THERMAL LOAD HISTORIES FOR NORTH AMERICAN ROOF ASSEMBLIES USING VARIOUS CLADDING MATERIALS INCLUDING WOOD-THERMOPLASTIC COMPOSITE SHINGLES

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Abstract

Since 1991, thermal load histories for various roof cladding types have been monitored in outdoor attic structures that simulate classic North American light-framed construction. In this paper, the 2005 thermal loads for wood-based composite roof sheathing, wood rafters, and attics under wood–plastic composite shingles are compared to common North American roof cladding materials, solid wood shingles and black- and white-fiberglass shingles. WTPC-shingles have appeared to suffer no damage after over three-years of weathering and solar exposure. The summertime thermal load data for flakeboard and plywood sheathing temperatures under wood-plastic composite shingles were cooler than sheathing under North America's most commonly used fiberglass shingles. Lower shingle, sheathing and rafter temperatures should provide increased roof-system service-life.

Introduction

Until recently, few reliable data were available on actual thermal loads for individual wood and composite components used in roof systems in North American light-framed construction. Thus we were unable to specifically correlate laboratory experiments to field exposures having diurnal and seasonal temperature histories. Actual roof system temperature histories which represent comprehensive thermal-load data are now available for 10 years of exposure in Madison, Wisconsin (43°N latitude) and 4 years in Starkville, Mississippi (33°N latitude) (1-4). This paper is another in that series. First it reports 2005 thermal loads for all roof-cladding systems evaluated and compares the performance of wood-plastic composite shingles relative to other common North American rood cladding materials. This is needed to understand the critical performance issues related to durability, thermal stability, and UV weathering for wood–plastic roofing shingles.

Winandy and coworkers (3-4) monitored the temperatures of various types of shingles and roof-system components. Temperatures of various types of primary roof cladding materials (hereafter termed as "shingles") were monitored at the mid-point of their cross-sectional thickness. Summer temperatures were found to be much higher for black fiberglass shingles than for similar white fiberglass shingles. Western redcedar (WRC) and wood–thermoplastic composite (WTPC) shingles experienced similar internal temperatures but were cooler than either black or white fiberglass shingles. During a typical summer day, plywood or flakeboard wood-composite sheathing under fiberglass shingles was often hotter than that under WTPC and WRC shingles. As expected, sheathing under WTPC shingles applied directly on lath was noticeably cooler than sheathing under WTPC shingles installed on felt over the sheathing. Winandy (5) has indicated that lower shingle, sheathing, and rafter temperatures should provide increased service life and might also have implications for overall energy costs associated with buildings using these roof materials.

Exposure Structures

In the summer of 1991, five field exposure structures were constructed 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°. Each exposure structure was constructed facing south in a shadeless area exposed to direct sunlight. The structures were spaced far enough apart to prevent any one structure from shading the next structure. Construction and material details for these structures have been reported(1-4).

The exposure structures were identical. They were 3.7 m wide by 4.9 m long and constructed to simulate typical North American light-frame wood construction. To replicate this type of construction on a smaller scale, the 3.7-m-wide structures simulated in cross section the 1/8- to 3/8-span section of a 14.8-m span, 3:12 pitch roof system in both roof area and attic volume (1). 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 (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 not insulated. The exposure structures were instrumented with type-T thermocouples (1-4).

In the fall of 2001, the shingles and plywood sheathing were removed from three of 5 structures at the Wisconsin site. These structures were re-sheathed with 12-mm-thick oriented strandboard (OSB) roof sheathing. The commercial OSQ was made from aspen flakes and an isocyanate resin. One structure was then shingled with western redcedar (WRC) shingles directly over felt, and the other two structures were shingled with prototype wood–thermoplastic composite (WTPC) shingles. The WTPC shingles were 0.86-m-wide by 0.45-m-high, made from a 50/50 blend of wood flour and high-density polyethylene, and compression molded (Figure 1). In one WTPC construction, the shingles were laid directly over felt as were the WRC shingles. This type of application is usually considered to represent a worst-case scenario for shingle durability. In the other WTPC construction, the shingles were laid over a horizontal course of 9-mm-thick lath that, in turn, was laid over a similar vertical course of lath. Thus, in four structures, the shingles (WRC, WTPC, and black and white fiberglass) were applied directly over felt (i.e., without lath). In the remaining structure, WTPC shingles were applied over lath.

Since the summer of 2002, we have monitored temperature histories of the five structures. Temperatures were monitored in five locations: shingles, sheathing (two measurements), rafter, attic air, and outside ambient air. The shingle temperature was measured using a type-t thermocouple embedded at the mid-point of the shingle cross-section and located about one-third the distance from the roof line, between the peak and lower eave. The other thermocouples (also type-t) were placed as follows: (a) embedded between the OSB or plywood sheathing and the roofing paper; (b) embedded at the mid-point of the nominal 2 by 6 (38 by 140 mm) rafter; arid (c) suspended 200 mm away (extending inside) from the back wall, about 1.55 m from the floor. A single thermocouple was used to measure outside air temperature; it was located under a metal shield (i.e., covered) about 50 mm away (extending outside) from the back wall, about 2 m above the ground. Specific details on thermocouple locations were reported previously (1,3).

At each thermocouple location, temperature data were collected every 5 min; an hourly average was recorded using a Campbell–Scientific (Logan, Utah) model CR10 data logger and a model AM416, 32-channel multiplexer. The data logger had a reported accuracy of 0.2% over a service temperature range of -55°C to 85°C. This 2005 data was obtained in an identical manner as previous reports (3-5).

To develop the temperature history for each roof covering and components, we calculated the number of hours recorded for each thermocouple into 5°C temperature bins. These 5°C bins (0°C to <5°C, 5°C to <10°C, …, 70°C to 75°C) are hereafter defined as "exceedence temperatures." The value reported as the exceedence temperature for 70°C is thus the number of hours that the temperature at that thermocouple location equaled or exceeded 70°C but was lower than 75°C.

Results and Discussion

The actual data for the 2003–2004 thermal load histories for black- and white-fiberglass shingles, WRC shingles and WTPC shingles was recently reported (4). A detailed analysis of that 2003-2004 data has also recently been reported (5). The 2005 thermal load histories for four exposure structures in Madison, Wisconsin are given in Table 1. A direct comparison of thermal load data from 2005 for the roof system sheathing under black-fiberglass shingles to a match set of previously reported data representing the 8-year average from 1992-1999 (2) clearly shows little difference between 2005 and previous years (Figure 2). A similar comparison of the 2003-2004 data and to this same matched set of 8-year averages from 1991-1999 (4) also found no practical difference in roof system thermal loads. This infers that direct comparisons between 2003-2004 to the 2005 data are plausible. Annual temperature histories (–30°C to <70°C) were calculated for shingles, top surface of roof sheathing, roof rafter, and attic air (Figures 3-6).

The 2005 thermal load data indicates that few practically significant differences exist in winter time thermal loads when directly comparing solid wood WRC shingles, black- and white-fiberglass shingles, or WTPC-shingles. Close inspection of Table 1 and Figures 3-6 clearly show this similar relationship for wintertime thermal loads for all components or zones within the roof systems.

The 2005 summertime thermal loads on roof systems were found to be directly related to the type of roof cladding material used. Each system had a unique, differential effect on the temperatures experienced in individual system components. Black fiberglass shingles experienced much higher thermal loads than white fiberglass shingles, which in turn were noticeably higher that WTPC or WRC shingle temperatures (Table 1, Figure 3). A similar trend was also found for the summertime thermal loads experienced by OSB composite sheathing, except that it was evident that the use of lath between WTPC shingles and the composite sheathing clearly lowered sheathing temperatures even further (Figure 4). The rafter temperatures and attic air temperatures experienced under black fiberglass shingles were also higher than thermal loads under white fiberglass shingles which in turn were both noticeably higher than those under WTPC or WRC shingles (Table 1, Figure 5-6).

The nearly 4-year analysis of data from this report and past work (3-5) suggests that use of WTPC or WRC shingles can result in lower summertime sheathing and attic temperatures which implies that a potential increase in roof system service life is possible. We found that attic air temperatures were measurably warmer during the summer in structures with black or white fiberglass shingles compared with WPC shingles (3-5). On the average, summer attic air temperatures were shown to be over 4.3°C warmer under black fiberglass shingles than under WTPC shingles (5). This new 2005 data clearly agrees with our past analyzes that concluded that WTPC shingles might result in lower overall energy costs associated with summer air-conditioning than fiberglass shingles (5).

Conclusions

Roof temperature histories (i.e., thermal loads) were reported for shingles, wood-sheathing and rafters under WTPC-, WRC-, and black and white fiberglass-shingles. The data clearly show that black fiberglass shingles experience much higher temperatures than do white fiberglass shingles. The WRC and WTPC shingles had similar internal temperatures and were cooler than either black or white fiberglass shingles. The data indicate that during a typical summer sheathing under WTPC shingles is much cooler than sheathing under fiberglass shingles. Lower shingle, sheathing, and rafter temperatures might increase roof service life and have implications for overall energy costs.

After analysis of 4-years of actual field data, we now feel comfortable in asserting that the internal temperatures within WTPC shingles are well below the laboratory-derived thermal degradation temperatures of the high-density polyethylene mastic used in WTPC shingles of the type tested and currently being commercially used, Current work is now specifically monitoring the long-term UV-stability of these WTPC shingles after 4-years of exposure.

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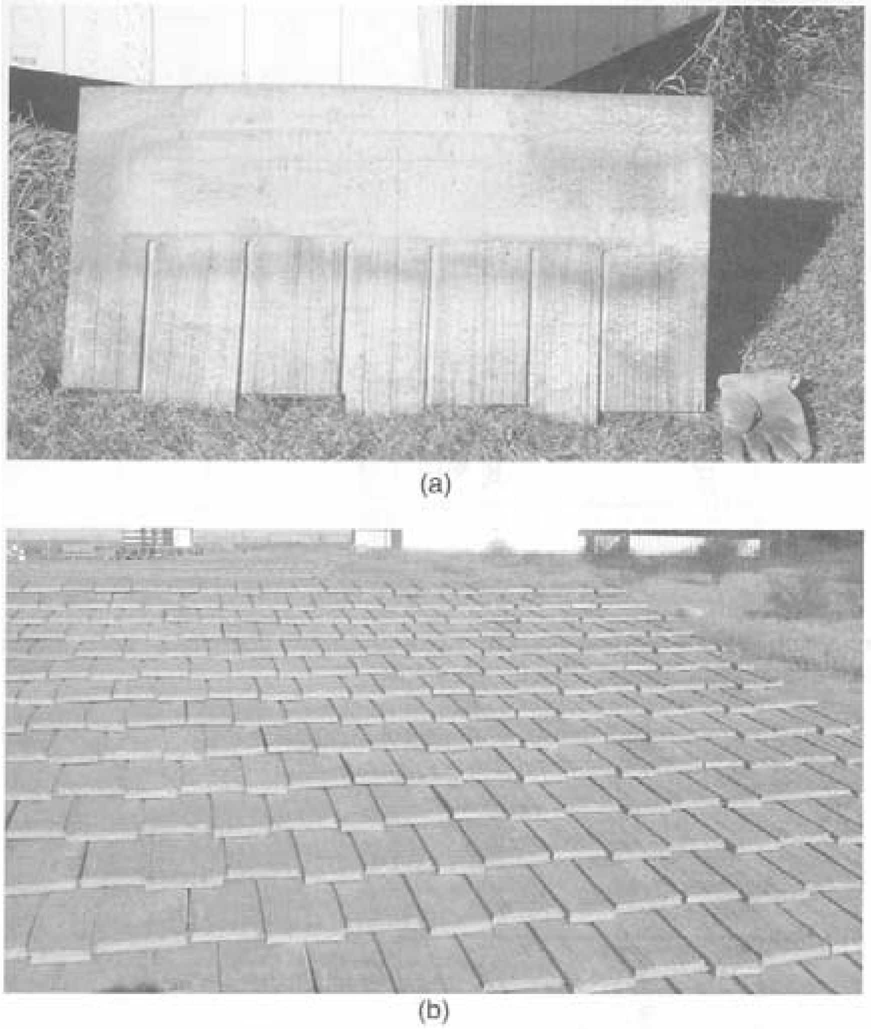
(a)

(b)

Figure 1 — Components for WTPC structure: (a) roof tiles, (b) shingles.

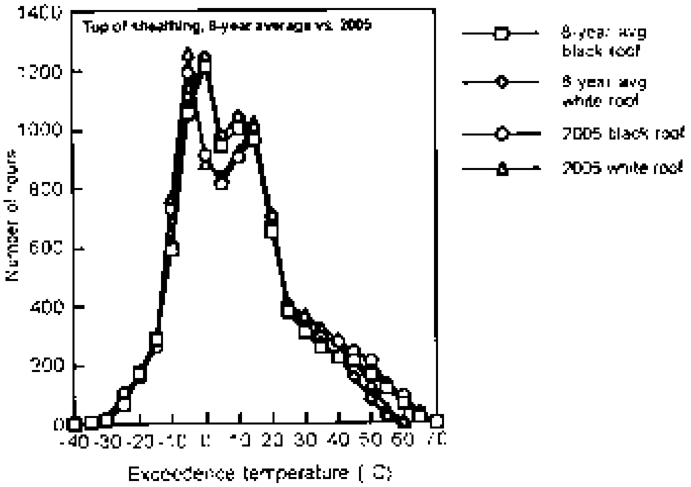

Figure 2 — Comparison of 2005 thermal loads on roof sheathing to corresponding 8-year averages from 1992-1999 (2).

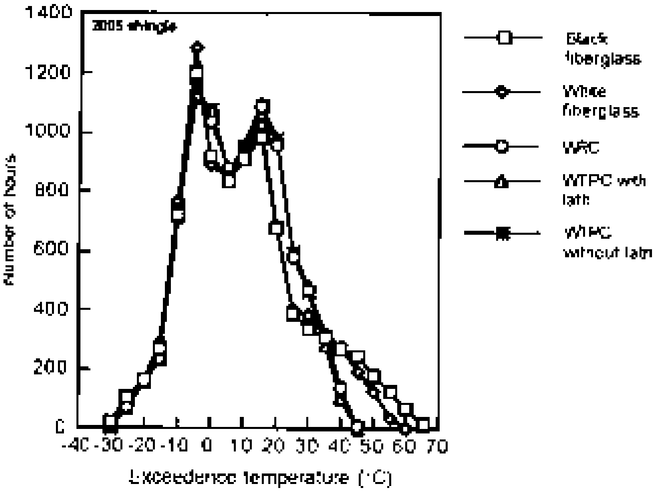

Figure 3 — Comparison of 2005 thermal loads for black and white fiberglass-, solid western redcedar (WRC)- and WTPC-shingles with and without lath strips.

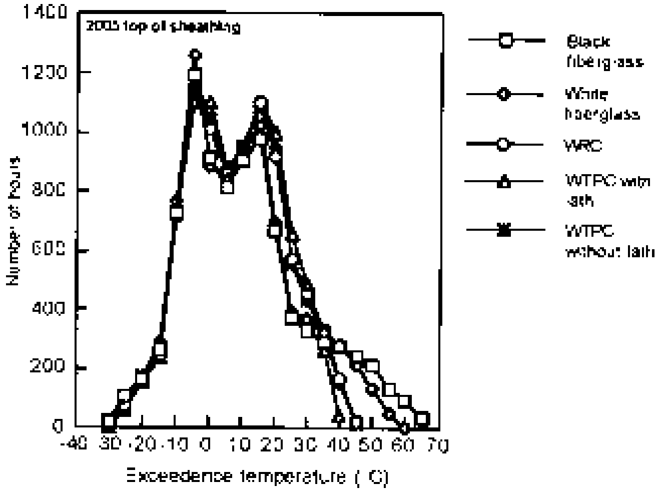

Figure 4 — Comparison of 2005 thermal loads for wood composite roof sheathing under black and white fiberglass-, solid western redcedar (WRC) or WTPC with and without lath strips.

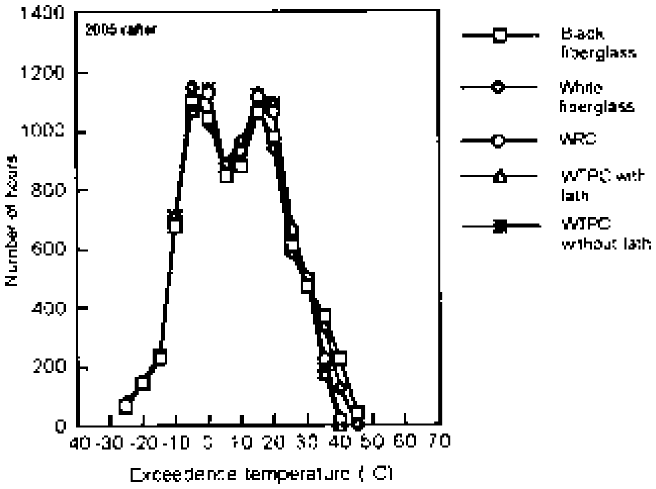

Figure 5 — Comparison of 2005 thermal loads for 38- by 106-mm lumber rafters beneath roof sheathing under black and white fiberglass-, solid western redcedar (WRC) or WTPC with and without lath strips.

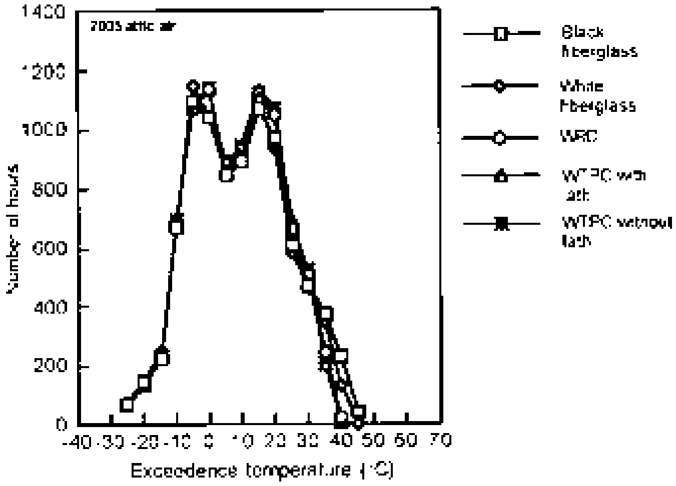

Figure 6 — Comparison of 2005 attic-air temperatures for roof systems using black and white fiberglass-, solid western redcedar (WRC) or WTPC with and without lath strips.

								Time (h) at various exceedence temperatures(°C)													
	Temp	Below 0°C						Above 0°c													
Shingle	site	>30	>25	>20	>15	>10	>5	>0	>5	>10	>15	>20	>25	>20	>35	>40	>45	>50	>55	>60	>65
Black	**Shingle**	21	105	164	270	725	1202	919	831	911	986	679	392	340	313	270	245	177	125	67	18
fiberglass	**Top**	20	107	165	266	730	1191	910	815	904	979	671	378	332	294	275	246	213	133	94	37
	Bottom	--	73	143	235	680	1114	1007	845	885	1058	929	566	444	387	260	126	8	--	--	--
	Rafter	--	70	147	229	679	1099	1045	849	883	1062	976	610	472	370	226	43	--	--	--	--
	Attic	--	70	144	224	668	1093	1044	850	892	1070	970	610	476	378	230	41	--	--	--	--
White	**Shingle**	21	108	169	289	770	1287	891	847	931	1023	684	402	382	314	281	194	128	37	2	--
fiberglass	**Top**	21	104	167	291	770	1256	887	839	928	1025	695	393	371	325	285	211	136	52	4	--
	Bottom	--	82	153	258	709	1167	998	884	946	1075	881	554	449	371	204	29	--	--	--	--
	Rafter	--	81	155	247	707	1150	1026	889	965	1076	937	585	476	336	127	3	--	--	--	--
	Attic	--	77	149	250	677	1146	1042	892	940	1105	936	586	469	352	133	6	--	--	--	--
WTPC with lath	**Shingle**	7	67	162	235	741	1128	1078	859	960	1093	969	594	481	283	102	1	--	--	--	--
	Top	5	61	155	238	725	1101	1105	877	948	1099	997	655	486	267	41	--	--	--	--	
	Bottom	--	62	146	232	723	1103	1109	879	937	1123	1044	652	500	229	21	--	--	--	--	
	Rafter	--	61	149	237	712	1071	1139	871	937	1131	1096	678	494	179	5	--	--	--	--	--
	Attic	--	67	135	233	699	1076	1134	857	943	1133	1068	687	512	207	9	--	--	--	--	--
WTPC w/o lath	**Shingle**	4	66	158	246	738	1116	1077	869	952	1092	979	592	464	291	112	4	--	--	--	--
	Top	7	66	170	263	748	1141	1044	863	949	1091	931	557	435	321	155	19	--	--	--	--
	Bottom	--	63	150	237	726	1093	1119	860	948	1119	1019	641	488	261	36	--	--	--	--	--
	Rafter	--	63	148	239	709	1086	1140	864	935	1123	1086	659	496	203	9	--	--	--	--	--
	Attic	--	66	140	230	696	1074	1141	848	946	1124	1069	660	527	226	13	--	--	--	--	--

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