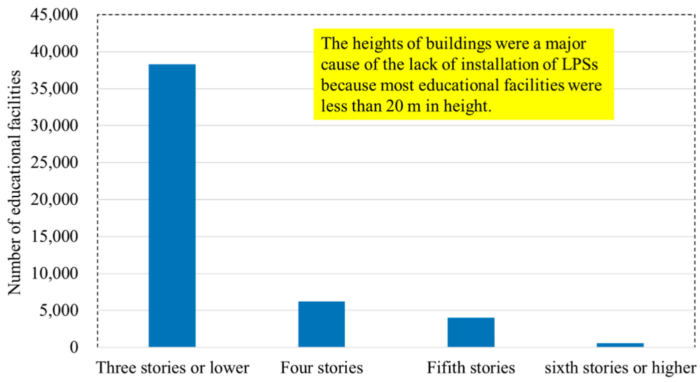
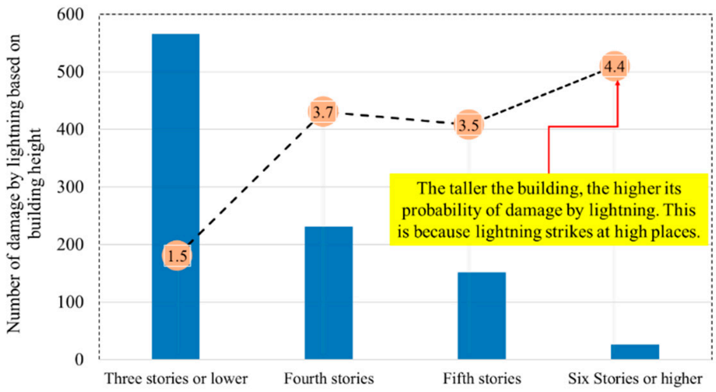


Figure 3. LPS installation type and damage rate of educational facilities: (**a**) LPS installation status, (**b**) Damage status by type of LPS installation, (**c**) Damaged systems.

Figure 4 shows the damage status by lightning based on the height of the educational facilities. As shown in Figure 4a, buildings that were three stories or lower accounted for the largest number of damage incidents (38,306 facilities), and 597 incidents occurred in buildings that were six stories or higher. The heights of buildings were a major cause of the lack of installation of LPSs because most educational facilities were less than 20 m in height, which is the minimum height required for the installation of LPSs under the Building Act. Figure 4b shows the number of damages by lightning based on building height. Although the largest number of damage events due to lightning occurred in buildings that were three stories or less (566 facilities), this figure represented only 1.5% of the buildings surveyed. This implies that the taller the building, the higher its probability of damage by lightning. This is because lightning strikes at high places.



(**a**)



(**b**)

Figure 4. Lightning damage status by height of the educational facilities: (**a**) Height distribution of nationwide educational facilities, (**b**) Number of lightning damage by building height.

To analyze the current LPS installation and management status in educational facilities, a field survey was conducted for six schools where lightning damage occurred twice or more. Among these six schools, the SPD, an internal LPS, was installed in two schools, and external LPSs were installed using lightning rods and catenary wires in five schools. In one school, neither internal nor external LPSs were installed. A common problem among the surveyed schools is that they had no LPS design data, and the standards by which the LPSs were installed could not be determined. It is common for old school buildings to be constructed without LPS installation standards, but the LPS design data could not be verified for recently constructed schools as well. Figure 5 shows examples of incorrectly installed or managed LPSs. In the first example, a TV reception antenna is installed on an external LPS. In the second example, the catenary wires are installed together with communication and power lines. In this case, when lightning occurs, the surge and ground potential can rise due to electrostatic induction and electromagnetic induction, and this may cause a failure of the equipment connected to the communication power lines. In the third example, air conditioning equipment is installed outside the radius of an auxiliary lightning rod. In the fourth example, the catenary wire is installed at a lower position than the air conditioning equipment. In another example, although the external LPS is installed, it cannot protect the entire educational facility considering the protection radius. In the case of an SPD, an internal LPS, a low protection effect was discovered because it did not follow the coordinating specifications suggested in IEC 62305 standard and IEC 61643-12 [20]. Furthermore, problems, such as installation without consideration of the grounding system at the field and installation of an SPD without considering its rating according to the inflow path of lightning stroke, were found, and these need to be corrected.

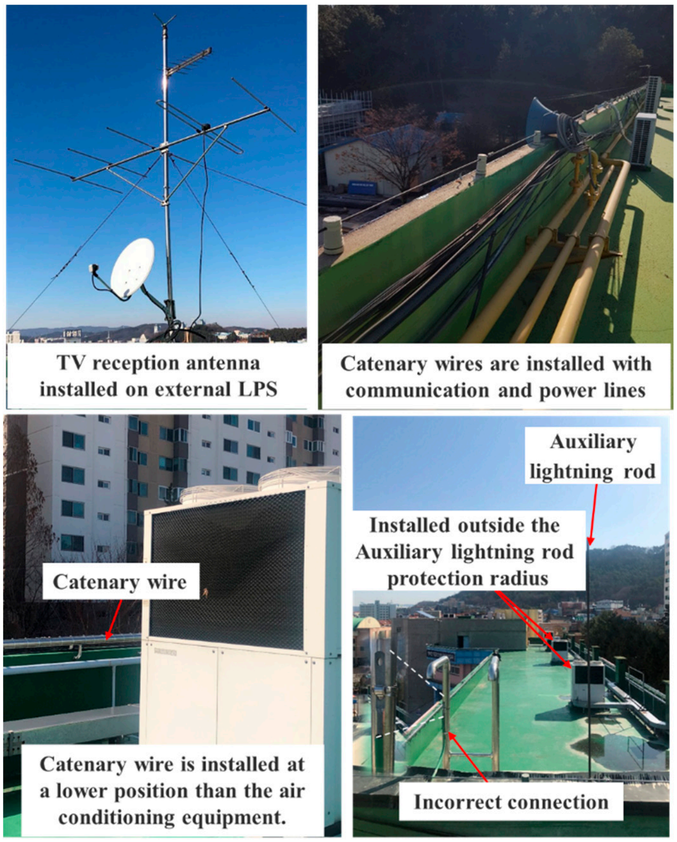


Figure 5. Incorrect installations of LPSs.

3.2. Lightning Damage Reduction Measures for Education Facilities

Furthermore, the protective effects for existing LPSs are inevitably low because the processes of selecting a protection level through risk assessment according to the IEC 62305 standard, designing and installing LPSs, and designing a grounding system, were not performed. Therefore, to reduce damage by lightning, a field survey for educational facilities in which LPSs will be installed must be conducted and a method of installing the LPSs must be proposed from the survey. Furthermore, design and construction that comply with the standards must be carried out. This study proposed that in this process, LPS experts must participate and prepare a report after determining whether or not there are errors in training, design, and construction for the persons in charge. Figure 6 shows the procedure for deciding the priorities of LPS installation and reinforcement. It was suggested that LPS should be installed first in facilities with high frequencies of lightning damage, the evacuation-vulnerable group, high buildings, and large-area facilities. For facilities with LPSs, installation errors should be identified and eliminated, and new LPSs should be installed in line with the standards. In the past, it was impossible to determine whether LPSs were incorrectly installed because the LPSs were installed through an administrative process without review by an expert. Thus, expert review should be performed for LPS installations. In terms of maintenance, a manual inspection of the LPSs should be performed annually. When a significant part of a building is changed or repaired and when lightning discharge occurs in the LPSs, an on-demand inspection should be performed.

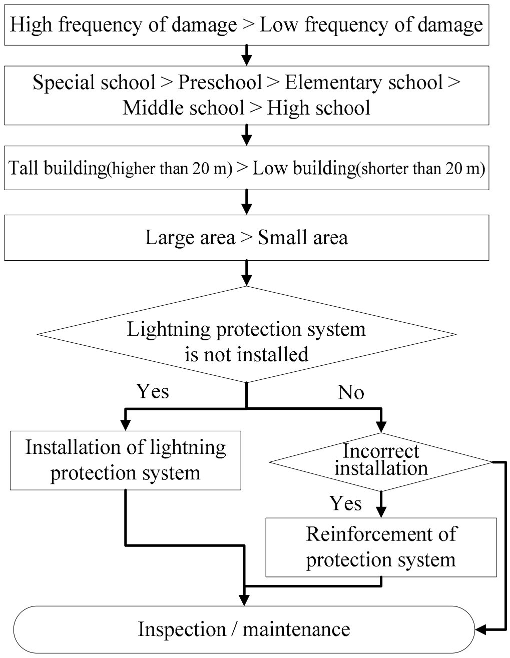


Figure 6. Priorities for LPS installation and reinforcement.

4. Conclusions

This study analyzed the damage compensation data of the Educational Facilities Disaster Relief Society, a questionnaire survey, field survey, and related laws in order to reduce the damage to educational facilities caused by lightning. Educational facilities are believed to have a large ripple effect in the event of an accident due to lightning because most individuals in these facilities are young and the density of people per unit area is generally high. However, only about 21% of educational facilities nationwide have external LPSs installed, and 4% have both external and internal LPSs (SPDs). Thus, the installation of new LPSs and the reinforcement of existing facilities are urgently needed to reduce human and property damage due to lightning. The main objective of external LPSs is to prevent damage to structures by lightning strikes and protect people from electric shock, and internal LPSs are aimed at protecting electrical and electronic systems from indirect lightning strikes and induced lightning. According to the damage compensation data of the Educational Facilities Disaster Relief Society, the damaged facilities are mostly air-conditioning and heating facilities, firefighting facilities, CCTVs, broadcasting facilities, elevators, and solar power facilities. Damage to these facilities is suspected to be caused by indirect lightning strikes or induced lightning rather than direct lightning strikes. The data also shows that the damage rate by lightning is reduced when external and internal LPSs are installed together, suggesting the need to install them simultaneously. Lastly, a design using a field survey must be performed prior to the installation of LPSs. Based on the survey, an estimate should be calculated, and the design, construction, and supervision should be performed.

Author Contributions: Conceptualization, methodology, validation, writing—original draft, writing—review and editing: S.-D.K., S.-C.K., and J.-H.K.; project administration: K.-B.P. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Korea Institute of Educational Facility Safety.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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