IBHS ROOF AGING FARMS

2014 MEASUREMENT SUMMARY

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1. EXECUTIVE SUMMARY

In 2013, the Insurance Institute for Business & Home Safety (IBHS) began a long-term roof material natural aging experiment. This measurement and testing program seeks to understand and report how the wind, hail impact, and wildfire performance of various roof cover materials change with age and exposure to the natural environment. Data from this research will provide IBHS members with information upon which to make product and underwriting decisions and describe vulnerabilities for risk modeling applications for multiple perils, and will allow for the investigation of scientifically appropriate methods of simulating the aging of roofing products to accurately evaluate performance under much shorter time scales than natural aging.

This report provides:

- A description of the overall program, which currently includes an aging farm of asphalt shingle roofing products at the IBHS Research Center in South Carolina as well as two smaller installations at IBHS member company properties in Wisconsin and Ohio.
- Detailed information about the weather observed during 2014 and its effect on variations in asphalt shingle temperatures.

Results summary:

- The first year of aging farm observations have shown that maximum shingle temperatures are driven by the amount of incoming solar energy.
- Asphalt shingles are subject to large oscillations in temperature due to passing clouds and the rapid onset of convective (e.g., thunderstorms) precipitation during the warm season.
- At the latitude of the IBHS Research Center: during the winter season (December–February), shingle temperatures on south-facing roofs can still reach temperatures and durations above that required by curing test standards. North-facing roofs may not reach these values during the winter months. During the warm season (April–September) both south and north faces regularly exceeded curing temperatures required by testing standards.

Future reports will include:

- Annual reports on weather conditions and observation-based changes to roofing products.
- Summaries of hail, wind, and fire performance of aged roofing products subjected to standardized tests when test panels are extracted from the aging farms, beginning in 2018.

2. AGING FARM DESCRIPTION

IBHS designed and built a roof aging farm at the IBHS Research Center in South Carolina, with four replicate specimens for each individual roofing product deployed on the farm. Baseline (control) data is being collected for each product. Aged specimens will be subjected to high wind, impact, and fire brand testing at 5-year intervals beginning in 2018. Specimens are being added to the farm each year, ensuring continual testing once the initial 5-year period has elapsed.

Two additional roof farms were constructed in late 2014 in Madison, Wisconsin at American Family Insurance and in Amelia, Ohio at American Modern Insurance Group using some of the same products as those installed at IBHS. These farms will allow researchers to investigate the effect that different climate zones play in material aging and performance. Along with roof temperature data, meteorological data such as temperature, humidity, precipitation, and solar radiation are being collected over the 20-year life span of each product installation. With all three facilities on-line and collecting data, annual reports will be issued summarizing the year's meteorological conditions at each site, and any observable changes (deformation, granule loss, tears, etc.) of the specimens to these conditions.

2.1 Specimens

Test specimens are constructed as a "set," where each set includes four separate roof specimens. Individual test panels from each roof will be removed together, at 5 years for the first roof in each set and at 10-, 15-, and 20-year aging intervals for the remaining roofs within the set for a given roofing product. This will allow for hazard vulnerability functions to be developed that account for changes in performance with age. Currently, all specimens at each of the three sites are oriented with roof surfaces facing north and south to examine differences that may be due to incident solar radiation. Each specimen has the following characteristics:

- Each specimen structure (Figure 2-1) is a gable roof, 6/12 pitch, with code-required ventilation, and is nominally 15 feet x 15 feet. The roof is enclosed on the sides and bottom to create an enclosed ventilated "attic."
- Roof products were selected based on type, manufacturer, market prevalence, and published standard test ratings.
- Each specimen features six removable panels—three north-facing panels and three south-facing panels:

i. Two each: 55 inch x 66 inch panels for use in ASTM D3161 and ASTM D7158 high-wind tests, and FM 4473 and IBHS impact tests
ii. One each: 36 inch x 36 inch panel for use in UL 2218 impact tests

Figure 2-1. Example of a roof aging farm specimen, with three test panels per face. Thermocouple probe locations are indicated in brown for the standard instrumentation setup. At each location indicated, there are two probes: one between roof cover layers, and one between the underlayment and roof deck. Probe locations shown in blue correspond to high-density instrumentation of the 20-year specimens at IBHS, where one thermocouple is located between roof cover layers.

The initial focus of the project is on asphalt shingles. Future specimen additions will explore other products such as tile or metal, and plans are in place to construct commercial roofs for aging as well. At IBHS, six sets of roof specimens were constructed in late 2013 and set into place in early 2014. Three more sets were added in November of 2014. All products are of similar color to reduce any differences due to material reflectance properties. Table 2-1 provides the specimen identifications and product types deployed at the IBHS site. Table 2-2 provides the specimen identifications and product types deployed in Madison and Amelia. Yearly installation of additional specimens is not anticipated at the member company sites.

Table 2-1.

Types of products currently deployed on the IBHS Roof Aging Farm site. XX denotes the 5-, 10-, 15-, and 20-year specimens.

SPECIMEN IDENTIFICATION	PRODUCT CLASS
2013-A-XX	Architectural
2013-B-XX	Polymer-Modified Impact-Resistant Architectural
2013-C-XX	Architectural
2013-D-XX	Architectural
2013-E-XX	3-Tab
2013-F-XX	3-Tab
2014-A-XX	Polymer-Modified Impact-Resistant Architectural
2014-B-XX	Traditional Impact-Resistant Architectural
2014-C-XX	Traditional Impact-Resistant Architectural

Table 2-2.

Types of products currently deployed on the Madison and Amelia Roof Aging Farm sites. XX denotes the 5-, 10-, 15-, and 20-year specimens. The matching specimens on the IBHS farm are also indicated.

SPECIMEN IDENTIFICATION	IBHS MATCH	PRODUCT CLASS
2014-AmFam-A-XX	2013-A-XX	Architectural
2014-AmFam-B-XX	2013-B-XX	Polymer-Modified Impact-Resistant Architectural
2014-AmFam-C-XX	2013-C-XX	Architectural
2014-AmMod-D-XX	2013-D-XX	Architectural

2.2 Instrumentation and layout at IBHS farm

The instrumentation configuration was based on previous research studies on the absorptive and reflective properties of various roof covers (Wendt et al. 1990; Wilkes et al. 1991; Rose 1992; Rose 2001; Winandy et al. 2004). Every specimen is instrumented with three Type K thermocouples on each test panel for "2013" specimens and two for subsequent deployments. A surface-mount thermocouple measures temperature between layers of shingles (to obtain an estimate of material temperature). A probe-type thermocouple measures temperature between the underlayment and roof deck (Figure 2-2). Care was taken to ensure the surface-mount thermocouple was between shingle courses and not directly on the adhesive strip. This allowed the sensor to remain out of direct solar radiation while still collecting representative material temperature measurements. Table 2-3 lists the locations of each numbered thermocouple probe.

Table 2-3.

Locations and identifications for all thermocouple probes. It is noted that thermocouple probes 19–34 are only located on 20-year, high-density measurement specimens.

THERMOCOUPLE ID	FACE	PANEL	LOCATION
TC1	North	Western	Shingle surface
TC2	North	Western	Underlayment
TC3	North	Western	Deck
TC4	North	Eastern	Shingle surface
TC5	North	Eastern	Underlayment
TC6	North	Eastern	Deck
TC7	North	Center	Shingle surface
TC8	North	Center	Underlayment
TC9	North	Center	Deck
TC10	South	Western	Shingle surface
TC11	South	Western	Underlayment
TC12	South	Western	Deck
TC13	South	Eastern	Shingle surface
TC14	South	Eastern	Underlayment
TC15	South	Eastern	Deck
TC16	South	Center	Shingle surface
TC17	South	Center	Underlayment
TC18	South	Center	Deck
TC19	North	Middle west	Shingle surface
TC20	North	Lower edge west	Shingle surface

THERMOCOUPLE ID	FACE	PANEL	LOCATION
TC21	North	Ridge west	Shingle surface
TC22	North	Lower edge center	Shingle surface
TC23	North	Ridge center	Shingle surface
TC24	North	Lower edge east	Shingle surface
TC25	North	Ridge east	Shingle surface
TC26	North	Middle east	Shingle surface
TC27	South	Middle west	Shingle surface
TC28	South	Lower edge west	Shingle surface
TC29	South	Ridge west	Shingle surface
TC30	South	Lower edge center	Shingle surface
TC31	South	Ridge center	Shingle surface
TC32	South	Lower edge east	Shingle surface
TC33	South	Ridge east	Shingle surface
TC34	South	Middle east	Shingle surface

A

B

Figure 2-2. Photographs of (A) roof deck and (B) roof cover material Type K thermocouple temperature probes.

Specimens slated for testing in 20 years receive additional surface-mount thermocouples (high-density installation) surrounding the removable test panels to collect a detailed profile of material temperatures across both faces of the specimen as shown in the Figure 2-3 example. This information will also allow for the quantification of temperature gradients across the specimen as a result of precipitation, solar angle, and cloud cover. Temperature and relative humidity measurements are also made in the attic space of these specimens. The construction and deployment of the first group of 24 specimens (referred to as "2013 specimens") was completed in late January of 2014. The second group of 12 specimens was completed in November 2014 (referred to as "2014 specimens").

Roof specimens are laid out in a gridded pattern with no tall vegetation nearby to allow for full solar exposure. Each specimen is set approximately 4 feet above ground level with 8 feet between specimens (Figure 2-4). An access panel is located on the gable side of each specimen to allow for instrumentation maintenance. Each specimen is equipped with a unique circuit board specifically developed by IBHS to maximize the ability to collect thermocouple temperature measurements. The circuit board allows for the acquisition of 48 individual thermocouple probes and 12 generic sensor inputs (used for temperature and humidity measurements in the attics of 20-year specimens) on a single data channel. Data from the specimens are acquired through a National Instruments CompactDAQ module located in the small building located to the immediate west of the specimen array, shown in Figure 2-4, which serves as the data center for the entire farm. All data are sampled internally at 1 Hz but processed data are stored both locally and remotely as 5-minute averages. The instrumentation and data acquisition system installation was completed by March 2014 for the 2013 specimens, allowing for 10 months of complete data records. While thermocouple probes and the data acquisition system are capable of very precise measurements, measurement error is introduced through the cold junction of the thermocouple amplifier located on the circuit board. Examining the data collected during development and nighttime temperatures on the roof farm, the measurement error is estimated at ± 0.25°C for any individual thermocouple probe. The instrumentation and data acquisition system are powered through an AC to DC power supply and the 5 volt regulator on the circuit board allows for a clean DC supply. A battery and solar panel are used as a backup system to ensure clean and uninterrupted power. Data are archived locally on the system and uploaded to the IBHS Research Center internal server network for redundant data storage. The associated computational programs for data acquisition, processing, and storage were all developed by IBHS specifically for this measurement program.

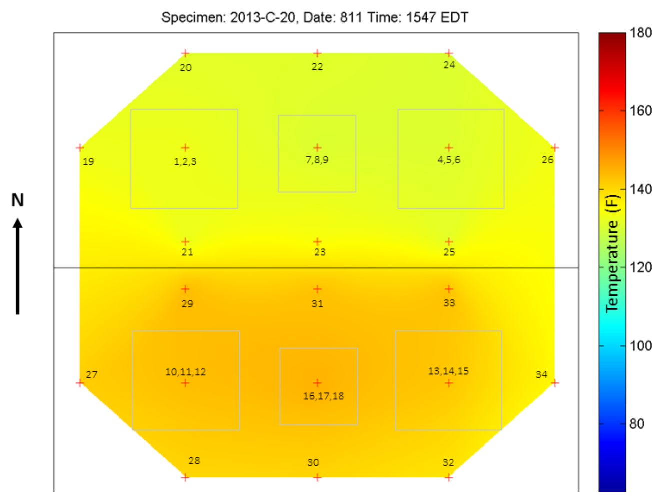

Figure 2-3. Shingle temperature data from a high-density instrumented 20-year specimen (2013-C-20) from 11 August 2014 at 3:47 pm. The red "+" indicate locations of thermocouple temperature sensors with their identification number. Also shown are the test panel locations (see Table 2-3).

Figure 2-4. Aerial photograph showing the layout of the IBHS Roof Aging site from November 2014. The identification code for each specimen is shown for reference. Additional specimens will be added in 2015 extending northward.

2.3 Weather monitoring at IBHS farm

The meteorological conditions at the IBHS Research Center are monitored by a research-grade surface weather observing station (Figure 2-5). The station was installed in 2011 and is based on those used by the Oklahoma and West Texas Mesonet observing networks (Brock et al. 1999; Schroeder et al. 2005). The station collects the following meteorological variables:

- 10 m wind speed and direction (official observing height)
- 9 m temperature
- 2 m temperature (official observing height)
- 2 m relative humidity
- Barometric pressure
- Total incoming solar radiation
- Roof slope total incoming solar radiation (6/12 slope north and south face)
- Precipitation (tipping-bucket automated gauge, manual gauge, optical rain gauge 2012–2013)

Figure 2-5. Photograph of the surface weather observing station at the IBHS Research Center. Photo was taken shortly after installation in 2011, before the roof aging farm installation began.

The station is located approximately 270 feet to the north-northwest of the roof aging farm. For the purposes of comparing the local weather conditions to climate averages, the record for Chester, South Carolina is used (1981–2012 period). The observing site is approximately 11 miles to the west-northwest of the IBHS Research Center and is the closest long-term official National Weather Service observing site. This station will be used to represent climatological averages for the IBHS Research Center.

2.4 Instrumentation and layout at the Madison, Wisconsin and Amelia, Ohio sites

The instrumentation configuration for the Madison, Wisconsin and Amelia, Ohio sites differ slightly from the configuration used at the IBHS site due to the need for remote data storage and project cost considerations. Type K thermocouple probes are situated on the central test panel (both north and south faces), on the roof cover material and the roof deck for consistency with the IBHS farm. No temperature or humidity data are collected in the attic spaces. The aging farm at American Family Insurance was laid out in a similar grid to the IBHS site (Figure 2-6) and specimens were also set in place at a similar height above ground level to the IBHS farm. The specimens at American Modern Insurance Group's farm were elevated in order to be multi-purposed as picnic shelters (Figure 2-7). The instrumentation and data acquisition system at each site is powered through a solar panel and external battery. Weather monitoring instrumentation was consolidated to the quantities necessary to the program. Each site has a consolidated station which collects the following:

- 2 m temperature
- 2 m relative humidity
- Rainfall (tipping-bucket automated gauge)
- Total incoming solar radiation

At these two sites, specimen and weather data are collected through two Arduino Microcontroller units and stored locally using SD flash memory cards. A remote data transfer solution back to the IBHS Research Center is being explored and could be implemented in 2015 at each site.

Figure 2-6. Photograph of the roof aging farm at American Family Insurance in Madison, Wisconsin.

Figure 2-7. Panorama photograph of the roof aging farm at American Modern Insurance Group in Amelia, Ohio during the final phases of construction.

3. 2014 IBHS WEATHER AND CLIMATE SUMMARY

The IBHS Research Center in Richburg, South Carolina is situated near 35° N latitude at an elevation of 450 feet above sea level, east of the Appalachian Mountains. The region represents a temperate climate zone (Class C), according to the Köppen classification system (Peel et al. 2007). Summers are typically hot and humid with generally mild winters. The region can experience most types of severe weather. Hail and tornadoes can occur although not with the frequency of the regions commonly referred to as "Tornado Alley" and "Dixie Alley." The area can be subject to the effects of inland-moving tropical systems, the most notable of which was Hurricane Hugo in 1989, which brought wind gusts to 90 mph and caused significant damage to trees and widespread power outages. While winters are generally mild, winter storms can bring measurable snowfall and accumulating ice.

The data collected in 2014 by the IBHS weather observing station allows for a comparison to "typical" conditions or climate averages. For this comparison, the 2 m temperature data are used to find the daily high and low temperatures. These represent the maximum and minimum temperatures from midnight to midnight local time. Precipitation records are referenced to the automated tipping-bucket rain gauge.

3.1 2014 IBHS climate summary

The weather in 2014 was characterized by colder than average temperatures early in the year and during the late summer. This was in response to a general weather pattern that supported southward excursions in the upper-level jet stream. This allowed cooler air from higher latitudes to spill southward into the region. At the IBHS Research Center, the average daily high and low temperatures for the month of January were 4 and 6 degrees below average, respectively (Figure 3-1). February temperatures returned to near-average values but fell again below normal in March. The summer was relatively mild compared to previous years as June temperatures were near normal and July and August were unseasonably cool. September through November saw relatively normal conditions while December of 2014 closed the year as a warm month compared to normal.

The year produced 92 days in which temperatures fell below freezing (32°F) at the IBHS Research Center, with a total of approximately 328 hours of subfreezing conditions. The coldest day of the year occurred on January 7, with a daily high temperature of 26.4°F and low of 6.2°F. With a more mild summer, the site did not experience any days with a maximum temperature above 100°F. This was much different than the summers of 2012 and 2013 which had above average temperatures. In fact, the June 29, 2012 high temperature of 107.6°F exceeded the all-time record high temperature for both Chester and Lancaster, South Carolina. The warmest day of 2014 occurred on August 22 with a daily high temperature of 95.7°F.

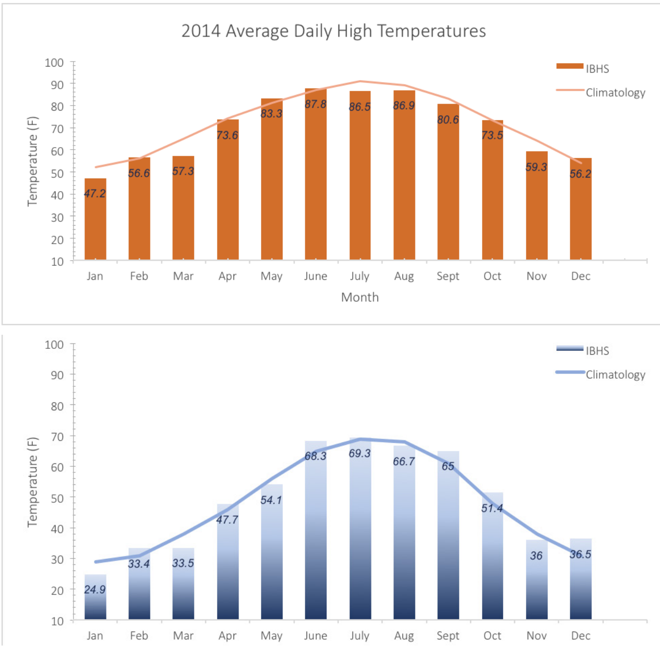

Figure 3-1. Average daily high (top) and low (bottom) temperatures for 2014 at the IBHS Research Center. Also shown are the average monthly high and low temperatures (1981–2012) for Chester, South Carolina.

Rainfall in 2014 was nearly 10 inches below normal, with 34.56 inches recorded at the IBHS Research Center. This compared to an average of nearly 45 inches. While 2014 was relatively dry, the previous two years (2012–2013) were above average which prevented the region from reaching meaningful drought conditions. During 2014, only September and October had precipitation totals above average (Figure 3-2). The year had 104 days in which measureable precipitation was recorded at the IBHS Research Center. The wettest 24-hour period occurred on September 19 when 2.65 inches of rain fell.

3.2 Notable weather events of 2014

Two significant winter storms occurred in 2014 which became the extent of any "extreme" weather events for 2014 at the IBHS Research Center. The climatological spring peak of severe weather did not produce any notable severe events at the IBHS Research Center. While a thunderstorm on May 23 did produce a very short period of pea-sized hail at the site, it did not reach severe criteria and was not accompanied by any severe wind. The IBHS surface weather observing station also did not record any wind gusts that reached the National Weather Service's severe thunderstorm threshold of 56 mph during 2014.

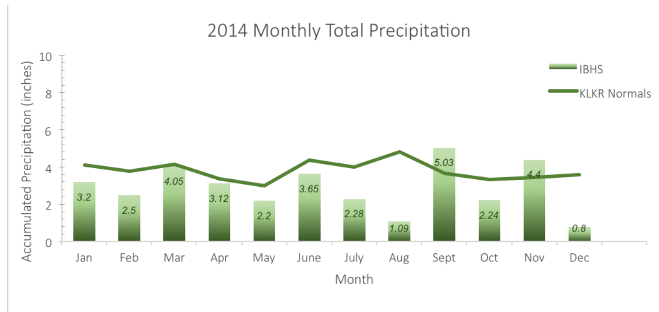

Figure 3-2. 2014 monthly precipitation totals for the IBHS Research Center.

JANUARY 28–29 SNOW

A strong artic air mass combined with a storm system tracking along the eastern seaboard produced 2014's first local winter storm on January 28. The initial round of precipitation began as a mixture of rain and sleet for much of the area. This was mainly due to surface temperatures remaining just above freezing, and a warm layer of air that was present a few thousand feet above the surface. Rain eventually began to change over to a mixture of freezing rain and sleet across the eastern portions of South Carolina, while western areas including the IBHS Research Center saw a change to all snow late in the evening of January 28. Regionally, snowfall totals averaged 1–3 inches with some isolated higher amounts also reported. At the IBHS Research Center, total snowfall approached 1 inch with light ice accumulation prior to the change to snow. Higher amounts were found to the south and east of the Research Center. For this particular event, temperatures at the Research Center remained below freezing for approximately 32 hours.

FEBRUARY 12–13 SIGNIFICANT SNOW STORM

Two separate storm systems impacted the Carolinas in quick succession bringing widespread snow to the region. The February 12–13 winter storm event had three distinct components that impacted South Carolina. The first was an expansive high pressure system that migrated east and transported cold dry Canadian air southwestward down the eastern slopes of the Appalachian Mountains forming a thickening "wedge" of cold air over the western Carolinas. A weak upper-level wave and offshore low pressure area on February 11 initiated a rain event that slowly transitioned into a sleet and snow event for most of the region. At the IBHS Research Center, the storm began with rain early in the day on February 12 before transitioning to snow by early afternoon producing accumulating snow as visible in the photograph provide in Figure 3-3. Approximately 2.00

inches of snow fell in a 12-hour period beginning at noon on February 12. After a brief lull during the day, a deeper, more energetic upper-level feature and a deepening coastal low pressure area over the northeastern Gulf of Mexico provided a complicated finish to this winter event. Significant snow began to develop across the Charlotte metropolitan area extending southward through York and Chester Counties in South Carolina (including the IBHS Research Center) as the coastal storm intensified. At the IBHS site, snow totals for this portion of the event approached 6 inches, with a 2-day storm total of 6–8 inches across much of the area. Further south, accumulating sleet and freezing rain impacted much of the rest of South Carolina resulting in very hazardous travel conditions and significant power outages. This event, however, was not accompanied by artic air and temperatures were able to rise above freezing on February 14.

Figure 3-3. Snow falling during the afternoon of February 12 at the IBHS Research Center.

4. 2014 IBHS ROOF AGING FARM DATA SUMMARY

Conditions experienced at the IBHS Research Center in 2014 were generally cooler and drier than climatological averages. The instrumentation on the roof aging farm provided an opportunity to examine how these and other factors influenced average material temperatures throughout the year. Temperatures for the 5-, 10-, and 15-year specimen test panels were generally within 5°F of their 20-year counterparts. Observations of the roof deck temperatures were on average 10°–20° cooler than the roof cover material temperatures. For the purposes of this report, focus is placed on roof cover material temperatures and measurements from the high-density instrumented 20-year 2013 specimens. These specimens had 10 months of continuous data. Shingle temperatures from the 11 surface-mount thermocouples on each face (north and south) were spatially averaged for each 5-minute observation to provide an estimate of the mean roof-face shingle temperature. Daily maximum and minimum temperatures were found in the same manner used for meteorological observations and averaged for each month of 2014 where data were available (March–December).

4.1 Influences on asphalt shingle temperatures

Material temperature fluctuations are not the sole factor in determining how a roofing material may age, but heat does play a major role in the natural aging of asphalt. In general, a flux asphalt will begin to soften at 140°F. However, residential roof shingles are typically made with an oxidized asphalt, which will have a higher softening temperature. The material standard which governs fiberglass asphalt shingles is ASTM D3462. It requires the softening point to be between 190°F and 235°F for unmodified asphalts. Some variability exists for individual shingle products depending on the oxidation of the asphalt and types of filler. Polymer-modified asphalt shingles may have a higher softening point (up to 320°F), but material variability exists within these products as well.

It is hypothesized that the material temperatures may approach levels in which the coating asphalt of the shingle may begin to soften, and that the cyclic softening and hardening of the asphalt shingle influences the durability of the material over time. Material temperature fluctuations can cause oxidation and volatilization, which can lead to hardening and brittleness within the asphalt (Wright 1979). Thus, the adhesion of granules and impermeability of the asphalt may be reduced as the material ages and oxidizes (Terrenzio et al. 1997). The time and temperature required to adequately activate the shingle sealant appears to increase as products age; even over the course of the few months it takes for product to move from manufacture to installation. Preliminary testing at the IBHS Research Center has shown that only a percentage of the sealant on a variety of different shingle products activates at material temperatures of 135°F to 140°F when cured in a dark oven over a 16-hour period following ASTM 3161 and ASTM 7158 conditioning protocols. If the sealant fails to cure properly, complete adhesion between the shingle and the sealant may not occur, leading to a wind performance vulnerability. This was shown by Dixon et al. (2014) and in testing at the IBHS Research Center. During IBHS tests, only 1 of 11 three-tab and 1 of 15 architectural asphalt shingle products having ASTM D3161

F rating (110 mph tests for 2 hours), obtained through the normal supply chain, were able to survive the ASTM D3161 testing at 110 mph when conditioned at air temperatures between 135°F and 140°F for 16 hours. Increasing the conditioning temperature to 155°F and 160°F or exposing the panels to solar radiation, where temperatures reached 160°F several times over a 1-week period, provided a much more robust sealing of the products.

4.1.1. Solar radiation

Several processes influence the material temperatures of asphalt shingles. The dominant mechanism responsible for heating shingle materials to their maximum daily temperature is the absorption of incident solar radiation. Through the absorption of solar radiation, shingle temperatures will increase well beyond the ambient air temperature. Asphalt shingles are well suited to absorb a large portion of the solar spectrum as a result of their often dark color and chemical composition. Most commercially available asphalt shingles generally absorb 85%–90% of the incident solar radiation (ASTM D-36, Jones 2006). The specific value will vary some due to different coating substances and shingle colors. Given the ability of shingles to absorb solar radiation, the peak temperature of the material on any given day will be well correlated with the maximum amount of solar radiation which reaches the shingle surface. Therefore, the factors which may play a large role in shingle material temperatures include latitude, roof slope, orientation of the structure, and any other factor which may affect the amount of solar radiation incident on the shingle surface (e.g., shading by other structures, vegetation, terrain slope, etc.).

The amount of solar radiation varies through the year, as indicated in Figure 4-1 from Ackerman and Knox (2009). During the summer months (June–July) the amount of incoming solar radiation is relatively similar with latitude as the sun's path across the sky is more northerly. During other parts of the year, higher latitudes will see far less incoming solar radiation (excluding any atmospheric effects) as the sun takes a more southerly path across the sky. Figure 4-2 illustrates the difference in the sun's path between summer and winter. The difference in solar insolation between 30° N and 60° N latitude in June and July is approximately 60 W/m2 while in December and January it is more than double (140 W/m2). This also results in a greater difference between the incident solar radiation on the north and south faces of the aging farm specimens during winter months.

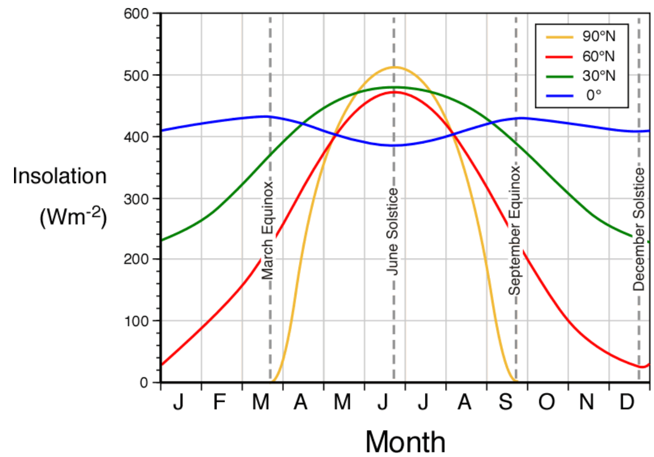

Figure 4-1. Incoming solar radiation by month shown for various latitudes. Source: Ackerman and Knox (2009).

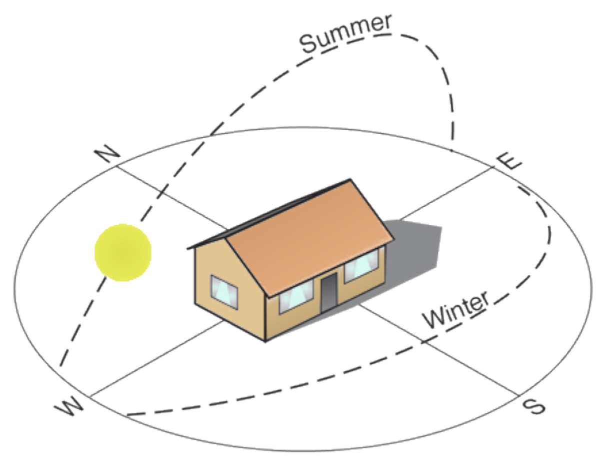

Figure 4-2. Diagram of the sun's path across the sky for the mid-latitudes in the northern hemisphere.

The absorptive properties of asphalt shingles are such that any processes or phenomenon influencing the incident solar radiation will affect the shingle temperatures and the subsequent transfer of heat energy to the underlayment, roof deck, and attic space. The absorptive properties of asphalt shingles also allow them to radiatively cool quickly through emission primarily in the far-infrared portion of the electromagnetic spectrum. For the IBHS farm which has no tall vegetation, cloud cover is the primary factor affecting incoming solar radiation. Clouds both reflect and absorb incoming solar radiation. In general, over long time scales, 22% of incoming solar radiation is reflected back to space and 19% is absorbed by clouds per unit surface area.

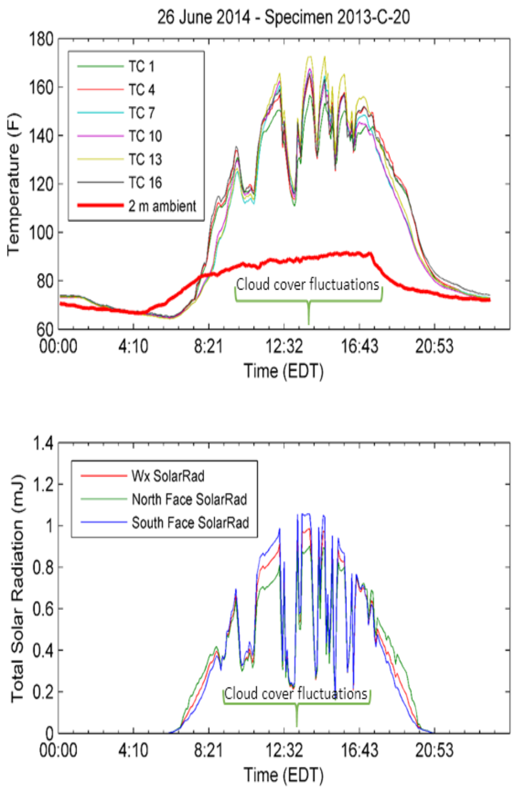

Figure 4-3. Shingle temperatures (top) for thermocouple probes on the center of each test panel embedded in Specimen 2013-C-20 on June 26, 2014. The ambient air temperature measured by the IBHS surface weather observing station is shown in red. Also shown (bottom) is the total solar radiation measured by the IBHS surface weather observing station (bottom, red), north face (bottom, green), and south face (bottom, blue). Data represent 5-minute means.

The influence of passing clouds at the IBHS farm is shown in the example provided in Figure 4-3. This case examines data from specimen 2013-C-20 on June 26, 2014. After sunrise, material temperatures rose very quickly but began a periodic oscillation that is highly correlated with the amount of incoming solar radiation measured by the surface weather observing station. These fluctuations were observed to result from passing cumulus clouds during the late morning and afternoon and no precipitation was measured during the course of the day. The shingle material temperatures peaked near 165°F at approximately 2:15 p.m., whereas the maximum surface air temperature (high temperature for the day) occurred a few hours later (86.5°F). As cloud cover reduced the amount of radiation reaching the shingle surface, a net energy loss from the shingle was observed as emission exceeded radiative absorption, resulting in rapid cooling. A similar effect is observed each night with the loss of solar radiation; shingle temperatures cool at a faster rate than the surrounding air but eventually reach an equilibrium state.

4.2.2 Precipitation

The rapid onset of rainfall during thunderstorms in peak heating months has been observed to produce temperature fluctuations of more than 50°F within a 5-minute observation period. To investigate how often these "shock" events occur, the 104 days in which precipitation was recorded at the IBHS Research Center were examined. Of the precipitation days, 23 were associated with thunderstorms (convective precipitation) while the remainder were due to stratiform precipitation in which low-level cloud cover is typically present. Of these 23 convective events, 6 occurred when shingle temperatures on the north or south faces were above 100°F for all specimens suggesting that the precipitation occurred with little preceding cloud cover. The 6 cases all occurred during warm season months (May, June, and September). During these 6 events, the spatially-averaged roof face shingle temperatures decreased by at least 30°F between 5-minute observations at the onset of precipitation. The average roof-face temperature departure for the 6 cases across all 20-year specimens was –38°F. The true rate of change is likely linked to the rainfall rate, raindrop concentration over time, and rain drop size distribution. One of the 6 identified shock events is shown in Figure 4-4. This particular case produced only 0.01 inches of rainfall but resulted in nearly a 50°F temperature decrease between 5-minute observations as a weak thunderstorm passed over the site. The temperatures between the roof deck and underlayment also experienced a similar rapid decrease.

It is hypothesized that the frequency of temperature shock events resulting from precipitation may influence the rate of aging of a given asphalt shingle and its performance with age. The rapid hardening of asphalt shingles as temperatures cool quickly could contribute to some degree of expansion and contraction. As asphalt expands and contracts, granule loss could become more prevalent, which reduces the ultraviolet protection of the shingle. Furthermore, this movement may weaken the sealant and could potentially lead to shingles unsealing. All of these hypothesized possibilities will be investigated through experimental laboratory testing at the IBHS Research Center.

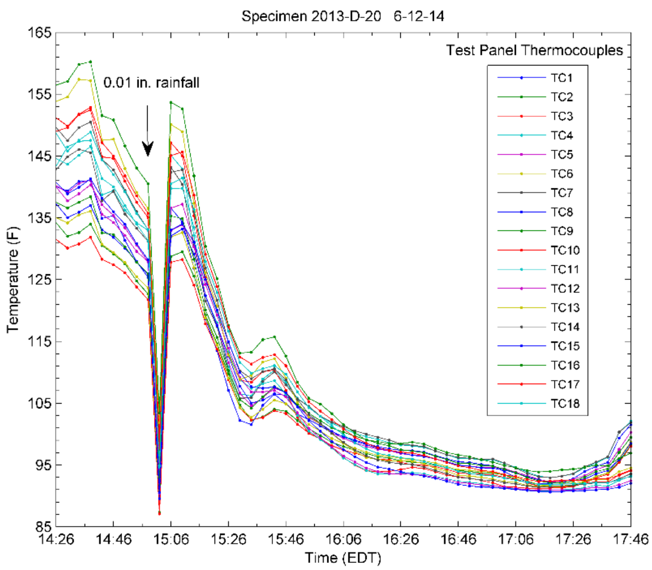

Figure 4-4. Thermocouple temperature measurements for the 6 test panels located on specimen 2013-D-20 on June 12, 2014 showing the effect of the passage of a weak thunderstorm. Note that the temperature decrease is reflected in temperature data from the underlayment and roof deck thermocouple probes. The IBHS surface weather observing station only recorded 0.01 inches of rainfall for this particular event. Data represent a 5-minute mean.

4.2 2014 Roof specimen climate summary

Daily average maximum and minimum shingle surface temperatures were calculated for each month for the two roof faces on the specimens. In general, maximum shingle temperatures were nearly twice the ambient environmental average high temperature, as shown in Figure 4-5. There was some variation between different specimens (different shingle types and manufacturers) for the daily average maximum, likely resulting from slight differences in color and therefore reflectance properties (darker shaded shingle colors were selected to limit these differences). These differences were often less than 15°F for the average daily maximum shingle temperatures. Peak in average maximum temperatures for south-facing roof surfaces occurred in September along with the overall peak observed temperature on any specimen (187.5°F on Specimen 2013-A-20). While this does not coincide with the solar maximum in June–July, it does represent the time of year in which the lower solar angle allows for greater incident radiation on the south-facing side of each specimen at the 6/12 pitch. Peak average maximum temperatures for north-facing roof surfaces did occur in June and July and were comparable to the maximum temperatures on the south-facing roof surfaces during those same months. A comparison of the average maximum temperatures for the south-facing roof surface versus the north-facing roof surface for the late summer fall and early winter data (August through December) clearly show the bias toward reduced average maximum roof temperatures on the north-facing roof surface as opposed to those on the south-facing roof surface.

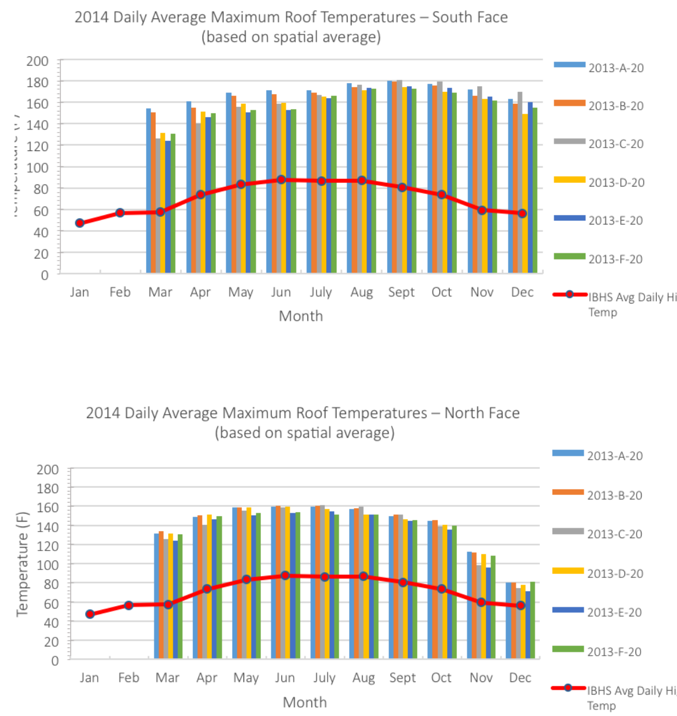

Figure 4-5. 2014 average daily maximum roof temperatures for (top) south faces and (bottom) north faces. Temperature data were averaged across each face. Also shown is the 2014 daily average atmospheric maximum temperature measured by the IBHS surface weather observing station (solid red). Specimen data for January and February were not available, as the data acquisition system was not yet fully operational.

As the solar angle changes throughout the year, larger gradients appear across the specimens, as shown in one example from November 2014 illustrated by Figure 4-6. This example shows the large difference in temperature between the north and south faces (approximately 60°F) as well as the gradient across each face that result from the low solar angle. The north side received less direct solar radiation during this time of year and was substantially cooler than the south face. The south faces were able to reach temperatures above 140°F despite ambient environmental temperatures below 40°F while the north faces were much cooler. The average daily minimum shingle temperatures for the specimens converged toward the average atmospheric low temperature as shown in Figure 4-7 with the loss of solar heating during the nighttime hours. At times during the warm season, minimum shingle temperatures remained slightly higher than the ambient overnight low temperature.

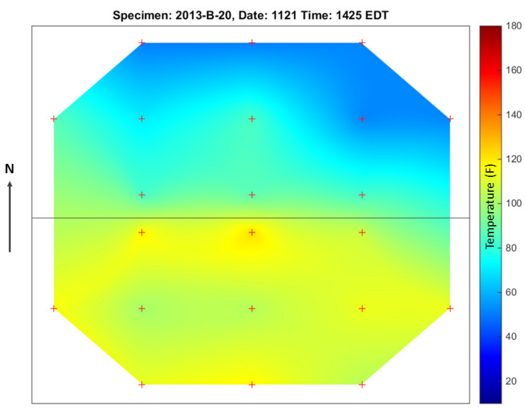

Figure 4-6. Shingle temperature profile for specimen 2013-B-20 on November 21, 2014 at 2:21 p.m. EST. Note the less uniform temperature distribution as a result of solar angle at this time of year. The atmospheric temperature at this time was 57°F.

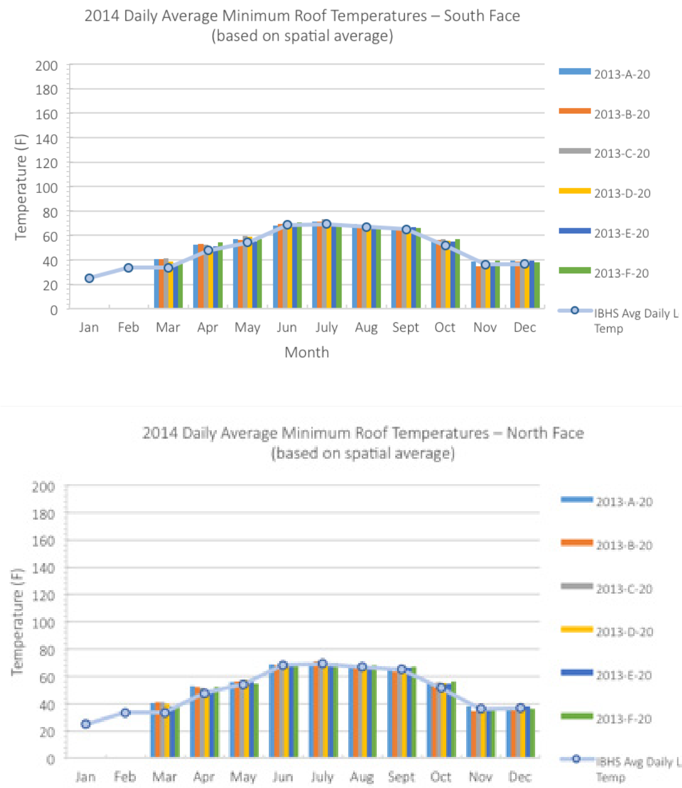

Figure 4-7. 2014 daily average minimum roof temperatures for (top) south faces and (bottom) north faces. Temperature data were averaged across each face to calculate the roof face means. Also shown is the daily atmospheric average daily minimum temperature measured by the IBHS weather observing station (solid light blue). Data for January and February are not available as the data acquisition system was not fully operational.

5. COMPARISON WITH STANDARDIZED TEST CONDITIONING REQUIREMENTS

Data collected on the roof farm allow for comparisons with current standardized test conditioning requirements for asphalt shingles (e.g., UL2218, ASTM D 3161). Each of these standards requires shingled test panels to be conditioned at an ambient air temperature of 135°–140°F continuously for 16 hours in a dark oven or kiln. The test standard does not discuss the shingle material temperature but it is implied that this temperature is adequate for the conditioning of asphalt shingles for wind and impact test purposes. Therefore, aging farm shingle material temperatures are examined in respect to this value. The total time that the average temperature for each face (south and north) was above this threshold, using data from the highly instrumented 20-year specimens, was determined for each month.

The south face of each specimen spent more time above 140°F than the north face (Figure 5-1). The maximum exposure to temperatures above this threshold occurred in August, when the south faces of all specimens exceeded 140°F for more than 100 total hours. This was a warm anomaly from the general trend, as below normal cloud cover and precipitation for the month allowed for long duration heating. With the exception of December, the roof cover on the south face of all specimens spent at least 60 hours above 140°F. Interestingly, July saw a departure from the residence time trend with less time spent above 140°F than that observed in June and August (Figure 5-1). However, the daily average maximum temperatures (Figure 4-5) still followed the trend with changing solar angle as sufficient heating occurred over short periods of time to produce the observed maximum temperatures.

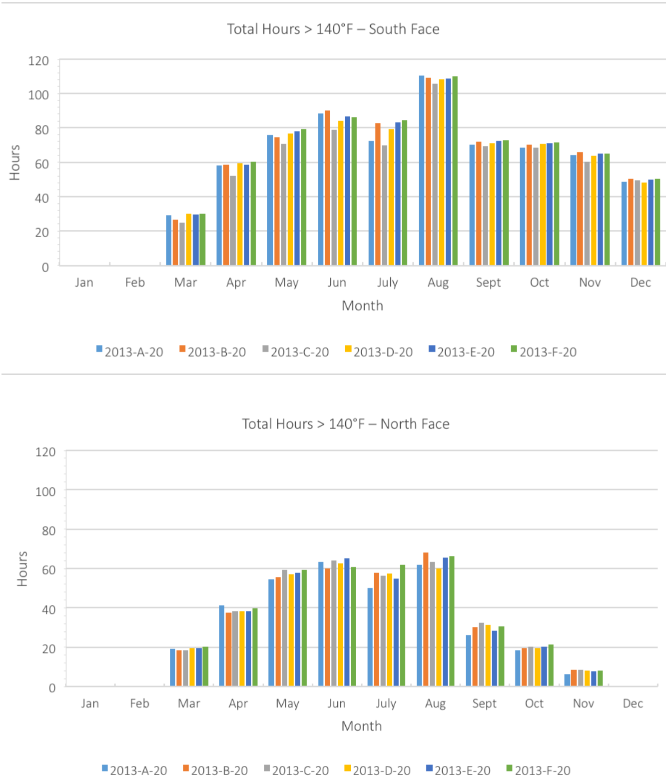

Figure 5-1. Total hours in which the roof face average temperature exceed 140°F for south (top) and north (bottom) faces.

The north faces experienced shorter periods of time where roof cover temperatures were above the 140°F threshold. This was to be expected given the latitude of the IBHS Research Center. For a site located at a lower latitude, such as South Florida, the difference would be less, while for a location such as Madison, Wisconsin, this difference would be even greater. North faces experienced temperatures above 140°F less than 75% of the time south faces experienced temperatures above 140°F. From June through August, the north faces experienced approximately 70 hours above 140°F during each month. With the seasonal change to fall and winter, the residence time for temperatures above 140°F dropped considerably and by December the average north face temperature did not reach 140°F. South faces were still exposed to sufficient incident solar radiation in December to exceed 140°F for more than 40 total hours.

6. SUMMARY

In-situ instrumentation deployed on the IBHS Roof Aging Farm and weather observing station have enabled a detailed look into conditions experienced by the farm's asphalt shingle specimens. The two major weather events impacting the site in 2014 were winter storms. The first brought ice and snow while the second produced a large snowfall for the region (exceeding 6 inches). The year was characterized by a cooler than normal winter followed by near-average temperatures for the remainder of the year except for a mild July. Rainfall was below normal by nearly 10 inches.

It was clear from the 10 months of data that asphalt shingle material maximum temperatures are strongly tied to incoming solar radiation. This energy is also transferred to the roof deck below, as temperatures were often only 10°F below that of the shingles. Asphalt shingles are known to be both a good absorber and emitter of solar radiation, which results in rapid heating and cooling rates as observed by the instrumented specimens. In general, daily average maximum roof material temperatures were about twice that of the average daily atmospheric high temperature during the months with the highest average daily maximum temperatures. The specimens returned to nearly ambient conditions when solar heating was lost. Variability was also observed as cloud cover changed and precipitation events induced large temperature fluctuations.

Differences between south and north face temperatures correlated with the seasonal changes in solar angle. As the summer gave way to fall, average specimen south face maximum temperatures continued to exceed 120°F even while average maximum atmospheric temperatures were below 60°F. The north faces only warmed 10°–20°F above the ambient air temperature during this same period with the loss of direct incoming solar radiation. At these lower solar zenith angles, larger temperature gradients were produced across the faces of specimens. During the month of December, north faces did not reach the 140°F standard conditioning threshold (UL2218, ASTM D3161). This may influence the ability of the shingle sealants to activate on the north-facing sides of roofs installed during winter months or at high latitudes. This may extend into early spring and begin in early fall in the northern latitudes. However, more research is needed in order to understand temperature and exposure duration requirements for sealant activation as a function of roof slope and sealant properties. Higher latitudes and steeper roof slopes are expected to prolong the time before asphalt shingles develop robust seals or possibly prevent them from ever sealing unless they are hand tabbed.

Data collected during 2014 will continue to be examined in more detail. One area of additional focus will be on temperature fluctuations due to precipitation events which may shock the roof cover and are hypothesized to contribute to subsequent failure of robust seals as shingles age. A second focus will be on developing conditioning protocols that better reflect actual exposure conditions for roofs installed in areas with different climate conditions and at various latitudes, times of the year, and roof slopes.

Five more sets of specimens will also be added to the IBHS farm in 2015. Future work may also explore the effect of shading on roof material temperatures to understand the effects of nearby vegetation.

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