Progress in Disaster Science 28 (2025) 100460

Contents lists available at ScienceDirect

Progress in Disaster Science

journal homepage: www.elsevier.com/locate/pdisas

Use caution with the word ‘shelter’ in lightning safety☆

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ARTICLE INFO

Keywords:
Shelter
Emergency shelter
Lightning
Lightning injury
Lightning protection standards

ABSTRACT

In some countries, lightning causes more deaths than other weather events more commonly thought of as disasters, so there is a need for safe refuges during thunderstorms. Lightning also occurs with volcanoes, hurricanes, tornadoes and other disasters so that disaster refuges in most areas should have lightning protection systems designed consistent with international standards. Of special concern is that the term ‘shelter’ in the U.S. and some other English-speaking countries is associated with many small structures that are nearly always unsafe from lightning. Factors that contribute to lightning risk are listed, as well as the importance of recognizing the mechanisms of lightning injury. Photographic examples are included of structures that are unsafe from lightning in several countries. How to make such structures safe from lightning is described as well as a brief overview of lightning injury prevention.

1. Introduction

In design of shelters for disasters, lightning protection may not be commonly considered. However, lightning occurs in hurricanes, monsoons, tornadoes, and volcanoes to name only a few types of disaster. This paper considers the common misuse of the word “shelter”, lightning risk, and introduces lightning protection standards that should be applied to emergency shelters.

1.1. The word “shelter”

The word ‘shelter’ can be misunderstood in lightning safety recommendations within developed English-speaking countries. A “shelter” is usually thought to be a temporary place to keep dry from rain or sun. Examples include rain shelters, beach shelters, sun shelters, and bus shelters. Worldwide, people often use trees as a ‘rain shelter’ [15]. Additional locations that may be wrongly perceived as safe from lightning are tents [4,12,29], small sheds, concession stands and team dugouts at sporting events.

There are only two “lightning-safe locations” where people can go to be safe from lightning. [22]. One location is a structure equipped with a lightning protection system (LPS) meeting the requirements of [19] (or equivalent national standards) with an area large enough to provide adequate separation distance from LPS down conductors. Most homes in developed countries, churches, libraries, schools, shopping malls, and other “substantial” buildings are considered “shelters” but not from the effects of lightning, including fire and damage to electronics, unless properly protected from the direct and indirect threats of lightning. Although such buildings may not have lightning safety systems explicitly installed, the grounded wiring and plumbing required by building codes typically provide some safety from lightning affecting the structure. Damage may and does occur to these structures, but people are nearly always able to exit in time to avoid death or serious injury if lightning causes a fire. The second location is a fully enclosed metal-topped vehicle such as a car, bus, or truck. Open air taxis, boda-bodas, motorcycles, cloth topped vehicles, convertibles, and golf carts are some examples that do not satisfy this “enclosed, all-metal” criterion. Lightning-safe locations both intercept the lightning and provide a safe path for lightning energy to travel around anyone inside based on the principle similar to that of a Faraday cage.

1.2. Is lightning a “disaster?”

Use of the term “disaster” to many people brings to mind a sudden

☆ This article is part of a Special issue entitled: ‘Disaster and Shelter Management’ published in Progress in Disaster Science.

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https://doi.org/10.1016/j.pdisas.2025.100460
Received 29 August 2024; Received in revised form 29 January 2025; Accepted 13 August 2025
Available online 15 August 2025

Table 1
Risk factors for lightning injury and death. Modified from [7]. Courtesy Dr. Mary Ann Cooper.

Factors that INCREASE Risk	Factors that DECREASE Risk
High lightning stroke density	Low lightning stroke density
Large rural population	Mostly urban population
Increasing population	Stable or decreasing populations
Labour intensive, outdoor work such as farming, fishing and animal husbandry	Mechanized farming and stricter lightning protection systems governing work conditions
Inadequate building construction. No lightning protection mandated for public and frequently inhabited buildings; lack of technical knowledge about lightning protection; use of lightning protection materials that are not compliant with international lightning protection codes	High quality building construction involving wiring, plumbing and metal components in the walls and roof combined to act as a 'Faraday cage' to safely divert lightning energy around inhabitants. Code-compliant lightning protection mandated for public buildings and those frequently inhabited by large numbers of people
Lack of lightning-safe areas for easy evacuation; lack of proven actions that individuals can take to decrease risk	Easy availability of lightning-safe buildings and fully enclosed metal-topped vehicles within easy reach. Widespread personal knowledge of lightning injury avoidance behaviour.
No or little lightning detection data or non-availability to the public	High-quality lightning detection data incorporated into weather forecasts
Lack of reliable and timely weather forecasts or forecasts that are only available to specific sectors of the economy, primarily aviation	Weather forecasting systems with high quality forecasts and weather apps available to the public on a free and real time basis
Delayed or nonexistent access to high quality medical care	Reliable medical care is usually available within minutes
Low literacy rate; multiple languages	High literacy rate
Little or no valid public education on lightning safety; strongly held beliefs that injuries are inevitable, regardless of personal behaviour, that lightning is called down by witches and other cultural beliefs	An active media; news reports of injuries; enthusiastic public education with wide access to lightning safety information; knowledge of how lightning is formed and where it is statistically more likely to hit

incident that causes great damage, great loss of life, or an event that overwhelms the capacity of the community to address the injuries or destruction. It is unusual for lightning incidents to cause more than one or two deaths or a few injuries at a time in developed countries, so it is not typically included as a disaster in most people's minds. Research in many developing countries, however, has shown that lightning causes more deaths annually than tornadoes, hurricanes, or other incidents commonly thought of as disasters [8,26,28,35].

There are usually no national reporting systems for injuries and deaths caused by lightning, so data may be difficult to gather. Unless it involves a school or many people, events are unlikely to trigger a disaster response from the health or disaster community or to draw the attention of the media. This is particularly true in countries where the media is not secure or well developed due to literacy levels, poverty, civil unrest or other factors. In addition to these limiting factors, in many developing countries, spiritual causes such as curses or punishment for sins may be attributed to lightning incidents so that families are unlikely to report their family member's injury or death for fear of being shunned and forced to move away from their communities and start anew [23].

However, compared to tornadoes, hurricanes, floods, and mudslides, lightning is the most common weather threat to life that people worldwide encounter. In several locations during rainy seasons, lightning is often experienced by people on a daily basis who often have no knowledge of what they can do to decrease their risk. This situation is particularly prevalent in areas with poor infrastructure and where lightning is poorly understood. Risk factors for lightning injury and death are shown in Table 1.

1.3. Mechanisms of injury by lightning

Most people recognize only a direct cloud-to-person strike as a cause of lightning injury or death, leading them to think of only protection from overhead danger. However, as Fig. 1 illustrates, studies have shown that "direct" strikes are a much less common cause of death than other mechanisms. [2,3,6].

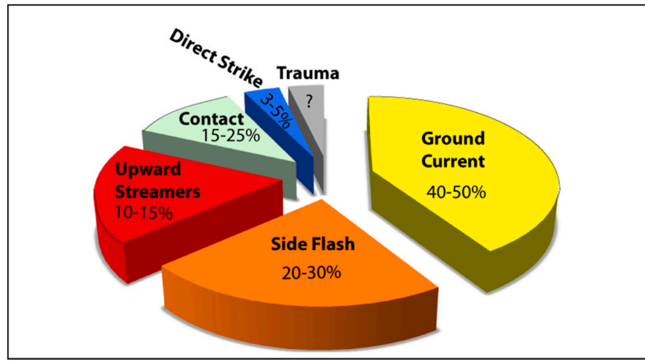

Fig. 1. Pie chart of the frequencies of the primary lightning fatality mechanisms. (Adapted from Fig. 2 in [6]).

Table 2
List of types of small structures that are often mistakenly used in developed countries for quick safety from lightning and other weather impacts.

Shelter type	Rain	Sun	Wind	Lightning
Beach {[13]]	Yes	Yes	Some	No
Bus [1]	Yes	Yes	Yes	No
Concession stands	Yes	Yes	Some	No
Golf [12]	Yes	Yes	Some	No
Lifeguard stands	Some	Some	Some	No
Daytime market stall	Some	Yes	Some	No
Park	Yes	Yes	Some	No
Picnic	Yes	Yes	Some	No
Rain	Yes	Yes	Some	No
Rest rooms at parks	Yes	Yes	Yes	No
Small shed [14]	Yes	Yes	Yes	No
Sun	Yes	Yes	Yes	No
Tent [12]	Yes	Yes	Some	No
Tree [15]	Some	Some	Some	No

Lightning injury mechanisms shown in Fig. 1 are explained as follows. Lightning safety messages must take into account all of these mechanisms, not only that from the relatively scarce situation of an overhead cloud source of lightning.

1. Direct strike – cloud to person.
2. Contact injury – someone is touching an object struck at a distance that has transmitted energy to the person such as a fence, plumbing, or wiring (also known as touch voltage).
3. Upward Leader (also called streamer) – an electrically charged thundercloud induces an opposite charge in anything under it, including people, often producing an 'upward leader' from the person or object. Even though lightning does not intercept this leader, there is enough energy to cause death or injury when the current collapses after lightning hits somewhere else.
4. Side Flash – energy has jumped from a struck object such as a tree to a person close by.
5. Ground current – when lightning hits the ground, it travels radially through the earth and can injure people at a distance (also known as step voltage and ground potential).
6. Barotrauma – the super-heating effect of lightning passing through the air close by acts as an explosion, causing pressure injuries.

Fig. 2. Lifeguard structure on the beach in San Diego, California, U.S. This is not a lightning-safe structure. (Photo courtesy Ronald L. Holle).

Fig. 3. Left: Picnic structure in large city park in Tucson, Arizona, U.S. Right: Sign mounted on roof inside structure. This is not a lightning-safe structure. (Photo courtesy Ronald L. Holle).

Fig. 4. Outdoor rest room structure at Lake Minnewanka, Banff National Park, Alberta, Canada. This is not a lightning-safe structure. (Photo courtesy Ronald L. Holle).

Fig. 5. Typical bus shelter at Grand Forks, North Dakota, U.S. This is not a lightning-safe structure. (Photo courtesy Daile Zhang).

Fig. 6. Typical housing in rural Zambia. These are not lightning-safe structures. (Photo courtesy Mary Ann Cooper).

2. Types of shelters

2.1. Developed countries

Table 2 provides some context for the typical protection provided by locations using the word shelter in developed countries. Unless these locations are protected from lightning with a specifically designed lightning protection system consistent with internationally accepted lightning protection (LP) standards, one should be counselled to assume they are unsafe.

The following are several installations listed in Table 2 and shown in photographs, as well as some published incidents of note:

- Fig. 2 shows a raised well-constructed lifeguard structure, but no lightning protection is apparent. Although San Diego has few lightning events, some storms can produce significant numbers of flashes for short periods.
- Fig. 3 shows a picnic shelter that has an unusual sign on its inside roof. This was installed at the request of a lightning science group in Tucson, since there is no installed lightning protection. However, note that it uses the word shelter and is not precise about where to proceed when leaving this lightning-unsafe structure.

Fig. 7. Informal settlement in rural South Africa. These are not lightning-safe structures. (Photo courtesy Ronald L. Holle).

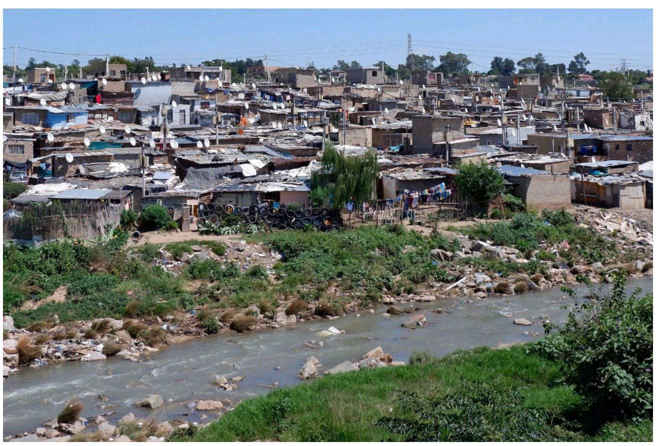

Fig. 8. Alexandra Migrant Settlement, Gauteng, South Africa (photo credit GSalamander).

Fig. 9. Typical school in Uganda where hundreds of students are killed and injured every year by lightning [27,30,31]. These are not lightning-safe structures. (Photo courtesy ACLENet).

- Fig. 4 has a substantial rest room facility at a popular lake in Banff National Park in Canada. Note that it has openings across the top, but no lightning protection is apparent.
- Fig. 5 shows a typical bus shelter at Grand Forks, North Dakota. [1] reviewed two cases of 16 lightning casualties occurring inside bus shelters in Ukraine that had no lightning protection.

2.2. Developing countries

In developing countries, the term "shelter" is not as broadly used for small structures as in the U.S., Canada, and the U.K. Many homes, schools, shops, and other dwellings are not much more substantial than the structures included in Section 2 [11,16,24]. They may be built of grass and mud brick, or from a collection of discarded or partial building materials (see Figs. 6, 7, 8 and 9). While they provide some protection from rain, sun, wind, and sometimes snow, none of these dwellings are safe from lightning since they have no continuous paths for current to travel safely around them to earth. In such situations, people inside are as vulnerable to lightning as if they are in an open field outside.

An additional danger that has been identified from incidents reported for thatched building is the devastating burn injuries that can be suffered if thatch is ignited but the people inside are unable to escape due to keraunoparalysis. This is usually a temporary post-lightning paralysis that lasts for minutes to hours after a lightning injury [34].

3. Lightning safety procedures

3.1. How to make small structures safer from lightning

Lightning protection systems (LPS) have four primary components: 1) air terminals, often called lightning rods or arrestors 2) down conductors, 3) an earthing system, and 4) bonding and surge protection to protect electrical systems, appliances, and people in the building. Although LPS design is beyond the scope of this paper, levels of lightning safety are addressed, and readers are referred to NFPA780 or [17–20]. It is usually much less expensive to include LPS at the design stage rather than retrofit them.

If a protected structure is not available, larger buildings such as homes, schools, shopping malls can provide a reduced level of protection. Schools and shopping malls in developed countries generally will have steel or reinforced-concrete construction that can provide some shielding from lightning electromagnetic pulse (LEMP). They are more likely to have surge protection although unlikely to have sufficient equipotential bonding or grounding system that meet LPS standards. They may suffer physical damage from direct strikes but protect those inside the structure. There is a wide variety of unsafe structures that are used as refuges from rain, sun, and other weather exposure such as grass-roofed houses, animal stalls, temporary shops, and other non-traditional facilities [9]. Each of them needs to be specifically addressed within the context of the situation, taking into account the number of people that may frequent them, and the difficulty and cost of making the structures lightning-safe.

Unprotected homes are considered safe locations by many but are not as safe as the above structures. The US National Weather Service reports that lightning starts approximately 4400 house fires with around 16 deaths attributed to lightning-caused fires, most being occupants of houses ignited by lightning [5]. NFPA reports that lightning is responsible for approximately 4 % of all reported house fires in the US. Additional sources of lightning-related reported deaths and injuries in homes are related to the use of electrical/electronic systems and metallic plumbing systems.

3.2. Protection of emergency shelters

Emergency shelters intended for disaster applications should be considered critical for life safety. Unfortunately, these shelters may also become long term homes in many situations for persons displaced when their homes have been destroyed, particularly in developing countries.

One of the aspects of disaster risk reduction is to protect emergency shelters against the effects of lightning [10,21,25,36]. It is necessary to reduce the lightning risk to the shelter and its contents, including people seeking refuge, to a tolerable level. It is critical that a Lightning Risk Assessment be performed in accordance with [18] that addresses all intended uses of the shelter and all critical contents. The results of the assessment will be used to establish the protection level and design of the protection system to meet the tolerable level required.

Fig. 10. Lightning safety information illustrated here and used originally in the U.S. was found to be too difficult to remember when needed in a crisis situation.

3.3. Lightning injury prevention

In many lightning safety programs, advocates often promote a long list of "don'ts" – what people should not do when there is risk of lightning injury (Fig. 10). Experience has shown that these may be complicated or confusing and not easily recalled in a crisis situation during a thunderstorm.

Extensive study of lightning casualty incidents over the years by the U.S. National Lightning Safety Council [22], a multidisciplinary group, has shown it is far better to provide short, succinct advice detailing behaviors that should be followed. Three mottoes that have been tested and used extensively for many years are:

- When Thunder Roars, Go Indoors.
- NO PLACE OUTSIDE is safe when thunderstorms are in the area.
- 30 min since thunder roared, now its safe to go outdoors.

Testing has shown that even preschoolers can remember "When Thunder Roars, Go Indoors" in a crisis. Unfortunately, in countries with insufficient infrastructure and few lightning-safe areas, this motto is not always the best advice [32–34].

4. Summary

Illustration of the use of the word "shelter" in this paper reveals it as a misleading and problematic word in lightning safety, so we urge the adoption of a less easily misunderstood term such as refuge. The distinction between lightning-safe locations and commonly misperceived "shelters" must be clearly communicated in both disaster planning and public education. Emergency shelters, which may serve as long-term housing for displaced populations, require particular attention to lightning protection. These facilities should undergo thorough Lightning Risk Assessments as specified by [18] and be equipped with appropriate protection systems. It is always less expensive to plan LPS into structure designs than to retrofit refuges after the need for lightning protection is recognized.

Looking ahead, there is a pressing need to integrate lightning protection considerations into disaster shelter design and emergency planning, especially in regions where lightning poses a frequent threat. Future disaster preparedness strategies must recognize lightning as a significant threat and ensure that emergency shelters truly provide comprehensive protection for vulnerable populations.

Funding

This paper did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Credit author statement

All four authors were substantively involved in all phases of the writing and proofing. Cooper, Holle, and Zhang contributed photos. MACooper did the final compilation and checking, along with highlights and author statements. Holle, Zhang and Cooper did the final proofing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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