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Lightning **Protection** and the Building Envelope

by Jennifer A. Morgan, CSI, and
Michael Chusid, RA, FCSI, CCS

Photo courtesy BigStock.com

GLOBAL WARMING COULD INCREASE LIGHTNING STRIKES BY 50 PERCENT, ACCORDING TO RECENTLY PUBLISHED CLIMATOLOGICAL RESEARCH. THE DISTRIBUTION OF LIGHTNING ACTIVITY MAY ALSO CHANGE, RAISING THE OCCURRENCE OF LIGHTNING IN REGIONS THAT HERETOFORE HAD LITTLE RISK.[1] AT THE SAME TIME, THE NEED FOR LIGHTNING PROTECTION BECOMES MORE URGENT AS BUILDINGS ARE FILLED WITH INCREASINGLY SENSITIVE ELECTRONIC DEVICES.

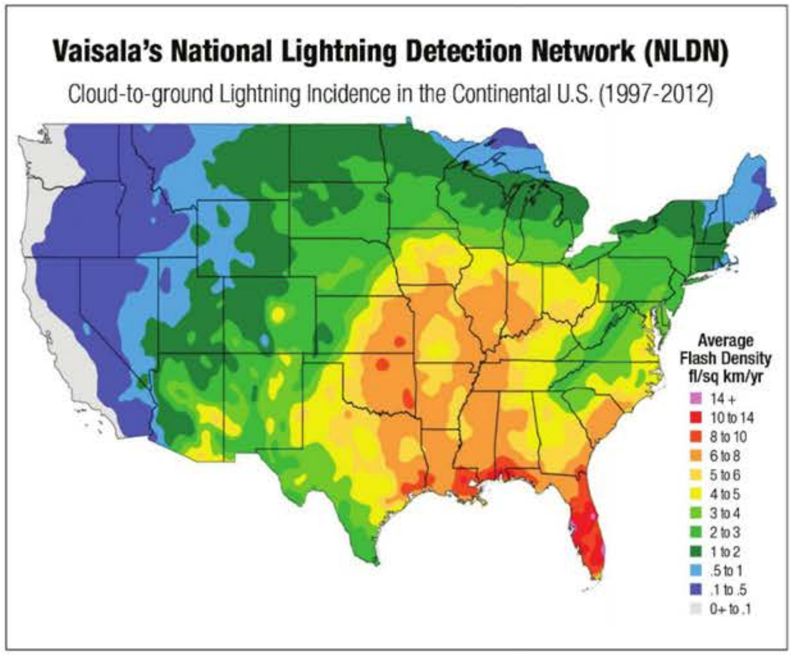
Lightning protection systems can be integrated with new architectural styles and innovative features—such as earth-covered roofs and rooftop photovoltaic (PV) collectors—and new strategies are emerging for special facilities such as stadia. There is also growing recognition that lightning protection contributes to the sustainability and resilience of buildings and communities.[2]

A discharge of static electricity between clouds and earth, lightning can send 300 million volts and 30,000 amps through the atmosphere—or whatever objects lie in its path. The electrical resistance encountered by the burst of energy can trigger fires, cause structural and physical damages, and disrupt electronics and other building services. It can also injure or kill people in or near the structure; lightning is the second most frequent weather-related cause of death.

Property damage from lightning has low probability, but high consequences. Lightning damage in the United States costs over $1 billion annually.[3] The dramatic zigzag bolt from the heavens—causing fires and structural damage—is the most typical image of lightning. Yet, damage can also occur when arcs leap from one structure into another, and when electrical surges travel for miles, through power or telephone lines, and fry circuits in computers, appliances, equipment, building control systems, and light-emitting diode (LED) lighting. These risks should be balanced against the modest cost of installing lightning protection.

Lightning protection is an intrinsic part of the building envelope that mediates between the building's contents and the electrical forces of nature. However, a building owner or a project's architect/engineer (A/E) may be concerned lightning protection will impact the building's aesthetic. This concern is understandable since everyone has seen buildings with carelessly placed components distracting from the structure's appearance.

Fortunately, the reality is most lightning protection systems can be nearly invisible from normal vantage points. Air terminals—previously known as 'lightning rods'—are typically slender, short rods that seem to disappear against the sky. Conductors, the cables that carry current to ground, can be run inside the building or can be detailed to blend into the design. As the case studies in this article demonstrate, lightning protection



Lightning is not limited to specific locations. More importantly, low flash density does not mean zero exposure to risk. California and Oregon, low-risk states, were among the 14 contiguous states that experienced lightning fatalities in 2013 (National Weather Service, http://www.iii.org/fact-statistic/lightning).

Image courtesy Vaisala

At Lake Sunapee, New Hampshire, this homage to lighthouses is a cleverly disguised air terminal on a deck. The top of the replica is made of solid brass and is connected to conductor cables concealed in the corner posts of the balustrade.

Photos courtesy Priestley Lightning Protection LLC

The short air terminals on this granite chimney are set back from the edge and are inconspicuous from the ground. To further minimize visual impact, down conductors penetrate through holes drilled in the chimney cap and are embedded in the masonry walls.

can be installed on most buildings without diminishing their appearance.

Design and certifications

The fundamentals of lightning protection have been recognized and improved upon for more than 200 years.[4] In the United States, they are codified in standards such as National Fire Protection Association (NFPA) 780, *Standard for the Installation of Lightning Protection Systems,* and Lightning Protection Institute (LPI) 175, *Standard of Practice for the Design, Installation, Inspection of Lightning Protection Systems.*

UL standards include:

- UL 96, *Lightning Protection Components*;
- UL 96A, *Installation Requirements for Lightning Protection Systems*;
- UL 497, *Protectors for Paired-conductor Communications Circuits*; and
- UL 1449, *Surge Protective Devices.*

Lightning protection systems must comply with industry standards, certifications, and listings to ensure quality of design, fabrication, installation, and inspection.

Design

Design should be performed by a qualified lightning protection system designer, such as an individual certified as a Designer Inspector (DI) or Master Installer Designer (MID) by the Lightning Protection Institute (LPI).

Complex projects, and those requiring careful coordination of lightning protection with the architectural design and layout of building services, benefit by obtaining guidance from a qualified lightning protection system designer at the early stages of project design. The system designer can be hired by the building owner or by the A/E as a consultant; in this case, detailed lightning protection drawings and specifications are issued as part of the project's contract documents.

Alternatively, the A/E can prepare a performance specification that delegates the detailed lightning protection design to the contractor. The lightning protection design is then prepared by a qualified individual working for the contractor or subcontractor. The design documents should be signed by a system designer, state the design complies with specified quality assurance (QA) requirements, and be submitted to the A/E as required in project specifications.

Fabrication

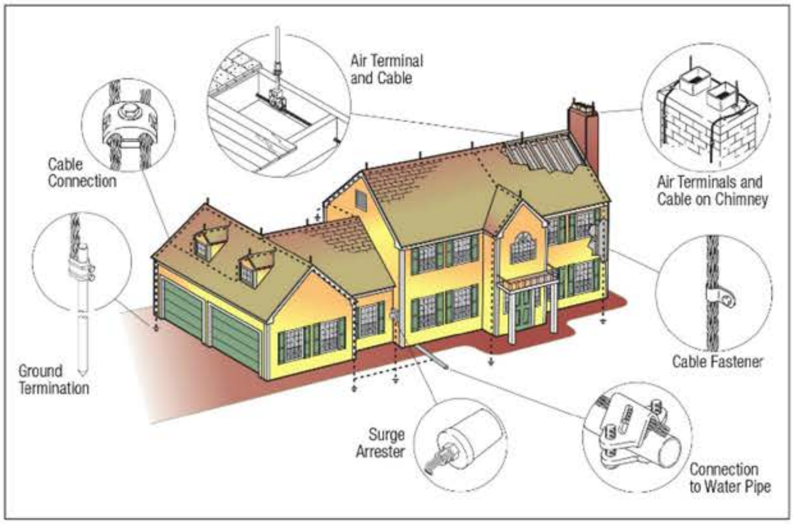
Components should be fabricated by firms that are UL-listed specifically for lightning protection; typical products listed for electrical systems might not be sized to handle a lightning strike. A full product line—including clamps, couplings, fasteners, and accessories—requires more than 2000 stock keeping units (SKUs) plus customization capabilities to meet the full range of construction conditions.

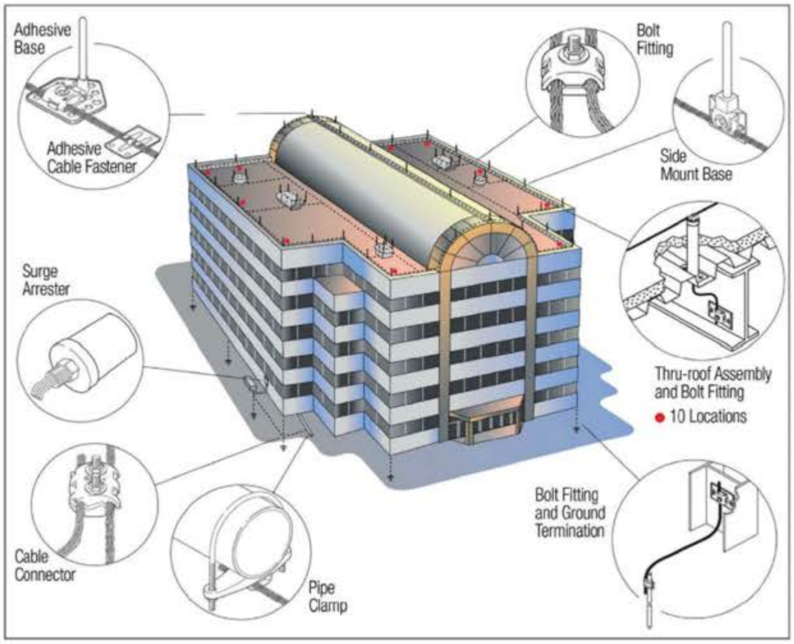
Installation

The International Association of Electrical Inspectors (IAEI) states, "Installation of a lightning protection system is much different from the installation of electrical service wiring." The installer should be a firm UL-listed for lightning protection. The firm should also be a dealer/contractor member of the Lightning Protection Institute (LPI) to ensure it has an employee certified as a Master Installer by LPI.

Inspection

Lightning protection systems are not inspected by most building code departments. For assurance





Lightning protection requires a continuous, conductive path from air terminals, through cables, to ground terminations. These components, along with connectors, mounting devices, surge protectors, and other accessories, should be manufactured by a company that is UL-listed for lightning protection equipment.

Images courtesy East Coast Lightning Equipment Inc.

the job was done correctly, a building owner should insist on an independent inspection and compliance with LPI's Master Installation Certificate program.[5]

While stringent, this criteria should be seen as minimum acceptable practices. Additional rules govern structures containing explosive materials, flammable vapors or gases, or other dangerous materials. Owners with mission-critical operations may also stipulate higher standards. At the new South Air Traffic Control Tower at Chicago's O'Hare International Airport, for example, the Federal Aviation Administration (FAA) boosted safety factors, created redundant systems, and installed more air terminals, including air terminals on the sides of the tower, than are justifiable in most buildings.

System components

Drawings and specifications prepared by the project's A/E should not attempt to size or locate lightning protection components or repeat requirements found in the standards. Only optional requirements and information essential for administration and coordination of project should be included.

Metal

Copper and aluminum are the most commonly used metals. Copper weathers to blend into dark-colored surfaces and can be treated to accelerate patina. However, it should not be used where runoff contacts steel or aluminum.

Aluminum may be more economical and blends well with light-colored surfaces. It should be used with aluminum roofing, but should not be embedded in concrete or used within 460 mm (18 in.) of grade.

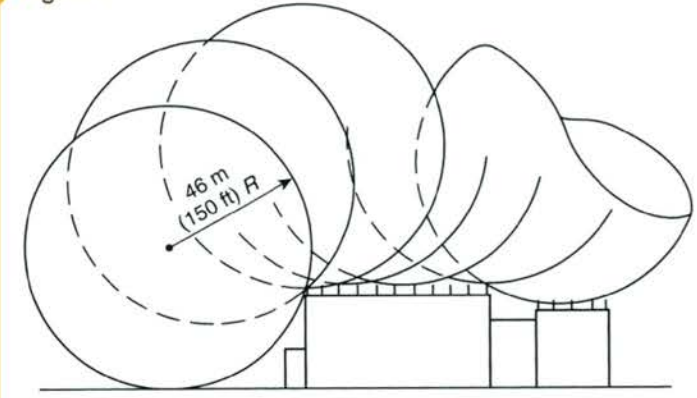
Tin-plated copper provides a dull metal appearance and is recommended for increased corrosion resistance in coastal areas. Stainless steel can be considered for use in highly corrosive environments.

Air terminals

Air terminals are located at the highest points on a structure and at spacings necessary to provide protection for the entire building. For example (NFPA), requires air terminals at regular intervals of no more than 6 m (20 ft) on center (o.c.) along a roof ridge and around the roof perimeter, and within 0.6 m (2 ft) of outside corners. An architect may want to require closer spacings, however, to align with architectural features or the modular spacing of elements on the exterior wall.

To minimize visibility from the ground, the air terminals can be mounted on the backside of parapets. While of less concern from a visual standpoint, air terminals are also required within the field of a large roof and on rooftop equipment; their location will be determined by using 'rolling sphere' calculations. See Figure 1 (page 16) for more about 'rolling sphere' calculations.

Figure 1



The rolling sphere method determines a building's 'zone of protection.' NFPA 780 states, "To apply the method, an imaginary sphere is rolled over the surface. All surface contact points are deemed to require protection, while the unaffected surfaces and volumes are deemed to be protected." A sphere with a radius of 45 m (150 ft) is suitable for typical buildings.

Image courtesy Lightning Safety Alliance

Temporary structures may also justify lightning protection. The "Big Bambú," designed by artists Mike and Doug Starn, was exhibited on the roof of the Metropolitan Museum in New York City in 2010. The Associated Lightning Rod Company collaborated with the artists to minimize visibility of air terminals and down conductors as well as collaborated in order to extend the museum's existing lightning protection system during construction.

Photo courtesy Mike and Dough Starn

Most air terminals are inconspicuous, but decorative options allow for ornamental and architectural expression. Sculptor Fitzhugh Karol says that this 2032-mm (80-in.) tall grouping was inspired by lightning rods and the shape of lightning strikes.

Photo courtesy Fitzhugh Karol

The simplest air terminals are metal rods. An air terminal can be as narrow as 9.5 mm (3/8 in.) in diameter and extend as little as 255 mm (10 in.) above the element on which it is mounted. Project conditions, however, may dictate larger and longer rods to provide sufficient conductivity and coverage. While tapered rods may be preferred to match historic styles, blunt-tip rods perform as well as pointed ones and offer greater safety to personnel that might fall onto them. Additional safety can be had by mounting air terminals on springs; spring-mounting also reduces damage that can be caused by roof-mounted window-washing equipment.

Creative expression can be given to air terminals. Decorative finials in a variety of historical styles are available. Additionally customized air terminals can be built into decorative elements, disguised as pennants, crowns, or spires, or treated like classical acroteria. For example, a residence overlooking Lake Sunapee, New Hampshire, has a deck that features air terminals integrated into lanterns—the look replicates the lighthouses that formerly guided ferries on the lake.

At the other end of the conspicuity spectrum, air terminals can be concealed or eliminated altogether. Handrails, snow rails, equipment screens, shade canopies, and other building elements can do double duty as air terminals when fabricated from 4.5-mm (3/16-in.) thick metal and installed with electrical continuity. Aire, a residential tower in New York City, for example, is in a high rent district near Lincoln Center. Designed by Handel Architects, its posh accoutrements include a fourth floor terrace surrounded by low walls topped with a stone coping. A nearly invisible metal plate is

For more on lightning, including risk assessment and cost estimates, visit www.constructionspecifier.com/lightning-risk.

At the cargo facility (left), rooftop conductors are covered with soil and plants while air terminals are left exposed. An air traffic control facility (right) exceeded industry standards, ensuring operational security even during worst-case scenarios. For this project, rooftop conductors were elevated above the plantings on stanchions and extra-long air terminals were specified in order to simplify inspection.
Photos courtesy HLP Systems Inc.

embedded in the stone and made electrically continuous to eliminate the need for air terminals. The same purpose is served at the building's roof where parapet copings that are neatly tailored from aluminum plate.[6]

Similar $^{3}/_{16}$-in. thick metal copings will also be used several blocks away at the 220 Central Park South building designed by Robert A.M. Stern. Zoning limits the building's height to 290 m (950 ft) to minimize shading of Central Park, and intense political pressure has prevented issuance of a variance—even for slender air terminals that will not be visible from ground level.

Special air terminals such as these might be specified in other sections, including work in Divisions 05 (Metal Fabrications), 07 (Flashings and Roof Specialties), or even 12 (Sculpture). Details and specifications must be carefully coordinated to ensure work is fully described without duplicating requirements.

These authors caution against the use of so-called 'early streamer emissions,' 'dissipation array,' and 'charge transfer' air terminal devices. Claims these devices 'attract' or 'repel' lightning to reduce the quantity of air terminals needed to protect a building have been debunked by NFPA, court rulings, and international studies.[7]

Conductors

The conductors are next on the path from air terminal to ground. They are typically made from braided metal cables; metal rods and straps can be used for special conditions. Conductors must be attached to the building with approved mechanical anchors or adhesives at intervals prescribed by NFPA 780.

Installing down conductors on the outside surface of exterior walls can be economical, simplify trade coordination, and facilitate inspection and system modifications. If a building site is not secure, it may be necessary to cover the conductors, especially copper, to deter theft or damage.

Even when exposed to view by the public, conductors can be placed with sensitivity to the architectural design. For example, conductors can run down the 'back' side of chimneys, be installed along building edges, or in corners, and be located away from main entrances.

Conductors (but not air terminals) can also be painted to match adjacent materials. Several of these techniques were employed recently when the lightning protection at Thomas Jefferson's Monticello was updated—flat-strap conductors were attached to the back of balusters around the rooftop and painted to match the woodwork, with down conductors tucked behind downspouts.

Conductors can also be concealed within the building. The conductors are sized to carry the momentary surge of power without generating enough heat to cause fires. This means they can be located beneath roof decks and in attics, in wall cavities and chases, cast into concrete, run through conduit, and installed in grooves routed

A braided aluminum cable leads from a through-roof penetration assembly and is joined to a structural steel column using a specially-sized bonding lug. The column conducts lightning down through the building, and at the bottom a bronze bonding lug holds another braided copper cable which leads to the lightning protection grounding system.

Photos courtesy Labeled Lightning Protection Inc.

into other material. Further, structural steel members can be used in lieu of conductors if they provide electrical continuity.

Concealing conductors is the obvious choice for new construction. However, they can also be concealed in remodeling projects. For example, the Virginia Museum of Fine Arts in Richmond was recently retrofitted for lightning protection without using exposed conductors. Rooftop conductors entered the building through abandoned roof vents and were bonded to existing structural steel columns that connected to ground electrodes installed in the basement of the building.

Penetrations

Locations where conductors pass through roofs, walls, structural members, and other building materials require the A/E's attention to ensure the function of the penetrated construction is not compromised. The integrity of fire-rated assemblies and water-resistant barriers, for example, must be maintained. A preinstallation meeting can help with trade coordination and scheduling.

Roof penetrations can be made with various types of boots, pitch pockets, and flashings—the selection and installation must be coordinated with the roofing supplier to make certain the roof warranty is not voided. It may be possible to avoid roof penetrations altogether. In one example, the owner of a computer server farm prohibited roof penetrations as a way to reduce the likelihood of roof leaks. Since the building's walls were tilt-up concrete panels, down conductors were located in the gaps between panels and became concealed when the joints were sealed.

Through-structure assemblies for wall penetrations are typically made with metal rods that can be cast or built into the walls or installed through drilled holes or in conduit.

Bonding

Lightning does not 'care' what path it takes between sky and ground; it will side-flash (arc) from components of the lightning protection system to parts of the building not designed to handle the current. The lightning protection system must, therefore, be connected (bonded) to grounded metal structural elements, piping, ductwork, wiring, equipment, antennae, and other equipment/building components within about 2 m (6 ft) of a conductor.

In this regard, judgment should be exercised before specifying corrugated stainless steel tubing (CSST) in buildings to be protected against lightning. Used to distribute liquid petroleum gas (propane), CSST is more economical to install than black iron pipe because it is flexible and requires fewer joints. While CSST can be bonded to the lightning protection system, its thin walls are still susceptible to perforation when exposed to a lightning side flash, allowing ignition of escaping fuel.

A research report states:

> The underlying issue…is whether or [not] CSST is as safe as conventional black pipe. In this regard, reported fire losses indicate it is not as safe as black pipe in regards to the issue of lightning. While we cannot state black pipe will never fail from lightning, we have yet to see such a fire.[8]

Ground electrode

The conductivity of soil at a building site affects its suitability as a ground for lightning protection. Wet clay may not be desirable from a structural perspective, yet it is highly conductive and performs

Properly installed conductors can be safely run through wood framing without creating a fire hazard. Conductors are made electrically continuous with steel columns using bolted connections and bimetallic fittings to prevent galvanic corrosion between dissimilar metals. At the foundation wall, the conductor runs behind masonry veneer to the location of the earth termination.
Photos courtesy Priestley Lightning Protection LLC

well as a ground. Dry sand, gravel, and rock have more resistance and will require more extensive methods to ground. If an owner obtains a soil investigation report, it can be made available to lightning system designers and installers; contractual provisions, however, should spell out what happens if site conditions differ from those in the report.

In conductive soil, a rod that has been located at least 0.6 m (2 ft) outside the building perimeter and driven 3 m (10 ft) vertically into the earth, may provide sufficient ground. In non-conductive soils, or where soil conditions make it difficult to drive a ground rod, a shallow ground plate or ground ring will help to distribute charges over a wider area. A ground ring, also known as a counterpoise, may be more economical than installing separate ground rods at each down conductor. Ground rings are also required for tall buildings

A test well is recommended to simplify inspection of a ground. The well selected should have a cover suitable for traffic loads that may be applied.

Surge protection

Any wire that enters a building is a potential path for lightning. In addition to power lines, contemporary buildings can be connected with wires for:

- electric gates;
- telephone and cable TV services;
- wells;
- satellite dishes and antennas;
- irrigation controls;
- surveillance cameras and security systems;
- site lighting and remote power receptacles;
- fire pumps;
- building-mounted lighting and signage; and
- photovoltaic collectors and generators.

In addition to protecting against lightning, surge protectors resist transient voltage from other external sources. However, since they do not protect against surges that originate within a building, individual pieces of equipment may still require their own surge protectors.

Surge-protective devices are usually furnished as part of the lightning protection work as their selection is integral to a complete, successful, lightning protection system. However, installation is typically performed by an electrical contractor because few installers have the electrician license necessary to install surge protective devices.

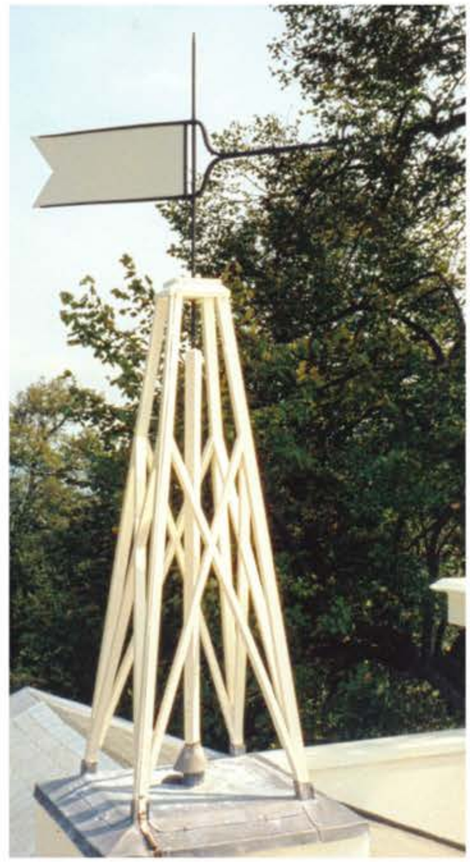
Site work

Tall trees next to buildings can present a problem when stuck by lightning, either by falling on the structure, or by causing the lightning to side-flash and strike building walls that are unprotected by air terminals. NFPA 780, therefore, recommends installation of lightning protection in trees with trunks within 3 m (10 ft) of a building or overtop of a building. Consideration should also be given to protecting valuable specimen trees, and other items onsite, such as pole-mounted lights with sensitive security concerns.

Items installed in open areas, such as pieces of equipment or small temporary structures, can be protected by a mast-mounted air terminal. Large areas—such as docks and military encampments—in which a multitude of masts would not be practical can be protected by conductors draped between widely spaced poles. This overhead shielding approach is called 'catenary lightning protection' after the shape assumed by the cables. It has been proposed as a means to protect arenas and other large outdoor venues where it is impractical to evacuate a crowd to safety when lightning approaches.[9]

An enduring investment

The building owner or manager should inspect the lightning protection system at regular intervals to make sure visible components are intact and securely mounted. Surge protectors can burn out due to lightning strikes or other surges; they should be equipped with indicator lights or connected to a monitoring system to facilitate inspection. LPI inspection certificates expire after three years,



Left: At exterior walls, down conductors are set into routs made in the masonry and hidden behind downspouts. In this photo, a short length of conductor is visible where it runs across the fascia just below the soffit.
Right: This weathervane, like most, can act as a lightning conductor. Metallic brush contacts were used to transfer current from the rotating spindle into down conductors. To conceal the conductors, flat metal straps were installed in the routed legs of the wood tower and painted to match.
Photo courtesy Loehr Lightning Protection Co. Inc.

following which a qualified inspector can be hired to test the system and make necessary repairs so the certification can be renewed.

While damage can occur from vandalism, abuse, or damage to the underlying structure, most problems are due to changes to the building. For example, this can occur when a new pump is installed and not properly bonded to the lightning protection system, or an air terminal is dislodged during maintenance of rooftop HVAC equipment. When new LED display panels were recently installed on the exterior of the United Center in Chicago, surge protectors were also added to make sure the only sparks flying would be when the Bulls or Blackhawks scored.

Re-roofing also requires attention. The owner should be consulted before disabling lightning protection in case special procedures are required, or the work schedule needs to be adjusted to maintain critical protection. NFPA 780 allows existing lightning protection components to be reused if they are UL-labeled, are equal to currently UL-listed products, and are determined by a qualified system designer to be in satisfactory condition. Modifications to the lightning protection work should be performed by a qualified installer to prevent the building's certification from being voided.

Conclusion

The duration of a typical lightning strike is about 30 microseconds. Fortunately, a properly designed and installed lightning protection system can last a bit longer, even for the life of a structure. Further, the metal components can be recycled after decommissioning. These factors, plus the protection to the building, its contents, and its occupants, make lightning protection an intrinsically green part of sustainable construction.

By observing these guidelines, a building owner should enjoy the peace of mind knowing the risk of lightning damage is nil even if lightning activity increases as is forecast. If only it were so easy to protect against other climate-related risks.[10] **CS**

Notes

[1] D. Romps et al had an article, "Projected Increase in Lightning Strikes in the United States Due to Global Warming," that was published in the newest edition of *Science*. The editor summarizes: "Lightning occurs more frequently when it is hotter than when it is colder… They predict the number of lightning strikes will increase by about 12 percent for every degree of rise in global average air temperature." C.G. Price, in "Global Lightning Activity and Climate Change,"

An example of a non-proprietary guide specification for a lightning protection assembly, written by these authors, can be downloaded from www.constructionspecifier.com/lightning-specs.

forecasts lightning-related forest fires will increase by 40 percent and the area burned by 65 percent, creating greater risk for buildings at the wildland-urban interface.

[2] The U.S. Federal Emergency Management Agency (FEMA) recognizes lightning protection as part of multi-hazard mitigation planning, especially with regards to the protection of critical infrastructure needed to respond to a disaster. Lightning, it should be noted, can occur in conjunction with tornados, volcanic eruptions, hurricanes, wild fires, flooding due to thunderstorms, and other disasters.

[3] According to the Insurance Information Institute, lightning accounted for about $1 billion in homeowner's insurance claims each year. Lightning fires in non-residential properties caused an average of $108 million in direct property damage annually, not including damage due to electrical or equipment malfunctions, non-fire-related structural damage, consequential damages, or harm to individuals. Visit www.iii.org/fact-statistic/lightning.

[4] In brief, the lightning protection system provides a low resistance path with adequate capacity for lightning's electrical charge. Air terminals are placed at locations most likely to be the launching point for a lightning strike. They are interconnected with highly conductive cables that lead to ground electrodes. For additional information, visit www.lightning.org.

[5] Recent changes have weakened UL's Master Label Certification by allowing installers to sometimes ascertain the 'quality assurance' (QA) of their own work. Furthermore, some lightning protection installer firms will obtain inspection certificates for work they did not actually install—it is important to check credentials in advance and make sure the firm named on a certification is the same as the firm that did the installation.

[6] See www.tinyurl.com/q4tu5u2 for the *Wall Street Journal* article.

[7]Visit, www.lightning.org/wp-content/uploads/2014/12/NFPA_DAS-CTS.pdf, www.lightningsafety.com/nlsi_lhm/early-streamer-emission.pdf, and www.lightningsafety.com/nlsi_lhm/magic.pdf.

[8] To read "Lightning Induced CSST Fires," by M. Goodson and M. Hergenrether, visit www.lightning.org/wp-content/uploads/2014/12/CSST_-_Interscience_2005_Report.pdf.

[9] The article, "Lightning Safety and Large Stadiums," by Joel Gratz and Erik Noblr (Bulletin of American Meteorological Society, September 2006), can be read by visiting www.journals.ametsoc.org/doi/pdf/10.1175/BAMS-87-9-1187.

[10] For assistance with this article, the authors wish to thank the following: Robert J. Cooper of Associated Lightning Rod Co. (Millerton, New York), Justin Harger of HLP Systems (Libertyville, Illinois), JJ Loehr of Loehr Lightning Protection (Richmond, Virginia), and Will Priestley of Priestley Lightning Protection (Piermont, New Hampshire).

ADDITIONAL **INFORMATION**

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Abstract

Lightning protection is an intrinsic part of the building envelope that mediates between the building's contents and the forces of nature. A building owner or a project's architect/engineer may be concerned lightning protection will disfigure the building, but most air terminals (*i.e.* what used to be called 'lightning rods') are nearly invisible from normal vantage points. At the same time, conductors, the cables that carry current to ground, can be run inside the building or can be detailed to blend into the design. As the case studies included in this article demonstrate, lightning protection can be installed without impact on the beauty of most buildings while still providing safety.

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26 41 00–Facility Lightning Protection

UniFormat No.

B3020–Roof Appurtenances
D5080.10–Lightning Protection

Key words

Division 26
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Fire protection
Grounding
Lightning
Safety
Surge protection