Lightning Strikes

SMART HOSPITALS PROTECTIVE MEASURES

Gisell Alban Morejon
[COMPANY NAME] | [COMPANY ADDRESS]

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1 Introduction

Lightning is a massive spark of electricity formed in the atmosphere between the clouds, the air or the ground. It is one of the oldest observed natural phenomena on earth due to its impacts around the globe. It is estimated that around 100 lightning bolts strike the earth every second, 8 million per day and 3 billion per year (NSSL, 2019).

In the coming decades, the effects of climate change will reach unprecedented levels, affecting the severity of lightning strikes, comprising a major hazard for health care facilities. Consequently, there is a need to prevent SMART Hospitals from being vulnerable to damages, safeguard people's life, and to prevent interference with power systems operations.

SMART hospitals is an initiative created by the Pan American Health Organization (PAHO), that integrates measures for climate change mitigation and resilience in safe hospitals, through the use of stringent construction standards to resist natural hazards, green technologies, energy efficiency, and carbon footprint reduction to prevent disruption in the facilities' operation in the occurrence of natural hazards (PAHO, 2017). These facilities are prepared to remain operational at maximum capacity after disasters and extreme weather events, by efficiently using energy and generating cost savings, by implementing a set of strategies for emergency preparedness, and by assuring the best health care services to their patients (Balbus *et al.*, 2016).

Lightning strikes attributed to climate change is a controversial topic, as studies around the world have produced different results. While the majority of researchers agree that lightning is anticipated to increase from 5% to over a 100% per degree Celsius of global mean temperature increase due to the rise in global temperature (Romps *et al.*, 2014), a recent study shows a decrease of lightning strikes incidence due to the lack of ice formation caused by the high temperature in the atmosphere (Finney *et al.*, 2018).

This guideline presents the link between increased temperature ascribed to climate change and lightning strikes and advises on the measures to be implemented in SMART hospitals to prevent and reduce the effects of lightning strikes. This document is relevant to every SMART hospital in the Caribbean where international electric codes are not always applied and it is aimed to assist engineers, maintenance personnel, disaster coordinators.

2 The link between increased temperature attributed to climate change and lightning strikes

In 1994, a research paper was published on the implications of global temperature change on lightning distributions and frequencies across the earth, and it concluded that in a scenario with an increase of global temperature, where the carbon emissions concentration in the atmosphere are doubled, would produce a 30% lightning activity increase, which constitutes an approximate 5-6% increase in global lightning frequencies for every 1^{o}C global warming (Price and Rind, 1994).

Similarly, in 1995, climate change and the association with lightning strikes were studied, when the Optical Transient Detector (OTD) was launched to space. The OTD was the first sensor to view lightning activity across the globe and was used to collect data to determine the changes in climate. It was established that there was a strong association between lightning and the increased temperature of the northern hemisphere, and it was estimated that around a 56% increase in lightning activity might be expected due to 1K wet-bulb temperature[1] rise. The conclusions of this study indicate that with warmer temperatures caused by climate change, lightning could become more frequent (Reeve and Toumi, 1999).

A study presented in 2014 on the Science Journal corroborates with previous research and estimates an increase of around 50% of lightning strikes in the US by the end of the century if the global temperature rises to 4^{o}C according to current emissions trajectory. Therefore, it is predicted that the number of lightning strikes will increase by about 12% for every increased degree in global average air temperature. This study related the convective available potential energy (CAPE[2]) times the precipitation rate to find the variance in the time series of total cloud-to-ground lightning flashes. It also showed that the amount of water vapor that air can hold increases exponentially with temperature. Since water vapor is the fuel for thunderstorms, lightning rates are sensitive to changes in temperature (Romps *et al.*, 2014).

An additional study presented in 2015 suggests that only a fraction of the increase in frequency of the lightning strikes should be attributed to climate change and the rest can be attributed to natural causes. It illustrates that the number of strikes has increased by 3.4% since the twentieth century and it suggests that the increase of lightning strikes is not solely related to warmer temperatures but also to seasonal reliance (Webster, 2015).

Nevertheless, a recent study incites debate among scientists by showing that lightning strikes are likely to decrease by 15% by 2100. This potential decrease would be a result of the lack of ice fluxes in the clouds due to the increasing temperature in the atmosphere, which is a necessary component for lightning to occur. This could prevent lightning from forming as often as before, reducing its chances of striking (Finney *et al.*, 2018). Cloud ice has not been included in previous simulations of lightning because its behavior to climate change is still unpredictable.

Though a range of 6000 to 24000 lightning fatalities has been reported globally (Holle, 2016), for years, climate change researchers have mainly concentrated their efforts on the effects of hazardous phenomena such as hurricanes, without considering the damage lightning strikes cause through infrastructure damages and fires. Therefore, the importance of addressing the effects of lightning beforehand will prevent losses and safeguard the infrastructure.

It is still unknown where the lightning will increase or decrease. However, lightning strikes are more frequent during the summer or in warm-weather regions due to the presence of moisture and high temperatures in the atmosphere. As the Caribbean is a highly hazard-prone region, due to its location and its temperature, it is key to have preventive measures in place to ensure the effective operation of the hospitals despite the lightning strikes, and to cope with the impacts of severe weather and climate change.

[1] A measure of how much moisture or water vapor is present in the air.
[2] A measure of the atmosphere's potential for creating towering clouds.

3 Measures to be taken as part of SMART Hospitals

Despite that lightning strikes can exceed 3 million volts, national electrical codes do not always contemplate lightning protection (Morgan and Chusid, 2017); therefore, international standards must be used to complement national procedures. This guideline follows the IEC 62305 standard for lightning protection, which assesses the general principles for the protection of structures, the risk management, the physical damage, and the life hazard and electrical and electronic systems within the structures (Bouquegneau, 2007), and the NFPA 780 Standard for the Installation of Lightning Protection Systems 2020, for structural protection.

Health facilities have critical operating functions that cannot be stopped (Furse, 2008) in case of natural or climate change-triggered hazards; consequently, they are considered to have a high level of risk to lightning strikes, according to IEC 62305-2 standard for lightning protection. A lightning protection system (LPS) then becomes a vital component in SMART Hospitals because it creates a path to safely channel the possible lightning strikes into the ground, avoiding the loss of lives and minimizing damage to the buildings, equipment, electrical infrastructure, and surroundings. These measures are to be implemented in new hospitals, as well as retrofitted in existing ones.

An LPS consists of an external and internal part. The external part intercepts direct lightning strikes and safety conducts and disperses the current to the ground, while the internal part prevents sparking or explosion inside the building. Therefore, SMART hospitals must implement both, as shown below.

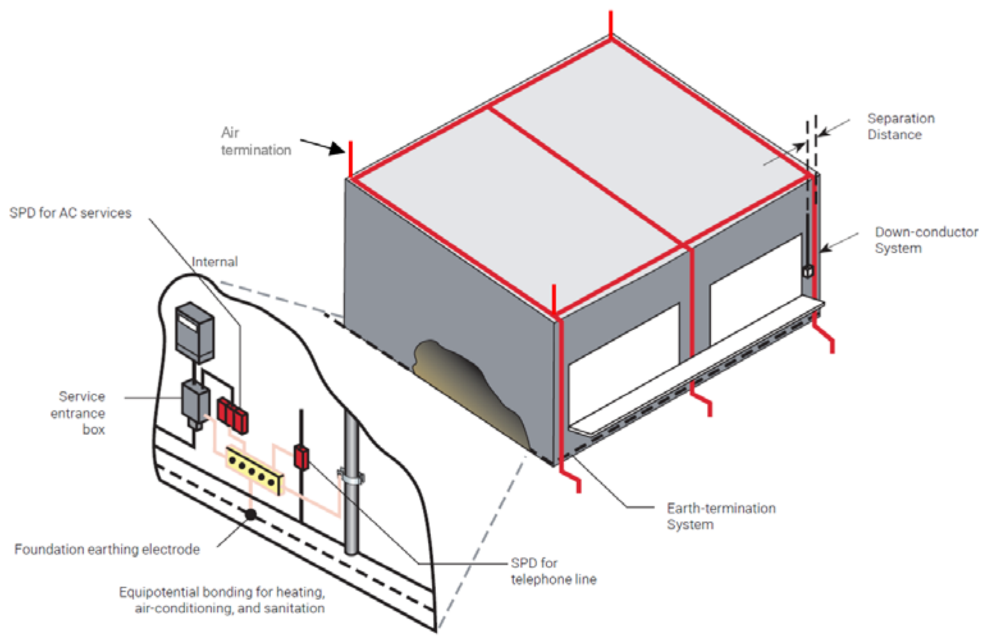

Figure 1 External and internal lightning protection system. Source: Lightning Protection Handbook (NVent ERICO, 2018).

3.1 External lightning protection system

3.1.1 Air terminals or lightning rods

An air terminal is a metallic column which is installed at the highest point of the roof.

- In a hospital building, various air terminals shall be connected every 10 to 20m on the roof and linked through copper or aluminum strips to the earthing system.
- The air terminal tip must be at least 254mm tall and they must be secured directly on top of the object they will be protecting (Association, 2019).
- They can be made of any conductive material and must resist corrosion.
- If the roof is made from conductive materials, e.g. sheet metal plates or tin roofs, they can be used as air terminals, if they have a minimum thickness of 0.5mm and are safely interconnected.
- The method for air terminals installation in SMART health facilities shall be the rolling sphere method since it is suitable in most roof configurations shapes and materials. Refer to the lightning protection guide (DEHN + SÖHNE, 2014).
- Exposed points, corners, and edges, especially on the top levels and on the upper parts of the facades shall also be protected (Bouquegneau, 2007).
- A tilt resistance to the wind is necessary to achieve air terminals stability, despite high winds.

3.1.2 Down conductor

Its function is to channel the intercepted electrical charge captured by the air terminal to the earthing system smoothly and efficiently, without producing any damage to the building. Consider this:

- The down conductors must be arranged in such a way that they are the direct continuation of the air-termination conductors.
- Several parallel current paths must exist to avoid damage to the building, and they should be installed straight and as short as possible.
- The number of down conductors depends on the perimeter of the external edges of the roof (perimeter of the projection onto the ground surface). They must be arranged to ensure that, starting at the corners of the structure, they are as uniformly distributed to the perimeter.
- The separation distance between down conductors is 10m according to IEC 62305.
- Down conductors must not be installed in gutters and downpipes, even if they are incorporated into an insulating material since the moisture in the gutters would cause corrosion of the down conductors.
- If the down conductor is equipped with a PVC sheath, aluminum can be installed in mortar, plaster, or concrete if it is ensured that the sheath will not be mechanically damaged, and the insulation will not break at low temperatures.
- Mount down conductors in such a way that a separation distance is maintained from all doors and windows.
- Metal downpipes can be used as natural down conductors if they are safely interconnected (soldered or riveted joints) and have a minimum wall thickness of 0.5 mm.
- If the wall is made of flammable materials, the down conductor shall be placed away from the wall.
- The mast shall serve as the down conductor, provided it is electrically continuous and a wall thickness of 0.064 in. (1.63 mm) minimum and the top of the metallic mast shall have a metal thickness of 3⁄16 in. (4.8 mm) or greater or be provided with at least one strike termination device.

- Depending upon the size of the structure, a minimum of two down conductors for the lightning protection system is required at opposite ends and these are each connected to an artificial ground which should be at least two feet away from the foundation walls.
- If the perimeter of the structure exceeds 250 feet, an additional down conductor should be provided for each additional 100 feet of perimeter, or fraction of the same, and each additional down conductor should be separately grounded.

3.1.3 Earth termination system

It conducts the electricity caught from the air terminal, down the down conductor and then dissipates it to the ground. A building is protected against damage by lightning if a means is provided or is available whereby a discharge may enter or leave the earth without passing through any nonconducting part of the structure (Hedlund, 1967), this assures the proper electrical function of the hospitals.

- Copper wires shall be used.
- The earth termination is placed 1m away from the building and at a depth of 0.5m.
- A ring conductor is highly recommended instead of multiple systems. Only if the building is surrounded by highly populated areas it is better to install multiple ring connectors to lessen the caused by step voltage[3]. Thus, it is very effective when there are trees around.
- The common-earth termination system is to be preferred and suitable for all purposes for the different electrical systems (lightning protection, telecommunications and, low-voltage systems).
- Due to the risk of corrosion at the point where a terminal lug leaves the concrete, additional anti-corrosion measures should be taken (PVC sheath or preferably stainless steel).
- It is recommended a low earth resistance of 10 Ω, or less (measured with a low frequency).
- The safest arrangement is to distribute the ground connections evenly around the perimeter of the structure, in which case current flow under or into the building will be less likely to occur.
- Overhead ground wires are used to provide a zone of protection. They must be made of a material to minimize corrosion from conditions at the site. They shall be a minimum diameter of 1⁄2 in. (13 mm) and shall be self-supporting with minimum sag.
- Two types of earthing arrangements are used: type A (horizontal or vertical earth electrodes connected to each down-conductor) and type B (ring conductor external to the structure in contact with the soil or foundation earth electrode).

3.2 Internal lightning protection

The internal LPS prevents dangerous sparking within the structure using either equipotential bonding[4] or a separation distance (electrical insulation) between the external LPS components and other electrically conducting elements inside the structure.

- Equipotential bonding is required for all electrical installations and on every building, because it removes potential differences, in other words, it prevents hazardous touch voltages[5] by using a meshed earthing system.

[3] A part of the earth's potential which can be bridged by a person taking a step of 1 m.
[4] An electrical connection maintaining various exposed conductive parts and extraneous conductive parts at substantially the same potential (Edvard, 2012).
[5] A voltage acting on a person between its standing surface on earth and when touching the down conductor.

- It is achieved by interconnecting (bonding conductors or surge protective devices SPD) the LPS with structural metal parts, metal installations, external conductive parts, and internal systems (electrical and electronic system within the structure to be protected).
- The following conductive parts must be directly integrated into the protective equipotential bonding system: earthing conductor, lightning protection earth electrode, conductive parts of the building structure, and earthing conductor for antennas, and metal shields of electrical and electronic conductors.
- Equipotential bonding conductors should be labeled as protective conductors: green/yellow.
- Equipotential bonding conductors do not carry operating currents and can, therefore, be either bare or insulated.
- The minimum cross-section of protective bonding conductors for connection to the main earthing busbar is 6 mm² (copper) or 16 mm² (aluminum) or 50 mm² (steel).
- All the conductors of each line entering the structure to be protected should be bonded directly or with an SPD. The eventual screens and conducts shall also be bonded near the entering point.
- Insulate the exposed down-conductors or impose physical restrictions and warning notices to avoid touch voltages.

3.3 Surge-protection devices (SPD)

- SPDs shall be installed between phase and earth to protect the electrical and electronic equipment against overvoltages.
- They must be installed for power lines entering the buildings.

3.4 Protection for Photovoltaic (PV) Systems

PV systems' large surface and layout in open areas make them more vulnerable to lightning strikes, which can affect the proper functioning of the PV generators, including their installation and sensitive electronic equipment such as inverters, batteries, and cables. In most cases, the cost of the damage exceeds the cost of the LPS implementation (Christodoulou *et al.*, 2016). Therefore, follow these measures:

- Connect PV systems to the existing lightning protection system in the building.
- Make provision for surge protection to avoid damages from the magnetic field produced by lightning.
- Place shielding of conducting systems to avoid lighting current from passing through the LPS to the PV system.
- Alongside surge protection devices, install an air termination and down conductor system either attached or not with the PV.
- Consider that low values of grounding resistance in PV installation (lower than 10Ω) is necessary to reduce potential overvoltages on PV systems.

3.5 Additional considerations

- Every device must be connected to the lightning protection system in the building. This includes medical equipment, PV systems, antennas, cameras, lighting, and energy back-up systems.
- There is a risk of uncontrolled flashover between parts of the external lightning protection system and metal and electrical installations in the building if the distance between the air termination

system or down conductor and metal and electrical installations in the structure requiring protection is not enough.

- If tall trees are close to the building, the lightning will strike the tree and produce flashes to the building, hence internal lighting protection must be considered alongside external one to prevent electrical damage.
- Staff should be trained to preserve the integrity of the lightning protection system.
- Only certified engineers should design and install lightning protection systems.
- Lightning protection systems should be inspected in-depth every year.
- Analyze the electrical part, the height of buildings, locations, surrounding structures to determine de risk of every hospital, this guideline considers the highest risk since the hospital's functions cannot be stopped in case of lightning strikes.
- Refer to the IEC 62305 standard for lightning protection for in-detail measures.
- In case of imminent fire, refer to Hospitals don't burn! Hospital Fire Prevention and Evacuation Guide.

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