



STATE OF THE RISK: Interior Water Damage

Insurance Institute for Business & Home Safety

Research Advisory Council

Residential Committee

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Executive Summary

Interior water damage to residential construction remains one of the most consistent and ever-present sources of insurance claims and losses. The Insurance Information Institute estimates that between 2016 and 2020, one in every sixty insured homes filed a claim resulting from interior water damage. Despite its omnipresent nature, the spectrum of loss drivers classified as interior water damage ranges widely from winter weather impacts and modern appliance failure rates, to regional construction practices, and human factors that influence maintenance and unfortunate accidents.

The Insurance Institute for Business & Home Safety's (IBHS) Residential Committee and Research Advisory Council developed this "State of the Risk" report to identify reoccurring interior water loss. The following represent consistent themes identified by the two IBHS committees as meaningfully contributing to today's picture of interior water damage with the understanding that inflation-driven cost pressures continue to affect the price of nearly all building materials.

Weather and Climate

- Despite a trend toward shorter winter seasons across the United States, arctic air outbreaks drive consistent water damage from frozen pipes, especially in transitional climate zones and areas where extreme cold is rare. Contributing factors identified include regional construction practices such as plumbing along exterior walls or pier and beam construction which are both prevalent across much of the southern and southeastern United States.
- Extreme rainfall events across arid climates—such as atmospheric river events—often expose roof problems, including degraded roof covers and issues with roof penetrations (e.g., vents, skylights, etc.).
- Wind-driven rain during landfalling tropical cyclones continues to drive interior water damage. Wind-driven rain-related losses stemming from windows and doors have become increasingly notable for both residential and commercial construction.

Home Design and Construction Practices

- As modern architecture and typical single-family home design evolved with societal need, the number of possible failure points of plumbing systems increased along with increasing home sizes. These design changes are reflected in the trend in the number of bathrooms in new construction. Since 2005, the number of new homes with three full bathrooms increased by nearly 10%. For the first time in 2021, homes with no half-bathrooms exceeded 50% of new construction.¹
- The increase in home sizes also contributes to a greater amount of material to replace when damage occurs. In 1980, the median home was approximately 1,500 sq ft. By 2015, it had risen to nearly 2,500 sq ft.²
- Common installation problems were identified in construction stemming from poor installation of flashing around roof penetrations, roof cover and underlayment details in valleys, installation errors in vapor barrier systems, and drywall fasteners driven into plumbing lines.

Appliances

- The duty cycle capacity and lifespan of today's appliances has declined, increasing failure rates. Today, washing machines and dishwashers only last an average 12-13 years. Water quality issues also accelerate the aging of gaskets, seals, and other plastic and rubber parts in appliance connections to the plumbing system. The increasing prevalence of hot water heaters and laundry rooms located above the first floor was identified as a concern related to declining appliance lifespans.

Human Elements

- The impact of humans was classified into categories:
 - 1) lack of maintenance and negligence,
 - 2) purposeful and fraudulent damage, and
 - 3) accidents.

These factors, while not exhaustive, emerged as common themes identified across the IBHS Research Advisory Council and Residential Committee.



Figure: Trends in housing construction like bathrooms and water-using appliances like washing machines relate to interior water loss trends.

¹ Wade, J., 2022: Eye on housing. *National Association of Home Builders*, Technical Report, 2 pp

² American Housing Survey 2021, United States Census Bureau

Introduction

Interior water damage from weather-related and non-weather-related failures continues to be the second most frequent driver of claims for homeowners, behind wind and hail.¹ When combining both of these interior water losses into a single category, there has been little discernable trend in loss frequency or severity.² However, when considering just non-weather-related interior water loss, there has been a detectable increase in loss cost since 2014.³ The IBHS members on the Research Advisory Council and the Residential Committee set out to explore the spectrum of loss drivers for both weather-related and non-weather-related interior water loss and how various trends—including trends in weather and climate as well as regional construction practices—may contribute to the picture of loss that the insurance industry is experiencing today. The potential drivers of interior water loss presented here, while not exhaustive, represent those that were common across the two IBHS member groups. The identified loss drivers were divided into four categories: 1) weather and climate driven, 2) home design and construction practices, 3) appliances, and 4) human factors. This report delves into what factors were identified as contributing to losses under these four categories.

Weather-Related Interior Water Damage

Winter Weather Impacts

Despite the trend towards warmer and shorter winter seasons across the United States as the climate changes, winter weather-driven interior water losses remain a consistent problem. Overall extreme cold has become less common across the United States (Figure 1) as the climate warms. However, damage from winter weather, specifically extreme cold, likely contains the influence of the “bullseye effect” like other atmospheric perils (e.g., tornadoes, hail, wildfires).^{4,5} The growth of suburban communities along with a trend toward larger homes has potentially masked the probability for fewer losses as extreme cold becomes rarer. Later sections will explore how regional construction practices may also be a contributor.

Cold extremes in winter (December-February)

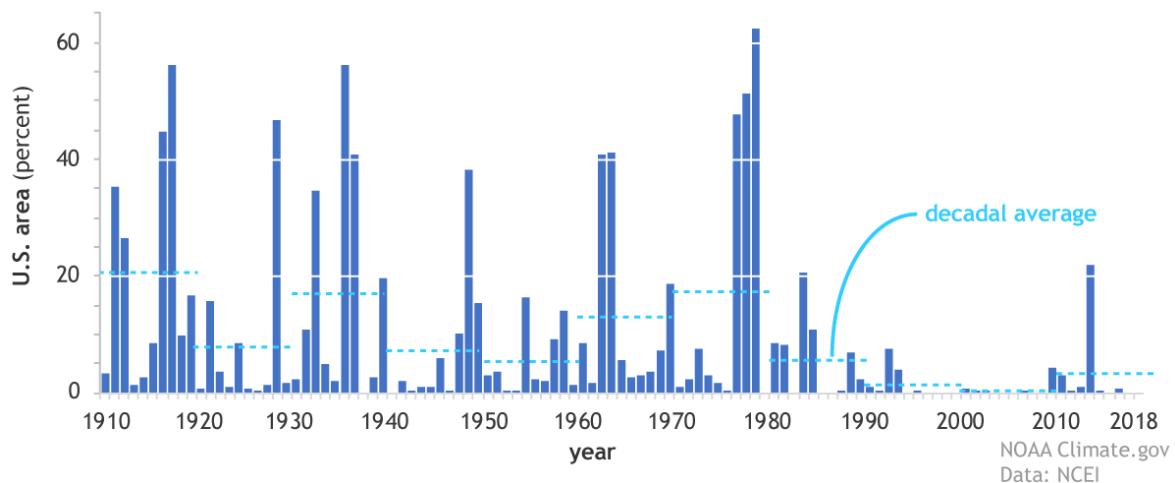


Figure 1. Winter season cold extremes (% area) across the United States from 1910-2019, courtesy of NOAA NCEI.

¹ Insurance Information Institute / Verisk <https://www.iii.org/fact-statistic/facts-statistics-homeowners-and-renters-insurance>

² Verisk, 2022: Executive insights: Homeowners, Technical Report, 19 pp. https://productcenter-cdn.iso.com/Executive_Insights_Homeowners_Report.pdf

³ LexisNexis, 2020: Home Trends Report. *Technical Report*, October 2020, 23 pp.

⁴ Strader, S.M., W.S. Ashley, T. Pingel, and A. Krmenac, 2018: How land-use alters the tornado disaster landscape. *J. Appl. Geog.* doi.org/10.1016/j.apgeog.2018.02.005

⁵ Strader, S.M., 2018: Spatiotemporal changes in conterminous U.S. wildfire risk and societal exposure from 1940 to 2010. *Nat. Haz. Rev.* doi.org/10.1007/s11069-018-3217-z

Extreme Cold Temperatures

The leading culprit driving damage from extreme cold was identified as burst plumbing pipes which have been a common occurrence in sub-freezing weather, especially in situations where power has failed for periods longer than twenty-four hours. Common residential plumbing materials—such as cross-linked polyethylene flexible pipe (commonly referred to as PEX), polyvinyl chloride (PVC) pipe, copper pipe, and galvanized steel pipe—are all vulnerable to issues when pressurized and uninsulated during long durations of sub-freezing temperatures.⁶ The most problematic material is uninsulated copper pipe. Copper pipe is typically thin walled but has little ability for expansion and contraction. Any metal piping will also act as a heat exchanger, and heat loss through metal is more significant than other materials. Metal plumbing pipes are often found on older homes, and repairs are often more costly. In addition, little is known about the longevity or service life of a repair or if a full plumbing system overhaul when a repair is needed would be a better approach to reduce the vulnerability of the system. The plastic-based materials—PEX and PVC—are subject to material property changes with age and become more brittle, especially if these materials have been exposed to solar radiation—specifically ultraviolet (UV)—at any point in their life span.

To produce a pipe failure, there are usually additional factors beyond extreme cold that contribute to the failure, such as extended power outages and lack of maintained insulation around pipes in areas with exposed plumbing (i.e., crawl spaces, etc.). Plumbing design standards in today's model building codes do not account for these anomalies. The design temperatures are solely based on the climatology of a specific area and are set to represent the outside air temperature in which there is a 97.5% probability that the temperature remains above throughout the year. Meaning, there is a 2.5% annual probability that the outside air temperatures reach or fall below the plumbing design temperatures. Table 1 provides a summary table of plumbing design temperatures in selected cities in climate transition zones and those which do not commonly experience extreme cold.⁷ Exposed and uninsulated pipes are the first areas of a home that will experience sub-design temperatures. For interior plumbing, modern heating systems should maintain a temperature above the plumbing design temperature even along exterior walls.

However, as observed during the 2021 arctic air event in the Deep South, when external factors cause extended power outages such as the collapse of the ERCOT grid across a large portion of the Interstate 35 corridor in Texas, temperatures even in interior spaces can begin to fall below their design limit. For the existing building stock of single-family construction in the southern United States, homes can typically maintain habitable conditions (i.e., interior temperature above 54°F) for 36–96 hours under sub-freezing conditions in the absence of heating. For example, a typical home in Atlanta, Georgia experiencing 7 days of a typical diurnal temperature cycle with a mean outside air temperature of 27°F can remain habitable for approximately 1.5 days without power under normal living conditions. With a typical heat loss rate of 1–4°F per hour for the typical building stock, not constructed to the latest codes in the southern United States, the worst-case scenario for this Atlanta home provides 8–32 hours before interior temperatures could reach the design level (22°F for Atlanta). For new construction under the modern energy codes (i.e., 2021 IRC, IECC), the duration a typical home can maintain habitable conditions increases to over 7 days (168 hours),⁸ meaning a new home, built under the latest codes, can last more than a week before plumbing design temperatures reach their limit in this example. It is noted that plumbing pipes on exterior walls will reach their design level sooner.⁵ Also, these temperatures pose a substantial threat to life safety. While heat loss for any given home will vary greatly depending on a myriad of factors (e.g., insulation, windows, wall sheathing types, doors, age, roof condition, etc.), it is clear that loss of heating through infrastructure failures—such as extended power outages—represent a substantial risk, especially when heating capabilities are lost for more than two days during sub-freezing mean outside air temperatures in areas that do not frequently experience long-duration extreme cold. Modern codes, however, are a useful tool in extending the habitability and lowering the risk of plumbing failures due to freezing pipes until power can be restored or temperatures recover.

⁶ Gordon, J.R., 1996: An investigation into freezing and bursting water pipes in residential construction, *Insurance Institute for Property Loss Reduction and Building Research Council*, University of Illinois at Urbana-Champaign, Technical Report, 52 pp.

⁷ International Plumbing Code, 2021, International Code Council.

⁸ Franconi, E. et al., 2023: Enhancing resilience in buildings through energy efficiency, Pacific Northwest National Laboratory Technical Report PNNL-32737, *US Department of Energy*, 177 pp.

Table 1. Plumbing design temperatures for select cities across the transitional climate zones and the southern United States from the 2021 International Plumbing Code.

State	City	Plumbing Design Temperature
Alabama	Birmingham, AL	21°F
	Mobile, AL	29°F
	Huntsville, AL	16°F
Arkansas	Little Rock, AR	20°F
Florida	Jacksonville, FL	32°F
	Tallahassee, FL	30°F
Georgia	Atlanta, GA	22°F
	Augusta, GA	23°F
	Savannah, GA	27°F
Kansas	Wichita, KS	7°F
Kentucky	Lexington, KY	8°F
	Louisville, KY	10°F
Louisiana	Baton Rouge, LA	29°F
	Shreveport, LA	25°F
	New Orleans, LA	33°F
Maryland	Baltimore, MD	17°F
Mississippi	Jackson, MS	25°F
Missouri	St. Louis, MO	6°F
	Kansas City, MO	6°F
North Carolina	Charlotte, NC	22°F
	Raleigh, NC	20°F
Oklahoma	Oklahoma City, OK	13°F
South Carolina	Columbia, SC	24°F
	Charleston, SC	28°F
Tennessee	Nashville, TN	14°F
	Knoxville, TN	19°F
	Memphis, TN	18°F
Texas	Austin, TX	28°F
	Abilene, TX	20°F
	Dallas, TX	22°F
	Houston, TX	32°F
	San Antonio, TX	30°F
Virginia	Richmond, VA	17°F
	Norfolk, VA	22°F

Catastrophic losses from interior water damage during winter weather events are nearly always tied to another factor that contributes to a cascade of events that ultimately result in extreme losses. The probability of widespread issues from extreme cold increases substantially during extended power outages. Over the last two decades, more than 80% of major power outages (i.e., service interruption of at least 50,000 customers) have been weather-related. Twenty-three percent of those outages were a result of winter weather hazards.⁹ Areas of the southern and southeastern United States are where these outages are the most common and where plumbing design temperatures are least equipped to handle extreme cold. With the increase in weather-related power outages and the aging electrical infrastructure in the United States, the likelihood of substantial impacts from winter weather are growing faster than the reduction in extreme cold events from a warmer climate. Given these factors, losses at a minimum should remain constant despite a warming climate and less frequent extreme cold.

⁹ Climate Central, 2022: Surging power outages and climate change, Technical Report, *Climate Central*, September 14, 2022, 8 pp.

Ice Dams and Water Intrusion

Another often-cited source of interior water damage from winter weather is ice dams. Ice dams most commonly form on older homes with inadequate attic insulation. Roofs experience repeated freeze and thaw cycles, owing to both the outside environmental conditions and the warmer attic space below the roof sheathing. As heat inside the home escapes into the attic warming the middle and upper roof deck, the bottom layer of accumulated snow and ice on the roof melts and the meltwater drains down the roof slope to the colder roof eaves where it can refreeze. Over time, this cycle can allow liquid water to pool behind a “dam” of ice. It is unclear if this water forces its way underneath shingles past the sealant strip, if it exploits unsealed shingle tabs, or if the water shedding abilities of substantially degraded roof cover material are compromised enough to allow this water to permeate the shingle mat leading to potential water intrusion. It is possible all the mechanisms described above contribute to ice dam water intrusion. Without a proper ice and water shield along the roof edges and/or a sealed roof deck, the water can find its way through seams in the roof decking and into the attic in the same way wind-driven rain can infiltrate the gaps in roof sheathing. Ice dams were noted by the IBHS Research Advisory Council and Residential Committee as a source of damage, especially in older homes not built under modern codes. However, ice dams were not considered a dominant, large-scale loss driver during winter weather. Across both member groups, it was indicated that newer homes built under modern building codes have nearly eliminated this hazard. IBHS, in a collaborative study with Verisk, [explored modern code provisions](#) that can help prevent ice dams and how those code provisions have or have not been adopted across Massachusetts.¹⁰

Extreme Rainfall

Leaking roofs during heavy rainfall events have always been a driver of interior water issues in structures. Heavy rain can exacerbate roof system problems such as degraded roof covers, issues with flashing installation around roof penetrations, drip edge installation, and vents. As the climate warms, the atmosphere’s capacity to store water vapor increases leading to more extreme precipitation events. The increasing frequency of these extreme precipitation events has been well observed as the climate warms, and it has been prevalent across nearly all areas of the United States, with the largest increase noted in the Upper Midwest and Northeast (Figure 2). Hawaii is the only location that has experienced a decrease in extreme precipitation. However, even regions with an arid climate that are experiencing more frequent droughts are also experiencing an increase in extreme rainfall events.¹¹ It was noted by the IBHS Research Advisory Council and Residential Committee that these events in arid climate regions are exposing vulnerabilities in roof systems and driving increases in damage severity. In other parts of the United States with greater precipitation frequency, it was suggested that roof vulnerabilities are often detected earlier and can be repaired before an extreme event. These hypotheses have not been tested or quantified at this time and have led to the following questions:

- Is the increasing frequency of extreme precipitation across the United States helping drive higher severity interior water losses? How does it vary regionally?
- IBHS continues to drive research forward exploring the service life of roofs when exposed to wind and hail, but what is the long-term water shedding service life of typical roof cover materials? If a loss trend is related to extreme precipitation, what are the dominant causes (e.g., roof cover, roof penetrations, flashing, maintenance issues, etc.)?

¹⁰ IBHS and Verisk, 2022: Ice Dams and building codes are you protected?, IBHS and Verisk Joint Study. Technical Report, 8 pp.

¹¹ USGCRP (U.S. Global Change Research Program). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, eds. <https://science2017.globalchange.gov>. doi:10.7930/J0J964J6.

Observed recent change in extreme precipitation, 1958–2016

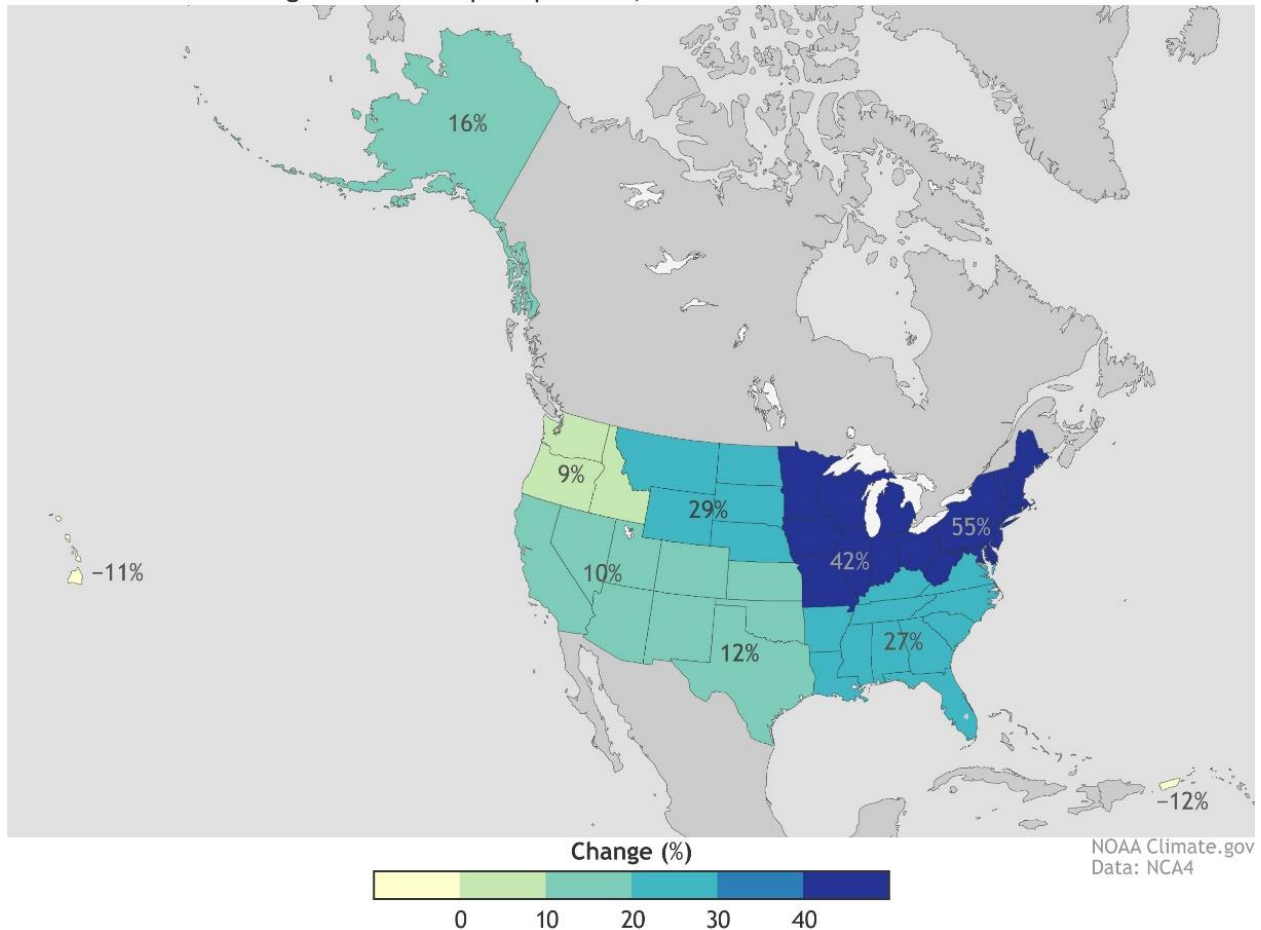


Figure 2. Changes in extreme precipitation across the United States from 1958-2016 from the 4th National Climate Assessment.

Wind-driven Rain and Water Intrusion

The threat for water intrusion from wind-driven rain accompanies any windstorm. Wind-driven rain can infiltrate the building envelope of a home through damaged roof covers, vents, poorly installed or damaged flashing around roof penetrations, around windows and doors, and in extreme cases through damaged wall covers. The ability for wind-driven rain to amplify interior damage and losses is so substantial that it is one of the core perils that IBHS studies (Figure 3). In a limited claims study following the 2020 Midwest Derecho, Giammanco et al. (2023) found that when water intrusion occurred from wind-driven rain penetrating a damaged roof cover, total losses were 4 to 7 times greater than the cost to replace the damaged roof cover alone.¹² This loss amplification is also why a sealed roof deck is the cornerstone of the FORTIFIED Roof™ standard. The IBHS Research Advisory Council and Residential Committee sited continued losses from water intrusion due to wind-driven rain, most commonly in tropical cyclones. The two groups also noted an increase in wind-driven rain-related losses for windows and doors.

¹² Giammanco, I.M., A. Weston, and W.H. Pogorzelski, 2023: Cedar Rapids, Iowa and the 2020 Midwest Derecho: The Performance of Asphalt Shingle Roofs in Extreme Severe Convective Storm Winds, *Insurance Institute for Business & Home Safety*, Technical Report, 23 pp.



Figure 3. Photograph of interior water intrusion damage following a full-scale wind-driven rain simulation in 2019 at the IBHS Research Center.

Roof System

IBHS has conducted extensive research on roof performance—specifically asphalt shingles—as well as full-scale wind-driven rain testing and its subsequent water intrusion through roof decks, vents, and soffits.^{6,13,14,15} The following summarizes the current state of understanding:

- Water entry through an unsealed roof deck with extreme roof cover damage (i.e., near 100%) was more than 3 times greater than water entry through a completely open soffit. While soffits are routinely damaged during windstorms, it is likely that water entry following damage to roof covers is the dominant driver of water intrusion for the roof system.⁹
- The methods of sealing a roof deck in the IBHS FORTIFIED standard can, on average, mitigate at least 70% of the potential water entry. The performance benefit increases as wind speed increases.¹⁶
- Water entry rates through eaves and soffits (i.e., an open soffit, assuming 100% damage) are dependent on wind speed and are maximized at winds of 70 mph.¹⁵ Water entry through gable end vents was not wind speed dependent.
- In a limited claims dataset from the 2020 Midwest Derecho, the homes with amplified losses due to water intrusion all had greater than 25% of the roof cover damaged.¹¹

¹³ Kovar, R., F. Lombardo, T.M. Brown-Giammanco, M. Morrison, and I.M. Giammanco, 2022: The effect of roof age on asphalt shingle performance: Hurricane Rita to Hurricane Laura, *Insurance Institute for Business & Home Safety*, Technical Report, 20 pp.

¹⁴ Giammanco, I.M., E. Newby, and W.H. Pogorzelski, 2023: Observations of building performance in southwest Florida during Hurricane Ian (2022): Part I Roof cover damage assessment on residential and light commercial structures, *Insurance Institute for Business & Home Safety*, Technical Report, 26 pp.

¹⁵ Quarles, S., T.M. Brown, A.D. Cope, C. Lopez, and F.J. Masters, 2013: Water entry through roof sheathing joints and attic vents: A preliminary study, *Insurance Institute for Business & Home Safety*, Technical Report, 13 pp.

¹⁶ Brown, T.M., S.L. Quarles, I.M. Giammanco, R. Brown, 2015: Building vulnerability to wind-driven rain entry and effectiveness of mitigation techniques, *14th International Conference on Wind Engineering*, Porto Alegre, Brazil, Preprint, 20 pp.

Windows and Doors

While IBHS has not conducted specific full-scale experiments exploring water intrusion around windows and doors, it has been routinely observed both in experimental tests and full-scale demonstrations. At the time of this report, research on wind-driven rain through windows is ongoing in collaboration with Australia's Cyclone Testing Station at James Cook University.

Critical Unanswered Questions

- Is water intrusion from wind-driven rain more prevalent in tropical cyclones than severe convective storms? If so, by how much?
- How do precipitation characteristics in both tropical cyclones and severe convective storms influence wind-driven rain and the probabilities of water intrusion?
- Without a sealed roof deck, at what percentage of roof cover damage does water intrusion become a problem? How does event duration affect this?
- How much water entry can occur before mold remediation is needed?
- Given current testing standards appear to only represent "typical" tropical storm wind characteristics, what changes or new testing protocols are needed?

Non-Weather-Related Interior Water Damage

In this section, non-weather-related factors that contribute to interior water damage and losses are explored. The themes described here represent those that consistently overlapped between the IBHS Research Advisory Council and the Residential Committee.

Home Design and Construction Practices

The design of typical single-family homes has evolved greatly over the past century as the needs of the occupants have changed. The changes in how homes are designed—specifically, the characteristics and trends related to kitchens, bathrooms, and laundry rooms where plumbing lines pass through interior walls and connect with various appliances—have created more points of failure that can lead to interior water damage.

When non-weather-related water damage occurs within a home, it typically involves the failure of a plumbing connection that can be internal to the home or to an "outside" appliance. The time scales of such issues can range from slow leaks that manifest over considerable amounts of time (e.g., weeks to months) to immediate catastrophic failures. Regardless of the time scale of the water leak, the result is the need to replace interior materials and possibly contents.

When considering loss trends, home size must be considered as larger homes require more material to be replaced, whether on the exterior due to damage from hail and/or wind, or on the interior because of water damage (both weather-related and non-weather-related). From the 1950s through the mid-2010s, single-family homes have been generally increasing in size, except for a short duration decrease during the "Great Recession" (2008–2010). Both mean and median home sizes peaked in 2014–2015 with the average new single-family home near 2,700 sq ft (median was nearly 2,500 sq ft), as shown in Figure 4. Homes built between 1990 and 2010 comprise 29.8% of the United States single-family home building stock.¹⁷ However, since 2015, there has been a slow decline in new home size, and in 2023, the median new home size reached a decade-long low.

¹⁷ American Housing Survey 2021, United States Census Bureau

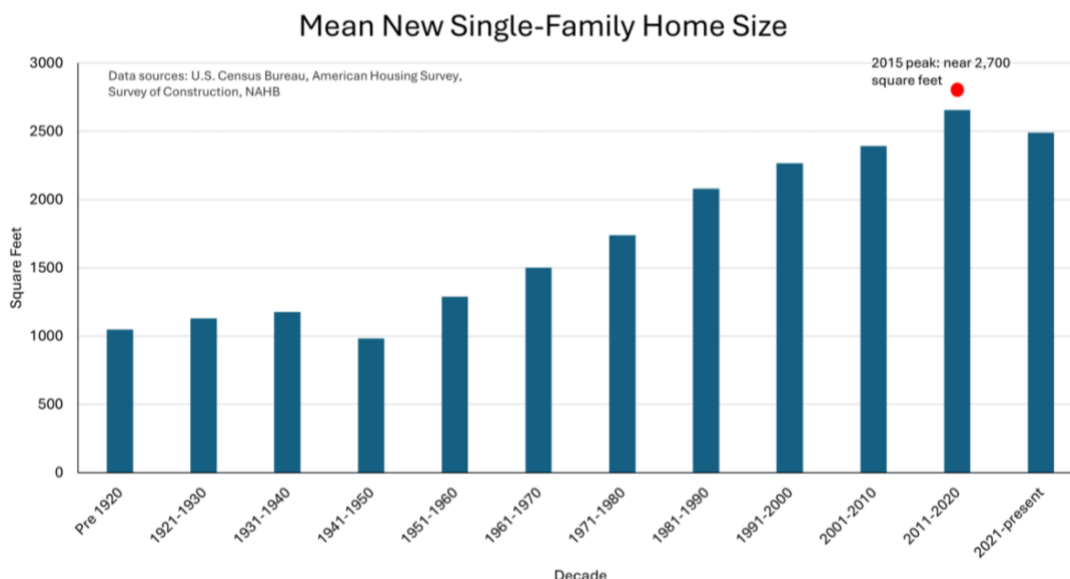


Figure 4. Mean size of new single-family construction by decade. Also denoted is the 2015 peak in mean new home size. Data sources: US Census Bureau, American Housing Survey, Survey of Construction, and National Association of Home Builders (NAHB).

In addition to the long-term increase in home size up until recently, single-family homes that are two or more stories have also been increasing since the 1970s. In 1975, single-story homes made up 63% of all new homes. By 1990, two or more story homes were slightly more common in new construction and have since remained above 50% of all new construction. However, there are some regional differences as shown in Figure 5 when considering more recent data from 2019-2021. Through the middle of the United States, single-story homes remain more common than multi-story homes with the largest market share (60%) across Texas, Oklahoma, Arkansas, and Louisiana. However, in the densely populated corridors of the mid-Atlantic and New England, two or more story construction has a much greater distribution and is near 75% of all new single-family homes. Both the IBHS Research Advisory Council and Residential Committee noted that multi-story homes often experience higher interior water damage claims frequencies and severities. This theme is to be expected, especially with plumbing pipes and even ventilation ducts running in the subfloor areas between floors.

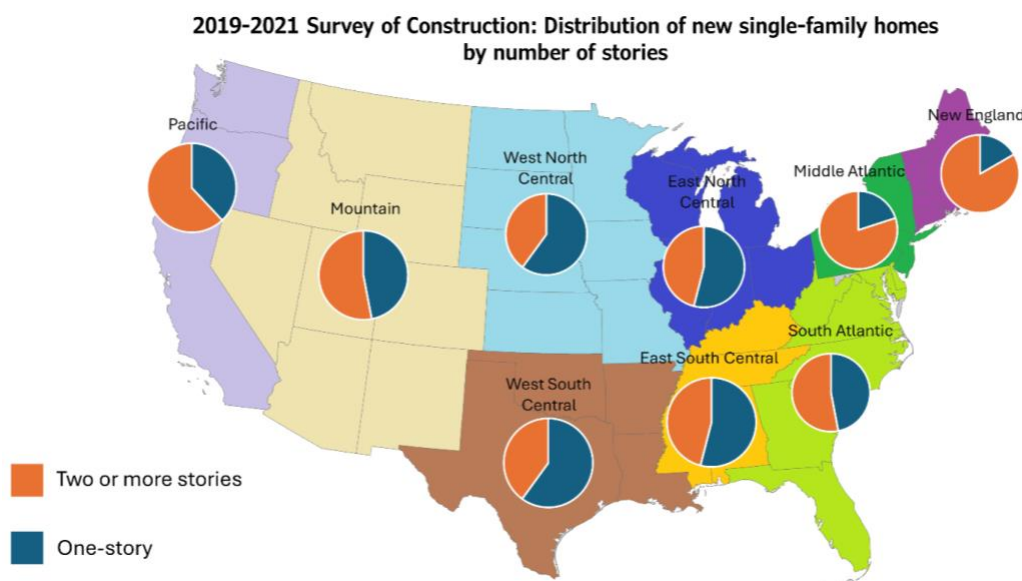


Figure 5. Distribution of single-story and two or more-story new homes constructed from 2019-2021. Data source: Survey of Construction 2021, National Association of Home Builders (NAHB).

With a growing number of two-story homes, the differences in where plumbing connections are placed, locations of appliances, and numbers of upstairs bathrooms must be considered as these represent locations where plumbing connections are located and failures can happen. The combination of larger homes that are now typically two or more stories has created more points of failure for plumbing systems.

The following are drivers of interior water loss associated with home design or construction practices for two or more story homes identified by the two IBHS groups:

- Installation of hot water heaters on upper floors or in attic spaces.
- Number of bathrooms on upper floors.
- Presence of a laundry room and associated washing machine plumbing connections and drain lines.
- Plumbing junctions in subfloor areas of upper stories.

The interior home layout has also shifted over the last century both because of the evolution of lifestyles, occupancy needs, and aesthetic trends. In general, home layouts in the early part of the twentieth century were very compartmentalized. By the mid to late 1900s, more open floor plans began to become the dominant layout with larger kitchens and bathrooms. By the 2000s, this general aesthetic was fully embraced. The open layouts have presented a challenge when water damage occurs, requiring large swaths of materials—notably flooring—to be replaced.

To accompany both the trends related to size, number of stories, and the changing layout of modern homes, the number of bathrooms in typical residential construction has also increased. This trend has added even more plumbing points of failure to the modern home. Since 2005, the percentage of new homes with three or more full bathrooms has increased by 10%. Also in 2021, the number of homes constructed with only full bathrooms and no half-baths eclipsed 50% for the first time.¹⁸ All of these trends contribute to more opportunities for plumbing losses to occur.

The IBHS Research Advisory Council and Residential Committee identified the following region-specific construction practices that are of concern to the industry along with the larger-scale trends in construction that have already been discussed:

In the South,

- Plumbing along exterior walls adds to vulnerability to extreme cold.
- Crawl spaces and elevated foundations, including pier and beam construction, that create uninsulated areas underneath homes, including where plumbing lines may be, also increases vulnerabilities in extreme cold.

In the Southwest,

- Specifically, Arizona and New Mexico, HVAC systems are located on both steep- and low-slope roofs. Failures of these units as well as condensation issues lead to water entry through the roof and the associated attachments and ducts.

In the Southwest, Southern California, and Florida,

- Where tile roofs are common, identifying the source of a leak on a tile roof is difficult and costly.

In the mid-Atlantic, the Northeast, and the Upper Midwest,

- Moisture issues and flooding of basements have always been common drivers of loss. Given the influence of climate change on moisture and precipitation, an increase in damage in this area of a home could be anticipated.



Figure 6. Plumbing in exterior walls of a home under construction in Louisiana.

¹⁸ Wade, J., 2022: Eye on housing. *National Association of Home Builders*, Technical Report, 2 pp.

Appliances

Over the span of the twentieth century into the twenty-first century, reliance on the use of household appliances has grown substantially. Today, appliances could even be considered necessities and are present in nearly every home across the United States. Washing machines, dishwashers, refrigerators, and hot water heaters are the systems that tap into a home's water supply and represent points of failure either in their connections to a home's plumbing system or their own mechanical failure modes. As a result of the trends in home design and construction practices already discussed, these appliances are now located in more precarious locations including hot water heaters installed in attics or laundry rooms with washing machines located on upper floors. The location alone can exacerbate damage should a failure occur. The modes of failure were broken into two categories:

- the failure of the connections between the appliance and the plumbing system, and
- the failure of the appliance system itself.

In today's modern appliances, most the of the water supply connections are achieved through flexible plastic hoses, often shrouded with stainless steel braid. The hoses use common metal or plastic threaded connectors with their associated internal rubber gaskets. Hoses could fail for a number of reasons spanning normal wear and tear, unintentional damage when moving appliances, too much water pressure, degradation of rubber or plastic materials due to exposure to extreme temperatures, and water quality issues.



Figure 7. Example of a kitchen with appliances and plumbing connections that can contribute to interior water losses.

The failure of the appliance itself can also cause losses, especially in today's modern appliances, which are more sophisticated with electronic control systems. While the more sophisticated controls have made modern appliances more efficient, it has introduced more places where a failure could happen and be detrimental, especially the failure of control components that govern water supply use. The failure rates of modern appliances have increased mostly because of reduced duty cycles from less durable parts and materials. Today, the average lifespan of a washing machine is 12.6 years and a dishwasher is 12 years.¹⁹ Considering these two appliances, Tecchio et al. (2019) identified the typical lifespan of specific components. Those related to the water supply that would influence interior water damage potential are listed in Table 2. The more sophisticated appliances of today are made of less durable and less

expensive materials. In addition, appliances are being used more and the frequency of operation has been directly correlated to failure rates.¹⁵ Unfortunately, there are no existing minimum standards for the durability of appliances.

Table 2. Mean lifespan for relevant components influencing water damage potential on washing machines and dishwashers. Adapted from Tecchio et al. (2019).

Appliance	Component	Mean Lifespan (years)
Washing machines	Inlet valves	17.7
	Pump	9.5
	Pressure controller	22.9
	Drain system	12.0
Dishwasher	Inlet valves	15.3
	Pump	9.0
	Door	12.8
	Pressure controller	13.3
	Spray arm	7.7
	Pump filter	8.0
	Drain system	9.1

¹⁹ Tecchio, P., F. Ardente, and F. Mathieux, 2019: Understanding lifetimes and failure modes of defective washing machines and dishwashers, *J. Clean Prod.*, **215**, 1112-1122.

Human Elements

The influence of human decision making has been a part of risk assessment and management since the built environment emerged centuries ago. A vast spectrum of human behavioral elements contribute to damage and loss. For the purposes of this investigation into drivers of interior water loss, the IBHS Research Advisory Council and Residential Committees separated the human elements into the following:

- purposeful and fraudulent actions,
- negligence and lack of maintenance, and
- unawareness and accidents.

The influence of these categories on the potential for interior water loss will be ever present as it is in nearly every aspect of how people live and work in the built environment, as well as people who construct our homes and businesses.

In this section, consider a few anecdotal examples of these factors identified by the IBHS member groups.

Purposeful and Fraudulent Actions

Within the two IBHS member group sessions, a common theme emerged with regards to fraudulent damage: during economic downturns fraud across the spectrum of claims increases. Fraudulent damage was considered the least common of the three categories identified. With regards to interior water, purposeful damage was often identified as not being as simple as intentionally breaking a plumbing pipe. Simply loosening connections and turning off thermostats during extreme cold were cited as examples of a homeowner's intent to create damage.

Negligence and Lack of Maintenance

The most commonly cited loss driver within this category influencing interior water damage was clogged plumbing drains. Situations typically involved drains that were allowed to remain clogged causing either a large backup of water or a failure. The second most-identified loss driver was clogged gutters causing both exterior and interior water damage. The third most common theme centered around the construction industry. Variation in contractor and inspector quality, especially in areas with little to no regulations or requirements for contractors, has led to some evidence of increased claims frequencies. The area that was identified to suffer most from contractor and inspector quality was the roof, including details such as flashing around roof penetrations, proper handling of underlayment in roof valleys, and vent installations.

Unawareness and Accidents

Unfortunate accidents are the most common source of direct human-driven interior water loss issues. Accidents have happened and will continue to happen, especially as more people engage in "do-it-yourself" renovations or repairs in kitchens and bathrooms. However, some issues can be solved through improved education and outreach. For example, during the 2021 arctic air outbreak across Texas and Louisiana, damage was exacerbated because many homeowners did not know how to turn the main water supply off to their home once a pipe had burst. Proper procedures to deal with frozen pipes were also unknown and likely not well communicated to homeowners as the event was unfolding.

Summary

Interior water damage to residential construction remains one of the most consistent and ever-present sources of insurance claims and losses. Despite its omnipresent nature, the spectrum of loss drivers resulting in interior water damage is wide ranging from winter weather impacts to modern appliance failure rates, to regional construction practices, and human behavior influencing maintenance and unfortunate accidents.

Weather and Climate

- Despite a trend toward shorter winter seasons across the United States, arctic air outbreaks drive consistent water damage from frozen pipes, especially in transitional climate zones and areas where extreme cold is rare. Contributing factors identified include regional construction practices such as plumbing along exterior walls or pier and beam construction which are both prevalent across much of the southern and southeastern United States.
- Extreme rainfall events across arid climates—such as atmospheric river events—often expose roof problems, including degraded roof covers and issues with roof penetrations (e.g., vents, skylights, etc.).

- Wind-driven rain during landfalling tropical cyclones continues to drive interior water damage. Wind-driven rain-related losses stemming from windows and doors have become increasingly notable for both residential and commercial construction.

Home Design and Construction Practices

- As modern architecture and typical single-family home design evolved with societal need, the number of possible failure points of plumbing systems increased along with increasing home sizes. These design changes are reflected in the trend in the number of bathrooms in new construction. Since 2005, the number of new homes with three full bathrooms increased by nearly 10%. For the first time in 2021, homes with no half-bathrooms exceeded 50% of new construction.¹⁸
- The increase in home sizes also contributes to a greater amount of material to replace when damage occurs. In 1980, the median home was approximately 1,500 sq ft. By 2015, it had risen to nearly 2,500 sq ft.¹⁷
- Common installation problems were identified in construction stemming from poor installation of flashing around roof penetrations, roof cover and underlayment details in valleys, installation errors in vapor barrier systems, and drywall fasteners driven into plumbing lines.

Appliances

- The duty cycle capacity and lifespan of today's appliances has declined, increasing failure rates. Today, washing machines and dishwashers only last an average 12-13 years. Water quality issues also accelerate the aging of gaskets, seals, and other plastic and rubber parts in appliance connections to the plumbing system. The increasing prevalence of hot water heaters and laundry rooms located above the first floor was identified as a concern related to declining appliance lifespans.

Human Elements

- The impact of humans was classified into categories:
 - 4) lack of maintenance and negligence,
 - 5) purposeful and fraudulent damage, and
 - 6) accidents.

These factors, while not exhaustive, emerged as common themes identified across the IBHS Research Advisory Council and Residential Committee.

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