Feature

# Key Considerations for Roof Drainage Design

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**EFFECTIVE ROOF DRAINAGE** is critical for managing water from rain or snow and preventing water accumulation which could damage a building's roofing system and structure. Roof drainage systems consist of sloped roofing surfaces combined with primary and, where required, secondary (backup) drainage systems to collect and direct water from a building's roof. Primary roof drainage systems located at the low points in the roof are the intended means for evacuating water from building roofs. They can consist of internal drainage systems, perimeter gutters, or through-wall scuppers, all of which have various configurations suitable for project-specific conditions. On roofs where water can accumulate, secondary drainage systems, also known as overflow drainage systems, function as a backup in case the primary drainage system fails (e.g., clogged primary drains). Secondary drainage systems may include a combination of internal overflow drains and scuppers; where perimeter conditions limit the risk of ponding sufficiently, water is allowed to flow over roof edges for secondary drainage. While more recent building codes require buildings to be designed with both primary and secondary drainage systems, many older buildings were constructed with only primary drainage systems and are vulnerable to drain system failure until modernized.

The effectiveness of a roof drainage system impacts the overall performance, longevity, and integrity of a building's roof assembly, including roof structure, and depends on proper design, installation, and maintenance. Improperly designed, installed, and/or maintained roof drainage systems can result in various failures ranging in severity, including water leakage into the building interior, premature damage to roofing materials and the roof structure, and water accumulation that can result in excess roof deck deflection and potential collapse of the roof structure (**Fig. 1**).

Roofing drainage system failures can result from inadequate design, which may include a combination of poorly designed tapered insulation, selected placement of roof drainage systems, inadequate drain sizing, lack of redundancy, and drainage systems with difficult maintenance access. Even properly designed roofing drainage systems can experience performance problems with defective installation, such as misaligned, improper, or missing drain connections; improper selection and/or installation of gaskets; incompatible materials; and system/material substitutions of lower performance. Additionally, insufficient maintenance may exacerbate failures related to design and/or construction deficiencies or can cause failure of well-designed and well-installed drainage systems.

Anecdotally, the authors' understanding of the increasing frequency and severity of rain events over the past decade has heightened our awareness and focus on roofing drainage design. This understanding is given credence by studies conducted by the US Global Change Research Program (USGCRP), the National Oceanic and Atmospheric Administration (NOAA), and the US Environmental Protection Agency (EPA) that show the following:

- From approximately 1901 to 2016, annual average precipitation has increased by 4% across the US.[1]
- From 1958 to 2021, the number of extreme precipitation days (the heaviest 1% of days) have intensified in every major US region, led by the Northeast, with an increase of 60%, and the Midwest, with an increase of 45% (**Fig. 2**).[2] "The largest observed increases have occurred and are projected to continue to occur in the Northeast and Midwest, where additional increases exceeding 40% are projected for these regions by 2070-2099 relative to 1986-2015."[1]



  

**Figure 1.** *Water accumulation on a roof after a storm event (note damage to adjacent roofing).*

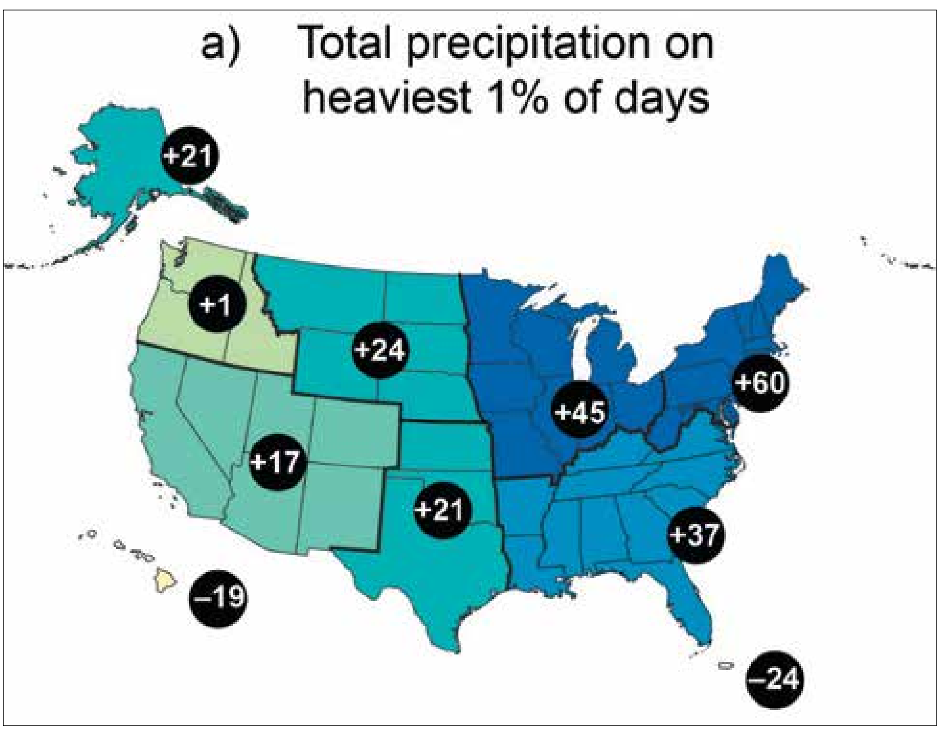


**Figure 2.** *Observed changes in the frequency and severity of heavy precipitation events (heaviest 1% of days). Courtesy of NOAA NCEI.*

- Nine of the top 10 years for extreme one-day precipitation events recorded since 1910 have occurred since 1995.[3]
- The Simple Hourly Rainfall Intensity Index (average rainfall intensity in inches per hour) has an increase of 13% across 150 US locations since 1970.[4]

We expect this precipitation study data to become a consideration for building designers, particularly related to the risk that increased rainfall intensity exceeds the code-prescribed data used for design. Recently, building codes have included updates to help designers understand and meet code requirements for the rainfall intensity during extreme precipitation events. For example, ASCE 7, *Minimum Design Loads for Buildings and Other Structures,*[5] published by The American Society of Civil Engineers (ASCE), recognizes the need to design secondary drainage systems to accommodate more intense, shorter-duration storm events. Specifically, ASCE 7-16 includes requirements for calculating rain loads based on a 15-minute duration, 100-year rainfall event.

While buildings are often designed with systems and materials expected to provide a service life of 20 to 50 years or more, in our experience it is uncommon to design drainage systems to consider the impact of future climate change. With increasing frequency and intensity of precipitation events, roof drainage systems designed 20 or more years ago may be nearing the end of their service life and may be likely to become overloaded and can be at greater risk of failure. For example, the 1995 *International Plumbing* Code (IPC)[6] had a rainfall rate of 4.6 in. (116.84 mm)/per hour in Houston, Texas, and the 2021 IPC had the same rainfall rate for the same location.

## ROOF DRAINAGE SYSTEMS

Roof drainage design considerations include the building design features, geometry, location, roofing system selection, roof perimeter details, rooftop equipment, interior space design, and owner's performance requirements. Effective roofing drainage for low-slope roofing assemblies typically begins with a membrane-level slope to direct water to drain assemblies. This slope is commonly achieved by a sloped deck or insulation beneath the roofing membrane. Low-slope roofing assemblies are typically designed with a ¼ in./ft (20.9 mm/m) slope by code but can be installed with less slope in reroofing applications (for example, Chapter 15 of the 2024 *International Building Code*[7] states that roof replacement or recover applications are not required to meet the current slope requirements as long as the roof provides positive roof drainage and meets the structural snow and rain load requirements).

Common roof drainage systems include the following:

- **Internal drains:** In low-slope roofs, the drain flange is integrated with the roofing or waterproofing membrane and connected to plumbing routed through the interior of the building (**Fig. 3**). Typical components include the drain bowl, clamping ring, strainer, and hardware for deck attachment. The interior plumbing is concealed behind wall finishes and above ceilings, with access panels for cleanouts, but is often not readily accessible.

- **Gutters:** A horizontally installed channel-type drain, installed along the roof edge to collect water (hung gutter) (**Fig. 4**) or recessed into the roof assembly (built-in gutters). Gutters are often sloped to direct water into exterior vertical leaders. Gutter profiles vary based on required strength and drainage requirements.
- **Scuppers:** These drain openings through a wall or curb are lined with watertight sheet metal or membrane roofing (**Fig. 5**). Scuppers may be used for primary and/or secondary drainage. Scuppers may drain into conductor boxes connected to vertical leaders or discharge freely from the opening (secondary drainage).
- **Other:** The authors are aware of less common drainage systems (for example, siphonic drainage assemblies and controlled drainage assemblies), but these are beyond the scope of this paper. For more information, reference the IPC and roof drain manufacturer literature.

**Figure 3.** *Common internal roof drain assembly on low-sloped roof.*

**Figure 4.** *Hung gutter and down leader drainage system.*

## DESIGN ROLES AND RESPONSIBILITIES

A recent project experience highlights the need to understand the coordinated multidisciplinary design effort required for a code-compliant roof drainage design. The scupper size designed by the architect, the drain flow analysis by the plumbing engineer, and the rain load used by the truss engineer of record were not coordinated, and some drains needed to be enlarged. The contractor, in turn, made drains smaller because of the way flashing was installed at the drains. The design must take into consideration the building type, location, geometry, roofing system, slope design, perimeter and rising wall conditions, roof structure capacity, primary and secondary (overflow) roof drain types and location, and constructability, and it must be coordinated within the design team and communicated to the contractor.

## ROOF DRAINAGE DESIGN REQUIREMENTS

The International Code Council (ICC) introduced the first *International Building Code*[7] (IBC) in 2000. The IBC references the *International Plumbing Code*[6] (IPC) to consolidate the regional codes previously used across the US. The IPC governs primary roof drainage system design requirements, while secondary drainage systems are designed according to requirements in both the IBC and IPC. This section provides a summary of common governing code requirements and design process for these drainage systems.

## PRIMARY ROOF DRAINAGE

Since 1995 and through the current 2024 publications, the IPC includes design rainfall rate maps indicating the 100-year, 1-hour (hourly) rainfall intensity across the US, which are used to design roof drainage systems; the

**Figure 5.** *Through-wall scupper drainage system.*

2000 IBC to the 2021 IBC provided similar 100-year hourly rainfall intensity maps. The 1995 IPC code rainfall rates remain unchanged through the 2024 IPC. However, the 2024 IBC removed these rainfall intensity maps and now references Chapter 8 of ASCE 7 for evaluating rain loads and provides updated design requirements discussed below. The 100-year hourly design rainfall maps in the IPC and prior to the 2024 IBC are based on some of the first comprehensive studies providing precipitation frequency estimates for various US regions, published by NOAA in 1973 (NOAA Atlas 2[8] in multiple volumes)[8] and 1977 (NOAA Technical Memorandum NWS Hydro-35[9]).

The IPC requires primary roof drainage systems to be designed by determining the total roof area (or projected roof area for steep slopes) plus one-half of adjacent rising wall areas to account for wind-driven rain on vertical surfaces that drain onto the roof below. Rainfall intensity (rates) are given on the rainfall maps applicable to the project location. Using this information, drain sizes can be selected based on the prescriptive tables provided in the IPC, including storm drainpipes (vertical and horizontal) and horizontal gutters.

Currently, these prescriptive rainfall maps found in Section 1106 of the IPC have not yet been updated for recent data related to rainfall frequency and intensity. Given that the building code allows the use of "approved" data, designers might choose to utilize updated weather data, such as rainfall data provided by NOAA Atlas 14.[10] We note that some jurisdictions have updated requirements for floodplain maps and stormwater management guidelines to reflect the more intense rainfall rates identified in NOAA Atlas 14, so the authors expect similar updates for roof drainage.

In addition to building code requirements, some building designers are required to follow other design criteria. For example, FM Global (FM) insured buildings are required to be designed to comply with supplemental criteria, which are generally more stringent than building code requirements. Since its introduction in 1986, and particularly after 2011, FM Global's *Property Loss Prevention Data Sheet 1-54 — Roof Loads for New Construction* (FM 1-54)[11] has incorporated methodologies for sizing roof drains based on flow rates and the corresponding hydraulic head (the water depth above the secondary roof drain; reference figures in FM 1-54).

## SECONDARY ROOF DRAINAGE

Secondary (emergency or overflow) drainage systems are critical to the performance of roof structures as they provide backup protection against water accumulation in case the primary drainage system fails (e.g., becomes clogged with debris or ice). Secondary drainage systems are designed to remove excess water from the roof once the water reaches a designed height (typically 2 in. [50.8 mm]) and before the roof structure is overloaded. Secondary drainage systems may include internal overflow drains, scuppers, or a combination of both; in some cases, roofs may be designed for overflow water to drain over the roof edge.

With respect to scuppers used for secondary drainage, the IBC requires sizing and placing scuppers to prevent the depth of ponding water, should the primary drainage system fail, from exceeding the depth for which the roof structure is designed. The roof structure, in accordance with the IBC, is required to be designed to sustain the load of water that will accumulate on the roof area(s) if the primary drainage system fails and the water level rises above the inlet of the secondary scupper drains (also referred to as hydraulic head). As noted above, all versions of the IBC through 2021 use the same 100-year hourly rainfall maps for designing the roof structure. However, the 2021 IBC was updated to design the roof structure using a 100-year, 15-minute duration rainfall event, rainfall rates determined from approved local weather data, or twice the 100-year hourly rainfall rate provided in the rainfall maps.

The IBC references the IPC for the sizing of secondary scupper openings. All versions of the IPC, including the current 2024 IPC, Section 1108, require sizing secondary scupper drains "in accordance with Section 1106 based on the rainfall rate for which the primary system is sized," which is based on the 100-year hourly rainfall maps. Therefore, the building code allows designers to size secondary scupper drains using less demanding rainfall rates than the rates used by the structural engineer for designing the roof structure.

The design of secondary roof drainage systems relies on commonly accepted industry standards when methodologies for calculating loads or sizing specific drainage systems are not provided under the IBC. IBC Section 1611 sets forth requirements for rain load design criteria, but it does not provide the methodologies for performing this analysis. However, ASCE 7, a key standard adopted by the IBC for the structural design of buildings, defines methodologies for rain loads. Designers should coordinate secondary drainage system design with both the IBC and ASCE 7. ASCE 7 (versions 7-10 through 7-22) provides, among other information:

- **Rainfall intensity:** ASCE 5 and 7-10 do not provide rainfall intensity requirements and reference the code having jurisdiction. ASCE

| | Annual Exceedance Probability (%) | | | | | |
|---|---|---|---|---|---|---|
| Duration | 50% | 20% | 10% | 4% | 2% | 1% |
| 60 minutes | 0.499 (0.446 - 0.549) | 0.729 (0.64 - 0.818) | 0.919 (0.793 - 1.05) | 1.21 (1.02 - 1.41) | 1.48 (1.22 - 1.75) | 1.79 (1.45 - 2.16) |
| 120 minutes | 0.619 (0.563 - 0.675) | 0.841 (0.747 - 0.937) | 1.01 (0.888 - 1.15) | 1.3 (1.11 - 1.51) | 1.56 (1.31 - 1.84) | 1.86 (1.53 - 2.24) |
| 3 hours | 0.71 (0.649 - 0.771) | 0.951 (0.851 - 1.06) | 1.14 (1 - 1.28) | 1.43 (1.23 - 1.64) | 1.68 (1.42 - 1.96) | 1.97 (1.64 - 2.35) |
| 6 hours | 0.89 (0.817 - 0.966) | 1.18 (1.07 - 1.31) | 1.4 (1.25 - 1.57) | 1.71 (1.5 - 1.95) | 1.96 (1.69 - 2.26) | 2.23 (1.9 - 2.62) |

**Figure 6.** *Excerpt of precipitation exceedance probability charts. Courtesy of NOAA.*

7-16 Section 8.2 established rainfall intensity requirements for design rain loads based on a 100-year, 15-minute duration rainfall event, which was further updated in ASCE 7-22 to a 15-minute duration rainfall event with a frequency based on risk category. ASCE 7-16 and ASCE 7-22 Chapter 8C reference the NOAA Precipitation Frequency Data Server[12] (PFDS), established under NOAA Atlas 14, for rainfall intensity data.

- **Hydraulic head:** ASCE 7-10 through 7-22 Chapter 8C provide information for calculating hydraulic head based on rainfall intensity, roof area servicing the drain, and drainage sizing.

## UPDATED WEATHER DATA

NOAA Atlas 15 precipitation data is currently under development and is expected to be released for peer review and comment in 2025 and for publication in 2026 for the contiguous US.[13] When released, this information should be taken into consideration when designing roofing drainage systems. A quote from the NOAA Atlas 15 informational web page[13] states,

- "In contrast to NOAA Atlas 14, NOAA Atlas 15 will provide spatially continuous coverage over the entire US and, for the first time, will also account for future climate variability (through the year 2100)."[13]

**Figure 6** includes an excerpt of *preliminary in-progress* NOAA Atlas 15 precipitation data (inches of water) that includes Annual Exceedance Probability (%) ranging from 50% annual exceedance to 1% covering storm durations ranging from 60 minutes to 6 hours.

## CONCLUSION

Successful roof drainage system performance requires coordinated design between the plumbing and structural engineers to ensure consistent design criteria is utilized for sizing their respective systems. Failure to effectively implement a multidisciplinary approach to roof drainage design can lead to either inefficient and overbuilt roof structures, undersized drainage systems, or both. Furthermore, building designers should be aware of updated roof drainage design requirements and regularly updated building codes. With increasing rainfall intensity and frequency, designers should also consider and monitor ongoing and future updates in weather data.

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## REFERENCES

1. Hayhoe, K., D. J. Wuebbles, D. R. Easterling, D. W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner. 2018. "Our Changing Climate." In *Impacts, Risks, and Adaptation in the US: Fourth National Climate Assessment,* vol. 2, ed. D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, T. K. Maycock, and B. C. Stewart. Washington, DC: US Global Change Research Program, pp. 72-144.
2. Marvel, K., W. Su, R. Delgado, S. Aarons, A. Chatterjee, M. E. Garcia, Z. Hausfather, K. Hayhoe, D. A. Hence, E. B. Jewett, A. Robel, D. Singh, A. Tripati, and R. S. Vose. 2023. "Ch. 2. Climate Trends." In *Fifth National Climate Assessment,* ed. A. R. Crimmins, C. W. Avery, D. R. Easterling, K. E. Kunkel, B. C. Stewart, and T. K. Maycock. Washington, DC: US Global Change Research Program.
3. "Climate Change Indicators: Heavy Precipitation." US EPA. www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation.
4. "Rising Hourly Rainfall Intensity." Climate Central. www.climatecentral.org/climate-matters/rising-hourly-rainfall-intensity-2023.
5. ASCE (American Society of Civil Engineers). *Minimum Design Loads for Buildings and Other Structures,* 2005, 2010, 2016, and 2022 eds. Reston, VA: American Society of Civil Engineers.
6. International Code Council. *International Plumbing Code,* 1995, 2000, 2003, 2006, 2009, 2012, 2015, 2018, 2021, and 2024 eds. Country Club Hills, IL: International Code Council.
7. International Code Council. *International Building Code,* 2000, 2003, 2006, 2009, 2012, 2015, 2018, 2021, and 2024 eds. Country Club Hills, IL: International Code Council.
8. NOAA (National Oceanic and Atmospheric Administration). 1973. *Precipitation-Frequency Atlas of the Western US,* vol. 1-11. Washington, DC: NOAA.

9. NOAA (National Oceanic and Atmospheric Administration) 1977. *NOAA Technical Memorandum NWS Hydro-35: Five- to 60-Minute Precipitation Frequency for the Eastern and Central US.* Washington, DC: NOAA.
10. NOAA (National Oceanic and Atmospheric Administration). *NOAA Atlas 14: Precipitation-Frequency Atlas of the US,* vol. 1-12. Washington, DC: US Department of Commerce.
11. FM Global. 2011. *Property Loss Prevention Data Sheet 1-54 — Roof Loads for New Construction.* Norwood, MA: Factory Mutual Engineering Corporation.
12. NOAA (National Oceanic and Atmospheric Administration). “PF Data Server-PFDS/HDSC/OWP.” NOAA. https://hdsc.nws.noaa.gov/pfds.
13. NOAA (National Oceanic and Atmospheric Administration). “Atlas 15 Info Page.” NOAA. https://water.noaa.gov/about/atlas15.

*Note: The authors used generative AI as a research tool in the preparation of this work to find references (e.g., NOAA data, building codes, and manufacturer literature). After using this tool/service, the authors referred to references and reviewed and referenced content as needed.*

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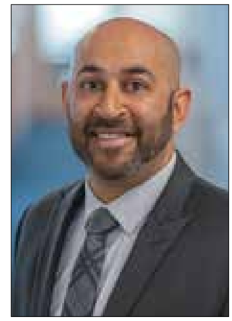

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