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# Water Entry through Roof Sheathing Joints and Attic Vents: A Preliminary Study

## Sealed Roof Deck Tests

Demonstrating the value of sealing the roof deck and providing information on the relative importance of water entry through vents compared to the roof.

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**ABSTRACT**

A study at the Insurance Institute for Business & Home Safety (IBHS) Research Center was conducted to evaluate the potential for water entry into the attic through typical vents and through a sealed and unsealed roof deck under wind-driven rain exposures. A duplex building was constructed where sheathing joints on one half of the roof deck were sealed and the other half was not sealed prior to installing an asphalt shingle roof covering. Water entry through gable end and soffited eave vents were also evaluated.

Drainage panels were installed between the lower chords of the roof trusses. This drainage system allowed for the collected water to be segregated by zones. A target rain deposition rate of 8-inches per hour was used for all tests. Water entry through gable end vents and soffited eaves was evaluated using up to three wind exposure regimes. Water entry tests for the sealed and unsealed roof decks were conducted after the shingles were removed. Water entry through the un-taped roof deck joints exceeded that through the taped deck and the vents. This study demonstrated the value of sealing the roof deck and provided information on the relative importance of water entry through vents compared to the roof.

**INTRODUCTION**

Recent testing at the IBHS Research Center provided an opportunity to quantify the amount of water entry through roof and attic ventilation systems during simulated wind-driven rain exposures to a full-scale duplex building. These experiments were conducted in order to quantify the amount of wind-driven water that penetrates openings in residential roof systems. The variables investigated were modeled on post-event damage assessments in areas where hurricane winds were strong enough to result in the removal of the roof covering, but not strong enough to blow off roof sheathing. In these events, significant property damage and extended occupant displacement can occur as a result of water intrusion.

The type of damage investigated in this study is common in inland areas, where hurricane-strength winds occur, but building codes and standards are not as stringent as those in coastal communities. For example, when Hurricane Wilma (in 2005) crossed the southern tip of Florida as a Category 2 hurricane (peak wind speed gusts of about 110 mph) it caused more than $10 billion in damages, most of which was related to roof damage and resulting water intrusion (Pasch, et al. 2005). Much of this damage occurred inland. Other hurricanes have caused catastrophic damage as they moved well inland. Hurricane Ike (in 2008), for example, made landfall in Texas and remained strong for two days, creating gust wind speeds in excess of 70 mph in Ohio and caused more than $1.5 billion in losses there (Berg 2009).

Water penetration can cause extensive damage to interior finishes, furnishings and other contents, and can lead to ceiling collapse when attic insulation is saturated. Where power is lost and/or a house cannot otherwise be dried out within 24 to 48 hours, additional difficulties are common, extending the period of time during which the property may not be available for use. IBHS researchers hypothesized that human inconvenience and financial costs associated with water penetration during hurricanes could be substantially reduced through widespread adoption of sealing the between-panel joints of the roof deck, a relatively simple and inexpensive procedure, particularly when re-roofing.

The objectives for IBHS simulated wind-driven rain study included:

- quantifying the relative volume of water that penetrated through the roof deck and other selected attic vent systems; and,
- cataloging the type and extent of water damage that occurred to different parts of a house.

## EXPERIMENT

For the series of tests reported here, a target wind-driven rain deposition rate of 203 mm/hr (8 in/hr) was used. This rate was based on the value specified for wind-driven rain in ASTM E 331-00 (2000).

### Duplex Building

A duplex building was designed and constructed for this study. Sheathing joints on one half of the roof deck were sealed prior to installing the roof covering and the other half was not sealed. The joints were sealed by applying a self-adhesive modified bitumen tape. Both halves of the roof were then covered with simple felt paper underlayment prior to installing the asphalt shingles. The duplex included gable ends fitted with gable end vents and nominal 0.3 m (1 ft) wide soffits at the eaves. Water entry through the soffits was evaluated with and without a perforated vinyl soffit material installed. The roof sheathing stopped short along the primary ridge to enable installation of a ridge vent during one series of tests.

### Establishing Wind-Driven Rain Capabilities

IBHS provided support to the University of Florida (UF) to assist with deployment of a research disdrometer in Hurricane Ike. UF developed novel instrument platforms to take measurements in extreme winds using conventional sensors. IBHS followed up with partial support for a graduate student to analyze rain droplet size distributions based on the collected Hurricane Ike data, and then to use the UF wind simulator to select a commercially available spray nozzle that would produce a similar distribution of rain droplet sizes (Lopez 2011). Matching droplet size is critical because the momentum of large drops will cause them to ignore the effects of wind flow around the building, while tiny drops will simply follow the flow and not wet the surface of the building. Prior to the water entry measurement testing, validation tests were run in the IBHS lab using the same research disdrometer.

### Measuring Water Entry Rates

Drainage panels and tracks (DrySpace™) were installed in the attic to create water collection channels between the ceiling trusses, as shown in Figure 1. These channels were outfitted with drains and pipes that allowed collected water to be captured in plastic containers arranged throughout the interior (non-attic) space in the two halves of the duplex. The drainage system was installed so that the collected water could be segregated by zones. These zones were roughly 3 m (10 ft) long by 0.6 m (2 ft) wide. The trusses ran from the front to back of the house. The between truss spacing was divided into three sections, each about 3 m (10 ft) long. Each drainage channel directed water to a separate numbered plastic container. Typical drain and collection locations are shown in Figure 2. Tests were typically conducted for a 1200 s (20-min) period, during which time a constant wind speed was maintained. The rainfall rate was set to produce 730 m/s (8 in/hr) on the test building (i.e., horizontally-driven rain). At the completion of each test, water in the buckets was measured and recorded.


**Figure 1. Photograph of water collection channels between ceiling trusses in duplex.**


**Figure 2. Photograph of water collection system inside the duplex.**

## Testing Program

Water entry was measured through vent and eave areas when the roof covering was in place and through vent openings and the roof deck after the roof covering had been removed. The first sequence of tests involved measuring water entry when the soffit cover was missing along the entire length of the back eave of the duplex ("open soffit tests"). The second series involved measuring water entry with a perforated vinyl soffit material installed ("closed soffit tests"). The open under-eave area was approximately 0.8 $m^2$ (8.5 $ft^2$). The perforated vinyl soffit material used in this series of tests consisted of uniformly spaced holes, each 3 mm (1/8 in) in diameter (0.125 in.). Both of these tests were conducted at 22.4 and 31.3 m/s (50 and 70 mph) with the back (eave side) of the duplex perpendicular to the wind direction. A quartering wind test (with the duplex oriented 45 degrees off perpendicular to the wind direction) for each of these conditions was conducted at the 22.4 m/s wind speed. The third test sequence focused on measuring water entry through the gable end vent ("gable end vent tests"). These tests were conducted with 13.4 and 22.4 m/s (30 and 50 mph) with the gable end of the duplex oriented perpendicular to the wind flow. During these tests, soffits were covered with perforated vinyl soffit material. A summary of the water entry tests prior to removal of the roof covering is given in Table 1.

Following the soffit and gable end test series, the roof cover on the front of the duplex was blown off using high winds. Similar efforts were started for the roof surface at the back of the duplex but the full removal of the back roof surface was completed manually to expose the sealed and unsealed roof decks above the same eave where soffit water entry testing was conducted. Removal of roof cover from the front and back surfaces exposed the gap at the top of the primary ridge, so it was fitted with a Florida Building Code High Velocity Hurricane Zone approved ridge vent.

**Table 1. Summary of under-eave and vented opening water entry tests, prior to removal of the roof covering.**

| Test No. | Test Duration, s | Wind Speed, m/s | Perforated Vinyl Soffit Condition | Gable End Vent Condition | Building Orientation | Dominant Water Entry Options |
|---|---|---|---|---|---|---|
| 1 | 1,200 | 22.4 | Removed (Open) | Uncovered | Normal to back of duplex | Open soffit |
| 2 | 1,020 | 31.3 | Removed (Open) | Uncovered | Normal to back of duplex | Open soffit |
| 3 | 1,200 | 22.4 | Removed (Open) | Covered | Quartering wind | Open soffit and open gable end vent |
| 4 | 1,200 | 22.4 | Installed | Covered | Quartering wind | Soffited eave |
| 5 | 1,200 | 22.4 | Installed | Uncovered | Normal to back of duplex | Soffited eave |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 1,200 | 31.3 | Installed | Uncovered | Normal to back of duplex | Soffited eave |
| 7 | 1,200 | 22.4 | Installed | Uncovered | Normal to end of duplex | Gable end vent and soffited eave |
| 8 | 1,200 | 13.4 | Installed | Uncovered | Normal to end of duplex | Gable end vent and soffited eave |

The final test evaluated water entry through the sealed and unsealed sheathing joints. The wind speed for this test was 22.4 m/s (50 mph), with the back (eave side) of the duplex facing the wind flow. This configuration put the exposed sealed and unsealed roof decks, shown in Figure 3, perpendicular to the wind-driven rain to allow a relative comparison in the amount of water entry in the attic for each half of the roof.

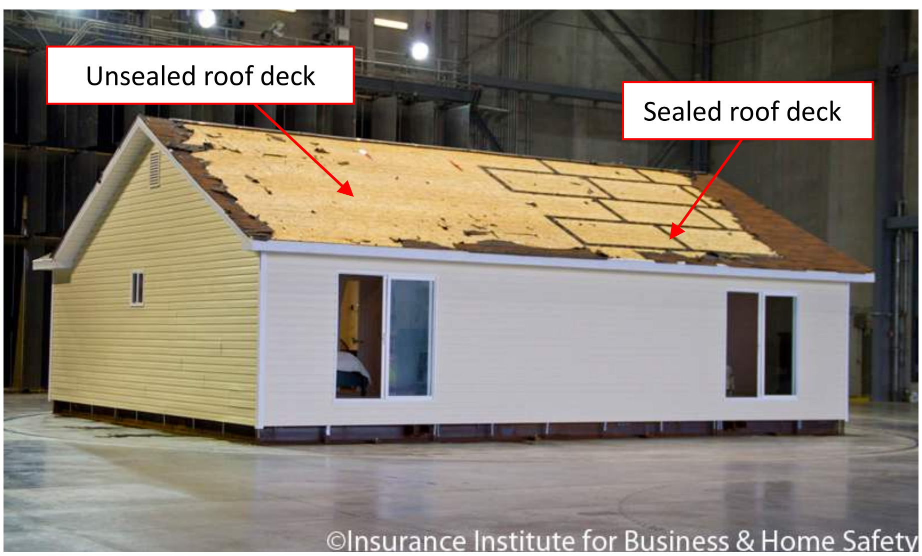


**Figure 3.** Photograph of the back of the duplex after shingle and underlayment (manual) removal, illustrating the sealed roof deck (right) and the unsealed roof deck (left).

## RESULTS AND DISCUSSION

### Eave and Gable End Tests

The amount of water that entered into the attic space as a function of the area of the opening is shown in Table 2. A wind speed of 22.4 m/s (50 mph) produced an overall water entry rate into the attic of about 33 mm/hr based on the area of the soffit. This was about 15% of the rainfall deposited on the adjacent (vertical) wall surface (203 mm/hr). Most water was deposited within the first 3 m (~10 ft) of the attic space immediately adjacent to the open soffit. A wind speed of 31.3 m/s (70 mph) produced an overall water entry rate into the attic of about 74 mm/hr (2.9 in/hr) based on the open area of the soffit. This was a little more than 33% of the deposition rate on the vertical wall surface. A quartering wind of 22.4 m/s (50 mph) produced an uneven distribution of water in the attic, but still resulted in about 40 mm/hr (1.6 in/hr) based on the open area of the soffit. This was about 20% of the deposition rate on a wall surface facing the wind flow.

During the test with the perforated soffit installed, a wind speed of 22.4 m/s (50 mph) resulted in water accumulation in the attic space of approximately 6% of the amount of water that entered during the same test for the open soffit case. A wind of 31.3 m/s (70 mph) produced about 9 times more water accumulation in the attic than the 22.4 m/s (50 mph) test. This was about 25% of the amount of water that entered the attic during the same test (31.3 m/s) for the open soffit case. A quartering wind of 50 mph produced very little accumulation of water in the attic. The amount was about 2.5% of the water entering during the same test for the open soffit case.

**Figure 5.** Small tears in the tape occurred when a roofing shovel was used to remove the roof shingles. Water droplets can be seen falling from the between-sheathing joint gap shown in this photograph.

For winds of 13.4 m/s (30 mph) and above, the water entry rate was about equal to the wind-driven water deposition rate based on the area of the gable end vent. There was a slight indication of less water entry for higher wind speeds, but this difference could have resulted from water that was blown further into the attic in an area around the attic access stairs where no collection pans were in place.

**Table 2. Water entry measurements for the eave and gable end conditions.**

| Wind Speed, m/s | Opening Condition and Duplex Orientation | | | | |
|---|---|---|---|---|---|
| | Open Soffit | | Perforated Vinyl Soffit | | Gable End |
| | Head On (0°) | Cornering (45°) | Head On (0°) | Cornering (45°) | Head On (90°) |
| | Accumulation, mm/hr (%)[1] | | Accumulation, mm/hr (%)[1] | | Accumulation, mm/hr (%)[1] |
| **22.4** | **33.0 (16)** | **40.6 (20)** | **1.9 (1)** | **1 (0.5)** | **~200 (100)** |
| **31.3** | **73.7 (36)** | **-----** | **17.3 (8)** | **-----** | **-----** |

**[1] Percent entry relative to the target wind-driven rain deposition rate of 203 mm/hr (8 in/hr).**

## Sealed and Unsealed Roof Deck Tests

The water entry data through the sealed and unsealed roof deck were evaluated by comparing the volume of water entering the attic after the roof covering was removed. The area of the gaps between sheathing panels was not measured. The total volume of water that entered the attic space through the under eave area (perforated soffit installed and open) and gable end vent were included in this comparison. A graph comparing the volume of water collected through these openings during the various tests is shown in Figure 4. Water entry through the roof deck after the covering was blown off or removed was more than three times that which entered through the open soffit, indicating that the roof deck was the principal source of water. The roof deck test was stopped at 16 minutes in duration, rather than the planned 20 minutes, because the nominal 11.5 l (3-gallon) containers on the unsealed side started overflowing.

These results also demonstrated the importance keeping the soffit material intact in order to minimize water entry into the attic though the eave – water entry through the open soffit was several times that with the installed soffit. Water entry through the eave (soffit material installed or removed) more than doubled when the wind speed was increased from 22.4 to 31.3 m/s (50 to 70 mph). Water entry through the gable end vent was not as affected by wind speed. Although the 31.3 m/s (70 mph) condition was not tested for gable end vents, the amount of water entry measured at the 13.4 and 22.4 m/s (30 and 50 mph) wind speeds were similar and in each case, most of the water impacting the vent entered the attic.

The sealed roof deck side, where joints between the roof sheathing were sealed by applying a self adhesive modified bitumen tape, experienced about one third of the water entry experienced by the side without tape. On the unsealed roof deck side, gaps where water entry could occur included those at the between-sheathing joints and nail holes where roof covering or roofing felt nails pulled out. On the side of the duplex with the sealed joints, gaps resulted from tears in the tape and nail holes. The amount of water entry on the sealed side clearly demonstrated that the taped joints were damaged when the roof covering was manually removed (Figure 5). Although not quantified, it is also possible that a greater number of roofing nails were removed when the covering was manually removed. Water entry through roofing nail holes was observed on the unsealed side of the duplex.

Water entry through nine nail holes and one damaged taped sheathing joint was measured during one test conducted at 31.3 m/s (70 mph). The water collection time at each nail hole was not uniform and in each case was less than that at the joint. The nail holes that would leak were not known until the start of the test. Once water was observed dripping from a given nail hole, water collection began. Water accumulation at one damaged joint was measured during the 20 minute exposure time. The results of this test indicated that water entry through the damaged joint was approximately three times that through a given nail hole. Because average measured accumulation times at a given nail hole was less than that at the taped joint, water entry at the joints would have been greater than the value reported here.

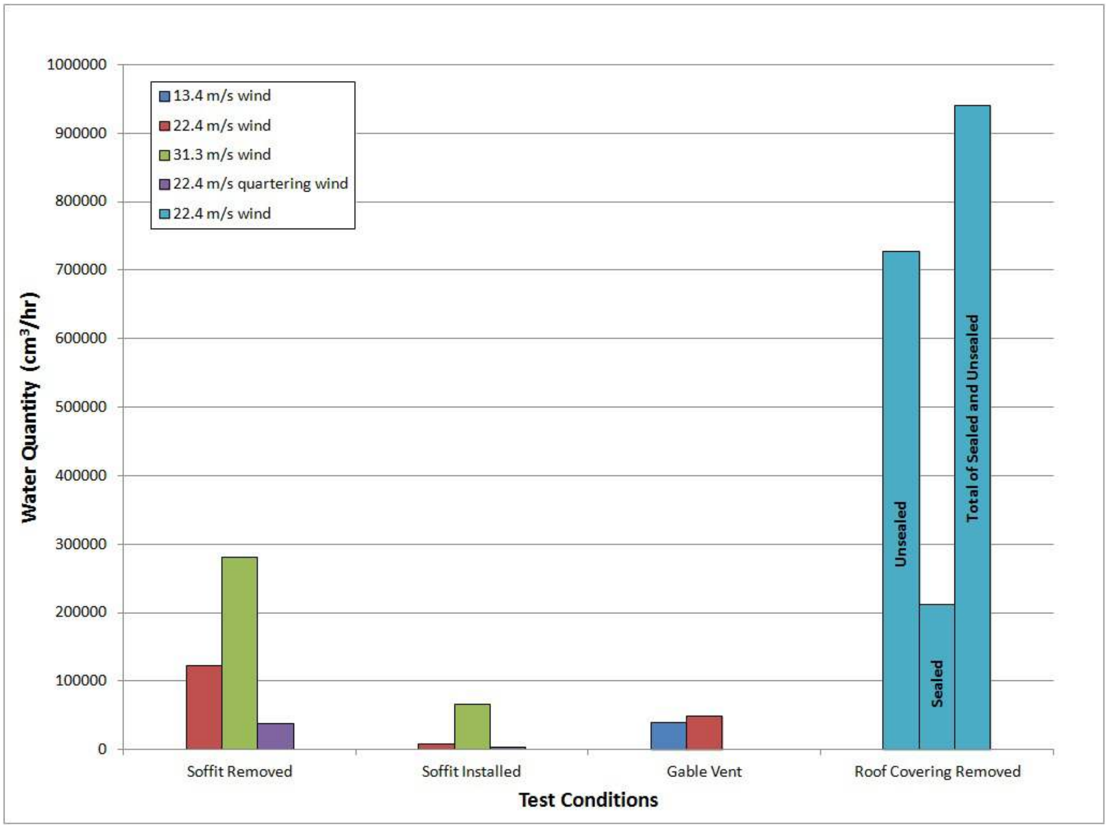


**Figure 4.** Total amount of water entry into the attic (per hour) for the eave, gable end conditions and roof covering removed test conditions.

Since these data are based on one test, they can only be considered to be an indication of the relative importance of nail hole versus damaged tape joint. This does provide evidence that during re-roofing projects, where the old roof covering is removed using a roofing shovel, sheathing joints should be re-taped.

## Consequences of Water Entry

Following quantitative testing, the water collection devices were removed from the structure and the required drainage holes in the ceiling were patched. Furniture was placed in the duplex to model actual living spaces. The finished structure was then subjected to a series of wind-driven rain events modeled after Hurricane Dolly. These tests gave IBHS the opportunity to demonstrate the consequences of water entry into attic spaces. Within 45 minutes of the conclusion of the 20-minute wind-driven rain exposure, the kitchen ceiling in the unsealed side of the duplex collapsed (Figure 6).

Following the test, IBHS brought in a property insurance claims adjuster to estimate the amount of damage each side of the duplex suffered. Damage was assessed on the front three rooms on both sides of the duplex, including the kitchen, dining room, and family room. The loss estimate for the side without a sealed roof deck was more than three times the loss estimate for the side with the sealed roof deck.

The blown-in attic insulation used in the demonstration event was a fiberglass material. The target insulation depth was 10.5 inches, sufficient to provide an R-value of 30. In order to compare the weight of wetted fiberglass insulation with that of an equivalent amount of cellulose insulation (based on R-value, 9.5 inches), a laboratory test was run. Prior to the test the insulation was equilibrated in an oven maintained at 55°C (130°F) for 48 hours.  Both kinds of insulation were then hand shifted into separate (weighed) containers. Sixty fluid ounces was uniformly distributed over the top surface.  Water was allowed to drain for five minutes from uniformly spaced 1/8 inch holes drilled over the bottom surface of the containers. After draining, the bucket with wet insulation was weighed.

As seen in Table 3, the wet weight of the cellulose insulation was approximately three times that of the fiberglass insulation. During the demonstration event, water could only drain through gaps between gypsum ceiling panels and, eventually, through nail holes after the panels began to deform under the weight of the wetted insulation. Given the same water entry scenario, and the difference in wet weight between the two insulation types, collapse of the ceiling panels could have occurred somewhat earlier if cellulose insulation had been installed.

**Table 3. Summary of data comparing wet weights of fiberglass and cellulose insulation.**

| Blown in Insulation | Basis Weight (g/cm$^2$) | |
|---|---|---|
| | Dry | Wet |
| Fiberglass | 0.3 | 0.7 |
| Cellulose | 0.8 | 2.2 |


**Figure 6.** Photograph of collapsed ceiling in the kitchen on the unsealed roof deck side of the duplex.

## SUMMARY AND CONCLUSIONS

These preliminary tests demonstrated that sealing the roof deck is an important protective component in reducing water entry during hurricanes and other storms where wind-driven rain is a factor. As a preliminary study, this work suggests that more investigation is needed to quantify the amount of water entry that can be expected for normal construction, how much water entry is likely to be reduced with various water entry prevention measures, and how much water entry can be tolerated before remediation associated costs become unacceptable.

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