Summer temperatures of roof assemblies using western redcedar, wood-thermoplastic composite, or fiberglass shingles

Jerrold E. Winandy*
H. Michael Barnes*
Robert H. Falk*

Abstract

For over 10 years, the Forest Products Laboratory has been monitoring the temperature histories of roof sheathing, roof rafters, and unventilated attics in outdoor attic structures that simulate typical light-framed construction. This report briefly summarizes findings from the roof temperature assessment project on black and white fiberglass shingles conducted from 1991 to 2001. Temperature histories are then presented for roof assemblies made with western redcedar (WRC), wood-thermoplastic composite (WTPC), and black and white fiberglass shingles and exposed in Madison, Wisconsin, from July 15 to September 15, 2002. The maximum temperatures recorded for the shingles during this period were 68.2°C for black fiberglass shingles, 59.1°C for white fiberglass shingles, 47.1°C for WRC shingles, and 48.7°C and 46.9°C for WTPC shingles with and without lathe, respectively. The black fiberglass shingles were almost 10°C hotter than the white fiberglass shingles and almost 20°C hotter than the WRC or WTPC shingles. Temperatures of the sheathing under the WTPC and WRC shingles were virtually identical and generally much cooler than temperatures of the sheathing under the fiberglass shingles. The sheathing under WTPC shingles applied on lathe was noticeably cooler than the sheathing under WTPC shingles installed directly on felt. The results of this study have implications for the effect of shingle type on the service life of roofing materials and the wood components of light-framed construction.

In the late 1980s, the degradation of wood treated with some fire-retardant (FR) chemicals in roof systems became a problem of major national significance. Our understanding of this deterioration in serviceability caused by thermal degrade was limited by our inability to correlate temperature histories of FR-treated roof sheathing plywood exposed in the laboratory using steady-state temperature with field exposures subject to diurnal and seasonal temperatures. This lack of correlation inhibited our ability to predict thermal-induced degradation of FR-treated plywood in the field from thermal degradation rates derived in the laboratory.

The FR thermal degrade program was initiated in 1988. This program involved more than a dozen interrelated studies over a 10-year period. The objective was to develop residual serviceability models for plywood roof sheathing and roof truss lumber (Winandy 2001). This paper is the third in a series dedicated to quantifying field thermal loads on shingles, sheathing, and rafter lumber. The previous papers reported the results of the roof temperature assessment project for black and white fiberglass shingles (Winandy and Beaumont 1995, Winandy et al. 2000). In the paper presented here, we summarize the results of the roof temperature assessment project. We also provide new roof temperature

The authors are, respectively, Project Leader, USDA Forest Serv., Forest Products Lab. (FPL), One Gifford Pinchot Dr., Madison, WI 57326-2398; Professor, Dept. of Forest Products, Mississippi State Univ., Box 9820, Mississippi State, MS 39762; and Research Engineer, FPL.
This paper was received for publication in May 2003. Article No. 9674.
*Forest Products Society Member.

Forest Prod. J. 54(11):27-33.

data for western redcedar shingles, wood-thermoplastic composite shingles, and black and white fiberglass shingles. This work is part of a long-term field-monitoring program to define and understand the critical issues of durability, color stability, and ultraviolet (UV) weathering of wood-thermoplastic roofing shingles (Falk et al. 2001).

Background

Thermal load histories provide an indication of the eventual service life of the roof coverings and materials within the entire roof system. Such thermal load histories can be used as data to identify how "hot" wood materials get in wood roof assemblies under diverse roofing materials.

Heyer (1963) reported temperature histories for wall and roof systems for six houses and one office building for periods ranging from 1 week to two consecutive summers (June-August). The houses were located in Tucson, Arizona; Athens, Georgia; Portland, Oregon; Diboll, Texas; and Madison, Wisconsin. Maximum roof temperatures were found to reach as high as 75°C. The cumulative duration of temperatures over 70°C did not exceed 21 hours, and the cumulative duration of temperatures over 65°C did not exceed 64 hours. Ozkan (1993) and Wilkes (1989) reported surface temperatures and various component temperatures as high as 93°C in flat roof systems under single-ply black rubber roofing.

Holton and Beggs (1997) studied two roof constructions, one with traditional dark-brown asphalt composition shingles and the other with a brown plastic roofing material. They found that attic air temperatures were about 11°C cooler under plastic roofing on hot summer days (33°C). They did not monitor the temperatures of members of the wood roof assemblies.

Thermal load data are critical to any subsequent modeling of the rate(s) of thermal degradation for roof shingles, wood composite sheathing, and rafter lumber (Lebow and Winandy 1999). Roof temperature data can be applied to predictive roof-temperature models to make performance interpretations for other building designs. Computer models have been developed that predict the temperature and moisture content of plywood roof sheathing and other lumber roof members based on various construction details, materials, ventilation factors, and solar gain (radiation load) for the roof (Wilkes 1989, TenWolde 1997).

TenWolde (1997) developed and later verified a predictive roof temperature model (the FPL model) designed especially for sloped wood-based roof systems. The FPL model shows that the temperature of the exterior surfaces of plywood roof sheathing is dominated by solar gain and the heat exchange between the surface and ambient air. Diurnal (daily cyclic) temperature variation and hourly sheathing temperature histories are also influenced by the radiant energy absorptivity of the roofing surface, roof pitch, and, to a lesser extent, insulation and attic ventilation. The combination of actual roof temperature data with the FPL model makes possible an integrated approach to predicting exposure temperatures of various components in wood roof assemblies across North America.

Data from a test facility at the University of Illinois (Rose 1992, 1995) was used to verify the FPL model (TenWolde 1997); the tests measure heat transfer, moisture movement, and airflow in typical residential attic structures under natural conditions (Rose 1992). The FPL model has been used to predict roof temperature histories for plywood roof sheathing at a dozen locations across the United States. Those predictions are then used to predict engineering design adjustments for FR-treated plywood roof sheathing in ASTM Standard D 6305-98 (ASTM 2002a) and for FR-treated roof truss lumber in ASTM Standard D 68 41-02 (ASTM 2002b).

Methods

The Wisconsin installation tested over the summer of 2002 was nearly identical to the earlier Mississippi (1995-1999) and Wisconsin (1991-1999) installations in construction and instrumentation, previously described in detail by Winandy and Beaumont (1995).

Exposure structures

In the summer of 1991, five field exposure structures were constructed at the Forest Products Laboratory Valley View field exposure site near Madison, Wisconsin (43° latitude). In Madison, the average incidence angle of sunlight is 19.5° from the southern horizon on the winter solstice (December 21) and 43° on the summer solstice (June 21). The annual average declination angle is 31.25°. The Wisconsin exposure structures (WI structures) were constructed to face south in a shadeless area open to direct sunlight. The structures were spaced far enough apart to prevent any one structure from shading the next structure. Construction of the WI structures was described in detail by Winandy and Beaumont (1995).

In 1994, matched exposure structures were built at the Mississippi Forest Products Laboratory, Mississippi State University, in Starkville, Mississippi (33.5° latitude). This research was part of an ongoing effort to relate temperatures in matched northern and southern U.S. roof systems. In Starkville, the average incidence angle of sunlight is 32.3° from the southern horizon on the winter solstice and 74.8° on the summer solstice. The annual average declination angle is 53.5°. The five exposure structures in Mississippi (MS structures) were constructed to face south in a shadeless area open to direct sunlight. Like the WI structures, the MS structures were spaced far enough apart to prevent any one structure from shading the next structure. The data from the MS structures provide a direct measure of a more severe (higher solar loading) location compared with Madison, Wisconsin.

All 10 exposure structures were identical. They were 3.7 m wide by 4.9 m long and constructed to simulate part of a typical multifamily attic-roof system in which U.S. Model Building Codes sometimes allow FR-treated plywood roof sheathing. To replicate typical North American multi-family roof construction on a smaller scale, our 3.7-m-wide single-pitch structures were designed to simulate in cross section a partial section of a typical 14.8-m span, 3:12 pitch roof system in both roof area and attic volume (Winandy and Beaumont 1995). Our single-pitch structures represent the middle 3.7-m-wide section for half of a 14.8-m-wide roof system.

Each exposure structure was completely enclosed and unventilated. The four exterior walls were sheathed with 12-mm-thick, 200-mm-grooved southern pine siding attached to nominal 2- by 4-inch (standard 38- by 89-mm) wall studs. The exterior surfaces were painted with a light gray, almost-white paint. The walls, floors, and roof system were

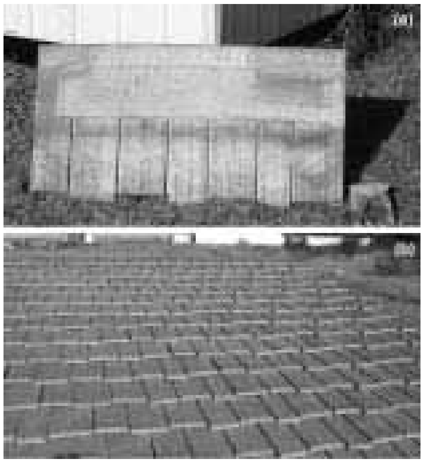

Figure 1. — Wood-thermoplastic composite roofing for Wisconsin exposure in 2001: (a) roof tile, (b) installed WTPC shingles.

not insulated. Earlier work by the two senior authors had shown that the sheathing and rafter temperatures experienced with our uninsulated exposure structures were very comparable to those recorded by Heyer (1963) in actual homes and small buildings.

Black fiberglass shingles were used on all five MS structures. Two MS structures were humidified using an atomizing humidifier system at ambient temperature such that the relative humidity was maintained at >85 percent for most of the diurnal cycle. The interior of the remaining MS structures was kept dry.

From 1991 to 2001, the WI exposure structures were roofed with black or white fiberglass shingles weighing 106 kg/square (a square is 9.3 mm^2 [100 ft.^{2}]). The black and white shingles had reflectance values of 3.4 and 26.1 percent, respectively. Both black and white shingles had an emissivity rating of 0.91 as reported by their manufacturer.

In the fall of 2001, the fiberglass shingles and plywood sheathing were removed from one white-shingled and two black-shingled structures at the Wisconsin site. The structures were re-sheathed with 12-mm- (7/16-inch-) thick oriented strandboard (OSB) roof sheathing. The commercial OSB was made from aspen flakes and an isocyanate resin. One structure was shingled with western redcedar (WRC) shingles and the other two structures with prototype wood-thermoplastic composite (WTPC) shingles (**Figs. 1** and **2**). The WTPC shingles were made from a 50/50 blend of wood flour and high-density polyethylene, compression molded, and were 0.86 m wide by 0.45 m high.

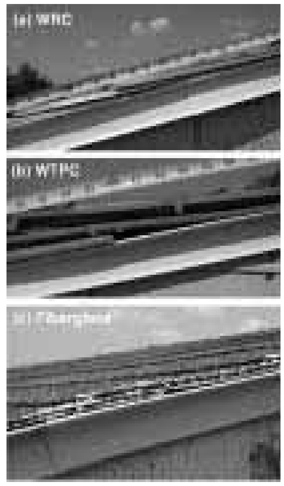

Figure 2. — Side view of shingles installed in 2001 at Valley View test site in Wisconsin. Ruler shown in inches.

The WRC shingles were laid directly over felt. The WTPC shingles were laid differently on each structure. On one structure, the shingles were laid directly over felt. On the other structure, the WTPC shingles were laid over a horizontal course of 9-mm- (3/8-inch-) thick lathe, which in turn was laid over a similar vertical course of lathe.

Recording of temperatures

All exposure structures were instrumented with type-T thermocouples placed at various locations within the structure; exact details of the thermocouples and their installed locations were given in Winandy and Beaumont (1995). From 1991 to 1999, temperatures were recorded in the following: 1) a black-shingled structure that was not ventilated or humidified; 2) a black-shingled structure that was unventilated and artificially humidified from April through October to maintain >85 percent relative humidity for most of the daily diurnal cycle; and 3) a white-shingled structure that was neither ventilated nor humidified, i.e., indoor temperature was not controlled.

In the summer of 2002, temperatures were recorded in the structures with WRC, WTPC, and fiberglass shingles at the Valley View exposure site in Wisconsin. Temperature data were collected every 5 min at each building, at each location within the buildings (shingle, sheathing, rafter, attic air), and of the outside ambient air. An hourly average was recorded from each thermocouple location using a Campbell-Scientific (Logan, UT) model CR10 datalogger and a model AM416, 32-channel multiplexer. The datalogger had a reported accuracy of 0.2 percent over the service temperature range of -55°C to 85°C.

Results

Summary of test results from 1991 to 1999

To fully understand the implications of the new 2002 data, we must understand the historic data. First, we need to define some terminology. For each structure, we compiled the number of hours recorded for each thermocouple into 5°C temperature bins. These 5°C bins (0° to <5°C, 5° to <10°C, **…**, 70° to <75°C) are hereafter defined as "exceedance temperatures." The value reported as the exceedance temperature for 70°C is thus the number of hours the temperature at that thermocouple location equaled or exceeded 70°C, but was less than 75°C. Winandy et al. (2000) reported the annual temperature histories in Wisconsin (1991 to 1999) and Mississippi (1996 to 1999) for various wood components used in conventional North American roof assemblies under fiberglass shingles.

Over the 4-year exposure in Mississippi, the maximum "1-hour average" temperatures recorded for black-shingled roofs in dry structures were 78°C and 63°C for the top and bottom plies of the plywood roof sheathing, respectively, and 58°C for the rafter. The maximum temperatures recorded for the matched WI structures were 75°C, 59°C, and 54°C, respectively. The MS and WI black-shingled structures showed only small differences (3° to 4°C) in maximum record temperatures. The average 8- or 4-year temperature histories for each thermocouple in each exposure structure were discussed by Winandy et al. (2000) and are shown for the roof sheathing and rafters in **Figures 3** and **4**, respectively.

The annual 1-hour maximum temperatures of various wood components were similar in the MS and WI roof systems; these temperatures were only 3° to 4°C higher in the MS structures. Although the annual maximum and the form of the recorded exceedance temperatures were similar in the MS and WI

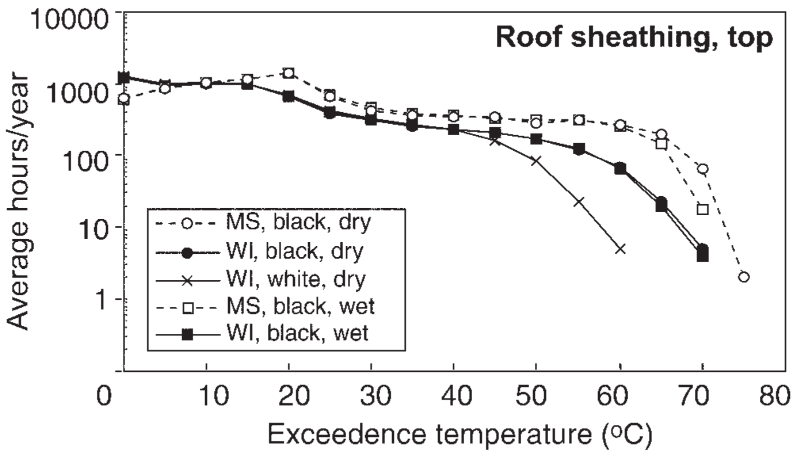

Figure 3. — Average annual roof sheathing temperature histories of black- and white-shingled structures in Wisconsin and black-shingled humidified structures in Mississippi. At both sites, one black-shingled structure was unhumidified (dry) and another was heavily humidified (wet).

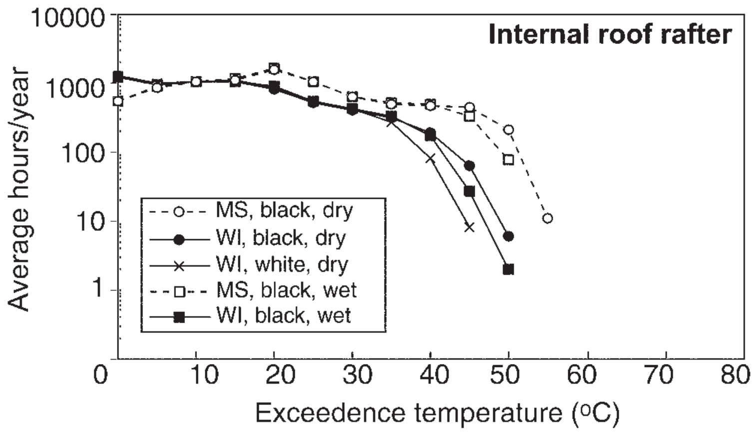

Figure 4. — Average annual roof rafter temperature histories of MS and WI structures.

exposure structures, the MS structures experienced temperatures in the higher range for many more hours per year compared to matched WI structures. Temperatures of wood components in the MS structures were generally 5° to 10°C warmer than those in matched WI structures. Black-shingled roof systems tended to be 5° to 10°C warmer on sunny afternoons compared with white-shingled systems. Temperatures at the top of the roof sheathing were controlled by solar gain, not outside air or attic air temperatures. Temperatures at the bottom of the roof sheathing were usually controlled by solar gain, except on a few of the hottest days, when sheathing temperatures were also influenced by outside air or attic air temperatures. Rafter temperatures were usually controlled by attic air temperatures, except on a few of the hottest days, when they were also influenced by solar radiation. The major difference in the temperature of wood components used in attics in the northern exposure (WI) compared with those used in the southern exposure (MS) was in minimum temperatures, which were as much as 20°C lower in the WI structures.

July to September 2002 test results

From July to September 2002, the WRC shingles and WTPC shingles on the WI structures were evaluated for their UV durability and their influence on the solar-induced thermal loads imparted to wood roof truss lumber and OSB roof sheathing in typical light-framed construction. Exceedence temperatures were compared with those in similarly designed roof assemblies under conventional black and white fiberglass shingles (**Fig. 5**). The data recorded from July to September 2002 are given in **Table 1**. Matched temperature histories (>20°C) are shown for shingles, top and bottom surfaces of roof sheathing, rafters, and attic air in **Figure 5**.

Table 2 shows maximum temperatures for roof assembly members and attic air from July to September 2002. The maximum temperatures recorded for the shingles during this period were 68.2°C for black fiberglass, 59.1°C for white fiberglass, 47.1°C for WRC, and 48.7°C and 46.9°C for WTPC with and without lathe, respectively. (**Table 2**). The black fiberglass shingles were almost 10°C hotter than the white fiberglass shingles and almost 20°C hotter than the WRC or WTPC shingles. Temperatures for the other members of the roof assembly and the attic followed the same trends.

Discussion

The overall data recorded from July to September 2002 (**Table 1**) for both black- and white-fiberglass-shingled structures were very similar to that previously reported for these same months from 1991 to 1999 (Winandy et al. 2000). Specifically, the sheathing, rafter, and attic air temperatures reported for 2002 were virtually identical to the annualized (i.e., averaged) thermal-load histories reported for the previous period. Thus, we can compare the 1991-1999 thermal-load histories for black and white fiberglass shingles in Wisconsin and Mississippi to the 2002 data for WRC and WTPC shingles in Wisconsin. We can also compare the long-term performance of wood sheathing and rafter materials during these two periods (Lebow and Winandy 1999, Winandy 2001).

Data recorded at the National Oceanic and Atmospheric Administration (NOAA 2002) Weather Station at the Dane County Regional Airport in Madison, Wisconsin, in the summer of 2002 indicated that the weather tended to be about 0.9°C warmer and 5.6 mm/week drier than normal for this period (**Table 3**). The Valley View field exposure site is approximately 15 km west-southwest of the NOAA Weather Station. While not expressly measured, UV radiation was assumed to be nearly normal or slightly higher than normal for this time of year because of the consistently

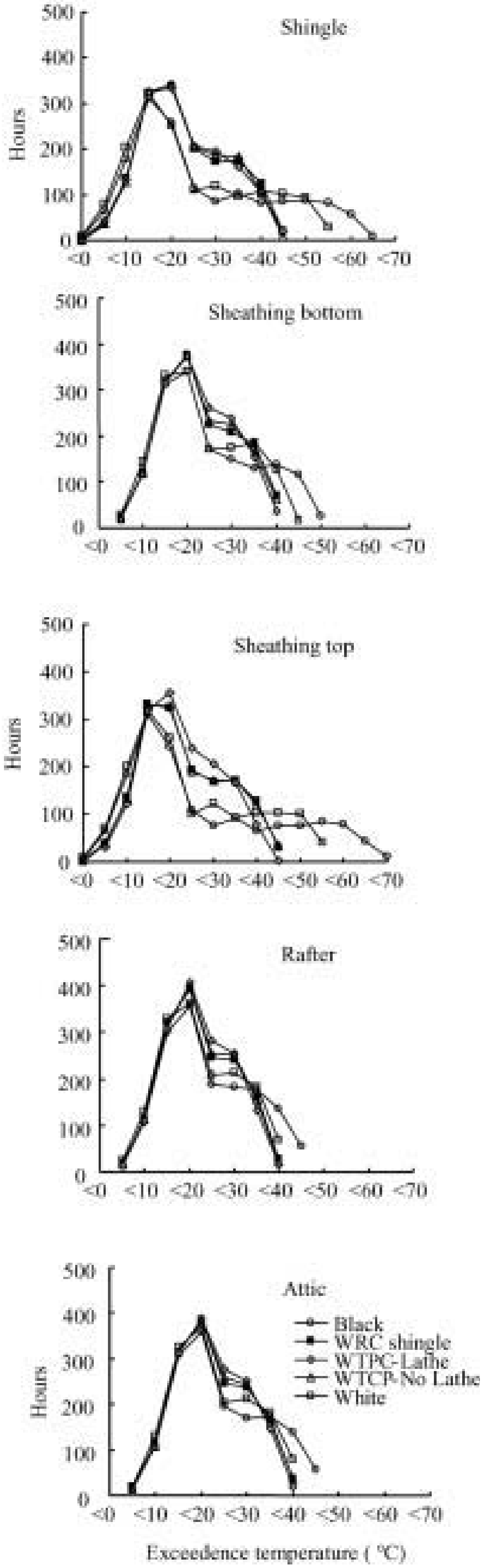

Figure 5. — Cumulative temperature histories of roof assembly components of test units at Valley View site, July 15 to September 15, 2002.

warmer ambient temperatures and less than normal rainfall (**Table 3**).

From July 15 to September 15, 2002, the temperature of the black fiberglass shingles exceeded 60°C for a total of 65 hours and exceeded 65°C for 9 hours (**Table 1**, **Fig. 5**). The temperature of the top layer of the roof sheathing beneath the black shingles was more than 60°C for 55 hours and more than 65°C for 11 hours. In comparison, the temperature of the white fiberglass shingles did not exceed 60°C; temperatures exceeded 50°C for 121 hours and 55°C for 29 hours. The top layer of the sheathing beneath the white fiberglass shingles was over 50°C for 142 hours and over 55°C for 42 hours. These data clearly show that during a typical summer season, the sheathing under both black and white fiberglass shingles is often hotter than the shingles themselves. TenWolde (1997) and Rose (1992) have attributed this phenomenon partially to convective cooling of shingles by wind and partially to radiant heat loss that occurs late in the day.

Temperatures of WTPC shingles (both with and without lathe) and WRC shingles were much cooler than those of black or white fiberglass shingles (**Table 1**, **Fig. 5**). Accordingly, temperatures of the top surface of the roof sheathing beneath WTPC and WRC shingles were generally much cooler than those of sheathing beneath fiberglass shingles. Temperatures of sheathing under WTPC and WRC shingles applied directly on felt were virtually the same. However, temperatures of sheathing under WTPC shingles applied on lathe were noticeably lower than those of sheathing under WTPC shingles installed directly on felt.

Similar, but progressively lower, temperature trends were also noted in the temperature histories recorded at the bottom of the sheathing, in the interior of the 2 by 6 rafter, and in the attic air (**Fig. 5**).

The implications of these data for shingle, sheathing, and rafter performance are obvious. More than 50 years of field experience with fiberglass shingles over plywood and more than 25 years of field experience with OSB sheathing have indicated little thermal degradation of untreated wood composite sheathing and wood truss lumber under black or white fiberglass shingles. The lower roof temperatures reported

Table 1.— Cumulative hours within each exceedence temperature (°C) range between July 15 and September 15, 2002 in Madison, Wisconsin.

Bldg	Type of shingle	Location[a]	0°	<5°	<10°	<15°	<20°	<25°	<30°	<35°	<40°	<45°	<50°	<55°	<60°	<65°	<70°
			(hr.)														
1	Black	Shingle	5	65	179	312	257	114	84	102	81	85	88	82	56	9	--
		Top	6	66	185	309	241	110	75	93	66	75	76	83	79	44	11
		Bottom	0	20	118	312	341	172	149	129	139	114	25	--	--	--	--
		Rafter	0	18	111	298	356	187	183	176	134	56	--	--	--	--	--
		Attic air	0	13	107	309	359	194	170	173	138	56	--	--	--	--	--
2	Cedar	Shingle	1	35	135	322	336	201	172	174	123	20	--	--	--	--	--
		Top	1	39	136	332	323	194	168	170	127	29	--	--	--	--	--
		Bottom	0	22	120	317	376	225	207	182	70	--	--	--	--	--	--
		Rafter	0	17	112	321	393	245	240	162	29	--	--	--	--	--	--
		Attic air	0	17	113	314	385	247	238	168	37	--	--	--	--	--	--
3	WTPC-Lathe	Shingle	3	41	132	325	333	207	194	160	104	20	--	--	--	--	--
		Top	0	30	121	317	355	240	206	166	80	4	--	--	--	--	--
		Bottom	0	20	117	314	375	262	239	155	37	--	--	--	--	--	--
		Rafter	0	15	107	308	406	281	254	132	16	--	--	--	--	--	--
		Attic air	0	15	108	314	387	276	252	146	21	--	--	--	--	--	--
4	WTPC-No Lathe	Shingle	1	36	127	326	341	203	186	185	105	9	--	--	--	--	--
		Top	2	42	133	328	330	189	171	170	119	35	--	--	--	--	--
		Bottom	0	20	119	318	374	233	226	166	63	--	--	--	--	--	--
		Rafter	0	16	112	310	398	253	251	156	23	--	--	--	--	--	--
		Attic air	0	15	106	315	382	261	243	161	36	--	--	--	--	--	--
5	White	Shingle	8	80	202	321	251	110	120	97	106	103	92	29	--	--	--
		Top	7	72	201	317	260	101	121	93	103	102	100	42	--	--	--
		Bottom	0	29	144	331	341	172	174	185	127	16	--	--	--	--	--
		Rafter	0	26	130	330	363	206	213	183	68	--	--	--	--	--	--
		Attic air	0	20	129	326	369	203	212	182	78	--	--	--	--	--	--

[a]Column heads indicate 5°C temperature bins; <5° refers to the 0° to 5°C bin, <10° refers to the 5° to <10°C bin, etc.
[b]Location of temperature measurement: top = top of sheathing; bottom = bottom of sheathing.

Table 2. — Maximum temperatures recorded between July 15 and September 15, 2002.

Shingle type	Shingle	Sheathing Top layer	Sheathing Bottom layer	Rafter	Attic
	(°C)				
Fiberglass					
Black	68.2	72.2	52.7	49.1	48.9
White	59.1	59.3	46.6	43.8	44.1
WRC	47.1	47.9	44.1	42.1	42.6
WTPC					
With lathe	48.7	47.1	43.3	42.0	42.4
Without lathe	46.9	47.6	44.2	42.4	42.6

Table 3. — Temperature and rainfall data recorded at NOAA Weather Station, 2002.[a]

Recording period	Temperature Max.	Temperature Min.	Temperature Avg.	Temperature ΔNormal	Days >32°C	Rainfall Total	Rainfall ΔNormal	Rainfall 24-hr. max.	Thumder-storms
	(°C)					(mm)			(days)
July 15-31	37	15	23	+1.4	6	52	+3	22	6
Aug. 1-31	34	9	21	+0.2	2	77	-33	27	7
Sept. 1-15	32	8	18	+1.9	1	22	-15	20	3

[a]Madison, Wisconsin (NOAA 2002).

for structures with WTPC or WRC shingles suggest that even less thermal degradation of wood composite sheathing and wood rafter lumber is likely to occur for these systems compared with black or white fiberglass shingle systems. The data also imply that the internal temperatures of WTPC shingles are well below the laboratory-derived thermal degradation temperatures of the high-density polyethylene mastic used in commercial WTPC shingles of the type tested.

Concluding remarks

Black fiberglass shingles experience much higher temperatures than do white fiberglass shingles. The internal temperatures of WRC and WTPC shingles were similar to each other, but cooler than the temperatures of either black or white fiberglass shingles. Our data indicate that during a typical summer afternoon, the sheathing under black and white fiberglass shingles was often hotter than the shingles themselves. The temperatures of the sheathing beneath WTPC and WRC shingles were generally much cooler than that of the sheathing beneath fiberglass shingles. The sheathing under WTPC shingles applied on lathe was noticeably cooler than the sheathing under WTPC shingles installed directly on felt. Lower shingle, sheathing, and rafter temperatures should increase structural service life. Our results may also have implications for the overall energy costs associated with buildings shingled with the types of materials studied. These last two issues represent areas for future study.

Literature cited

American Society for Testing and Materials (ASTM). 2002a. Standard practice for calculating bending strength design adjustment factors for fire-retardant-treated plywood roof sheathing. ASTM D 6305-98. *In*: ASTM Annual Book of Standards. ASTM. West Conshohocken, PA.

__________. 2002b. Standard practice for calculating bending strength design adjustment factors for fire-retardant-treated roof truss lumber. ASTM D 6841-02. *In*: ASTM Annual Book of Standards. ASTM, West Conshohocken, PA.

Falk, R.H., T. Lundin, and C. Felton. 2001. The effects of weathering on wood/thermoplastic composites intended for outdoor applications. *In*: Proc., PATH Conference on Durability and Disaster Mitigation in Wood-Frame Housing. Forest Prod. Soc., Madison, WI. pp. 175-180.

Heyer, O.C. 1963. Study of temperature in wood parts of houses throughout the United States. Res. Note FPL-RN- 012. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

Holton, J. and T. Beggs. 1997. Test and evaluation of the attic temperature reduction potential of plastic shake roofs. ASHRAE Pub. No. CH-99-11-5. Am. Soc. of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

Lebow, P.K. and J.E. Winandy. 1999. Verification of kinetics-based model for long-term effects of fire-retardants on bending strength at elevated temperatures. Wood Fiber Sci. 31 (1):49-61.

National Oceanic and Atmospheric Administration (NOAA). 2002. Local climatological data. July, August, and September 2002. Dane County Regional Airport, Madison, WI. U.S. Dept. of Commerce, Washington, DC.

Ozkan, E. 1993. Surface and inner temperature attainment of flat roof systems in hot-dry climate. King Saud University, Riyadh, Saudi Arabia.

Rose, W.B. 1992. Measured values of temperature and sheathing moisture content in residential attic assemblies. *In*: Thermal performance of the exterior envelopes of buildings. Proc., ASHRAE/DOE/ BTECC conference. Am. Soc. of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA. pp. 379-390.

__________. 1995. Temperature and sheathing moisture content in residential attics. Unpublished report. University of Illinois, Building Research Center, Champaign, IL.

TenWolde, A. 1997. FPL roof temperature and moisture model. Res. Pap. FPL-RP-561. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

Wilkes, K.E. 1989. Model for roof thermal performance. Oak Ridge National Laboratory Rept. ORNL/CON-274. Office of Scientific and Technical Information, Oak Ridge, TN.

Winandy, J.E. 2001. Thermal degradation of fire-retardant treated wood: Predicting residual service life. Forest Prod. J. 51(2):47-54.

__________ and R. Beaumont. 1995. Roof temperatures in simulated attics. Res. Pap. FPL-RP-543. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

__________, H.M. Barnes, and C.A. Hatfield. 2000. Roof temperatures histories in matched attics in Mississippi and Wisconsin. Res. Pap. FPL-RP-589. USDA Forest Serv., Forest Prod. Lab., Madison, WI.