Designation: D 6841 – 03

Standard Practice for Calculating Design Value Treatment Adjustment Factors for Fire-Retardant-Treated Lumber[1]

This standard is issued under the fixed designation D 6841; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers procedures for calculating treatment adjustment factors to be applied to design values for fire-retardant-treated lumber used at ambient temperatures [service temperatures up to 100°F (38°C)] and as framing in roof systems.

1.2 These design value treatment adjustment factors for the properties of extreme fiber in bending, tension parallel to grain, compression parallel to grain, horizontal shear and modulus of elasticity are based on the results of strength tests of matched treated and untreated small clear wood specimens after conditioning at nominal room temperatures [72°F (22°C)] and of other similar specimens after exposure at 150°F (66°C). The test data are developed in accordance with Test Method D 5664. Guidelines are provided for establishing adjustment factors for the property of compression perpendicular to grain and for connection design values.

1.3 Treatment adjustment factors for roof framing applications are based on computer generated thermal load profiles for normal wood roof construction used in a variety of climates as defined by weather tapes of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE).[2] The solar loads, moisture conditions, ventilation rates and other parameters used in the computer model were selected to represent typical sloped roof designs. The thermal loads in this practice are applicable to roof slopes of 3 in 12 or steeper, to roofs designed with vent areas and vent locations conforming to national standards of practice and to designs in which the bottom side of the roof sheathing is exposed to ventilation air. For designs that do not have one or more of these base-line features, the applicability of this practice needs to be documented by the user.

1.4 The procedures of this practice parallel those given in Practice D 6305. General references and commentary in Practice D 6305 are also applicable to this practice.

1.5 This practice is written in inch-pound units with SI units provided in parentheses for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 9 Terminology Relating to Wood[3]

D 5664 Test Method for Evaluating the Effects of Fire-Retardant Treatments and Elevated Temperatures on Strength Properties of Fire-Retardant-Treated Lumber[3]

D 6305 Practice for Calculating Bending Strength Design Adjustment Factors for Fire-Retardant-Treated Plywood Roof Sheathing[3]

3. Terminology

3.1 *Definitions*:

3.1.1 Definitions used in this practice are in accordance with Terminology D 9.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bin mean temperature*—10°F (5.5°C) temperature ranges having mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74), 175 (79) and 185°F (85°C).

3.2.2 *thermal load profile*—the cumulative time per year in each 10°F (5.5°C) temperature bin.

4. Summary of Practice

4.1 Test results developed in accordance with Test Method D 5664 are used in conjunction with computer generated thermal load profiles to calculate treatment factors that are applied to published design values for untreated lumber. These treatment adjustment factors account for the combined effect of fire-retardant-treatment and service temperatures.

5. Significance and Use

5.1 Fire-retardant-treatments are used to reduce the flame-spread characteristics of wood. Chemicals and redrying conditions employed in treatments are known to modify the strength properties of the wood product being treated. This practice

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[1] This practice is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.07 on Fire Performance of Wood.

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[2] American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329.

[3] *Annual Book of ASTM Standards*, Vol 04.10.

gives procedures for fire-retardant chemical manufacturers to use to calculate the effects of their treatment on lumber used in normal and elevated temperature service conditions.

5.2 The effect of fire-retardant treatments on the strength of lumber used in roof framing applications is time related. In this practice, the cumulative effect on strength of annual thermal loads from all temperature bins is increased 50 times to establish treatment adjustment factors for fire-retardant treated lumber roof framing.

5.3 The procedures of Test Method D 5664 employ an elevated temperature intended to produce strength losses in a short period of time. Although the exposure is much more severe than that which occurs in an actual roof system, the chemical reactions that occur in the laboratory test are considered to be the same as those occurring over long periods of time in the field.

5.4 Treatment adjustment factors developed under this practice apply to lumber installed in accordance with construction practices recommended by the fire-retardant chemical manufacturer which include avoidance of direct wetting, precipitation or frequent condensation. Application of this practice is limited to roof applications with design consistent with 1.3.

6. Test Data

6.1 Test Method D 5664 describes the procedures used to obtain the data needed to calculate the ratios of average treated and average untreated values for the strength properties.

6.1.1 Procedure 1 of Test Method D 5664 provides data for comparing the initial effects of fire-retardant treatments to untreated controls for bending, tension parallel, compression parallel, and horizontal shear properties. The procedure uses small clear specimens.

6.1.2 Procedure 2 of Test Method D 5664 provides data for assessing the differential trends between treated and untreated specimens on bending and tension parallel properties over the course of a prolonged exposure to elevated temperature. The procedure uses small clear specimens.

6.1.3 Procedure 3 of Test Method D 5664 is an optional procedure to provide additional information on size effects. The results are used to modify the test results for the small clear specimens of Procedure 1 and 2.

6.2 Specimens subjected to prolonged exposure to elevated temperature are exposed in a controlled environment of 150 ± 4°F (66 ± 2°C) and ≥ 50 % relative humidity. Durations of exposure are 36, 72, and 108 days.

7. Calculation of Strength Loss Rates

7.1 For each species and property evaluated, calculate the ratio of the average treated value to the average untreated value for the specimens conditioned at room temperature only (unexposed specimens) and for specimens exposed for the same period of time at elevated temperature.

7.1.1 The treated and untreated specimen averages used to calculate each ratio shall include the same number of specimens and each treated specimen value shall be matched to an untreated specimen value obtained from the same source piece of lumber.

NOTE 1—Test data show that the ratio of average treated and average untreated values is a more conservative measure of treatment effect than the median or the average of the individual matched specimen ratios.

7.2 The ratio of the average property value for unexposed treated specimens to the average value for unexposed untreated specimens shall be designated the initial treatment ratio, R_o.

7.3 Using the ratios of average treated to untreated specimens exposed to elevated temperature for the same period of time, R_{ti}, determine by least squares the linear regression.

$$R_{ti} = a + k_t (D) \tag{1}$$

where:

R_{ti} = ratio of average treated to untreated values,
D = number of days specimens exposed at elevated temperature,
a = intercept, and
k_t = slope, strength loss rate.

7.3.1 The ratio, R_o, for unexposed specimens (conditioned at room temperature only) shall be included in the regression analysis.

7.3.2 A property for which the strength loss rate, k_t, is not negative is assumed to be unaffected by the elevated temperature exposure.

7.3.3 The strength loss rate, k_t, shall be adjusted to a 50 percent relative humidity (RH) basis by the equation:

$$k_{50} = k_t (50/RH_i) \tag{2}$$

where:

k_{50} = strength loss rate at 50 % RH, and
RH_i = elevated temperature test RH.

7.4 Calculate strength loss per day rates for bin mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74), 175 (79), and 185°F (85°C) using the Arrhenius equation:

$$ln\,(k_{50}/k_2) = [E_a (T_1 - T_2)] / RT_1T_2 \tag{3}$$

where:

k_2 = strength loss rate at bin mean temperature,
E_a = 21 810 cal/mol, (**1**)[4,5] (91 253 J/mol),
R = 1.987 cal/mol-K (8.314 J/mol-K), gas constant,
T_1 = test temperature, K, and
T_2 = bin mean temperature, K.

7.4.1 Where the treatment effect was evaluated at more than one elevated temperature [for example 130°F (54°C) and 150°F (66°C)], the strength loss rates associated with the bin mean temperatures shall be calculated for each temperature separately and the rates averaged for determination of capacity loss values associated with thermal load profiles.

NOTE 2—This practice constructs an Arrhenius plot using classical chemical kinetics techniques, which is the simplest modeling approach. Other more sophisticated modeling techniques are available but require a different procedure for calculating strength loss rate (**2, 3**).[6]

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[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[5] Pasek and McIntyre have shown that the Arrhenius parameter, E_a, for phosphate-based retardants for wood averages 21 810 cal/mol (91 380 J/mol.).

[6] A description of other models is available in Refs (**2 , 3**).

8. Calculating Capacity Loss for Roof Framing Applications

8.1 Thermal load profiles applicable to roof framing are given in Table 1. The loads represent the cumulative days per year framing temperatures fall within 10°F (5.5°C) of the bin mean temperatures of 105 (41), 115 (46), 125 (52), 135 (57), 145 (63), 155 (68), 165 (74), 175 (79) and 185°F (85°C). Tabulated values are based on a verified attic temperature and moisture content model developed by the USDA, Forest Service Forest Products Laboratory (**4**) and reference year weather tapes. Input parameters used in the model were a 3 in 12 roof slope, south exposure, roofing absorptive factor of 0.65 and ventilation rate of 8 air changes per hour (ach).

NOTE 3—Additional information on the computer model and the input parameters used is given in Practice D 6305.

8.1.1 Two thermal load profiles are given in Table 1. This first profile shall be used with all properties except tension parallel to grain. This profile represents a weighted average of bin temperature days for the bottom of the roof sheathing and for the attic air with weights of 0.25 and 0.75 respectively. The second load profile shall be used for tension parallel to grain and is based on bin temperature days for the attic air.

NOTE 4—Field temperatures for upper and lower chords of roof rafters (truss) for two locations have been studied (**5**) (Fig. 1). This data indicates that the upper chord temperature tracks closely with the attic air temperature. The use of a weighted average of bottom sheathing and attic air temperatures for properties other than tension parallel to grain represent a conservative approach for locations where field data is not available.

NOTE 5—Thermal load profiles in Practice D 6305 represent the binning of the average of the hour by hour temperatures at the top and bottom of the roof sheathing.

NOTE 6—Thermal loads in Table 1 have been indexed to a 50 percent relative humidity basis by multiplying model generated loads by the ratio of the time weighted average attic relative humidity for all temperatures of 80°F and above and 50 percent. The adjustment is based on the use of a linear adjustment of test strength loss rates for relative humidity and the use of a linear regression model to characterize strength loss over time.

8.2 Calculate capacity loss for each property as the negative value of the rates (k_2) as determined in 7.4 for each bin temperature by the cumulative days per year for that bin for the applicable zone and property from Table 1. The summation of the capacity loss values for each temperature bin shall be designated as the total annual capacity loss (*CLT*) for that property and zone.

TABLE 1 Reference Thermal Load Profiles

Temperature, °F (°C)	Cumulative days per year					
	Bottom of roof sheathing/attic air			Attic air		
	Zone 1A[A]	Zone 1B[A]	Zone 2[A]	Zone 1A[A]	Zone 1B[A]	Zone 2[A]
105 (41)	11.194	25.584	6.233	11.613	22.720	5.236
115 (46)	9.248	9.326	2.232	9.697	5.236	0.416
125 (52)	7.846	3.097	0.766	7.782	--	--
135 (57)	2.987	0.947	0.180	1.383	--	--
145 (63)	1.526	0.024	0.009	0.020	--	--
155 (68)	0.652	--	--	--	--	--
165 (74)	0.005	--	--	--	--	--
175 (79)	0.005	--	--	--	--	--
185 (85)	0.010	--	--	--	--	--

[A] Zone definition:
Zone 1: Where minimum roof live load or maximum ground snow load ≤ 20 psf (960 Pa).
Zone 1A: Southwest Arizona, southeast Nevada (Las Vegas, Yuma, Phoenix, Tucson triangle)
Zone 1B: All other qualifying areas.
Zone 2: Where maximum ground snow load > 20 psf (960 Pa).

9. Treatment Adjustment Factors

9.1 For each property and zone, a treatment adjustment factor for design values shall be calculated as:

$$TF = [1 - IT - n(CF)(CLT)] \quad (4)$$

where:

TF = treatment adjustment factor = $(1 - IT)$,
IT = initial treatment effect = $1 - R_o$,
n = number of iterations = 50,
CF = cyclic loading factor = 0.6, and
CLT = total annual capacity loss.

9.1.1 Where a property has been evaluated at more than one elevated temperature, *IT* in Eq 4 shall be taken as the average of the R_o ratio for each temperature data set.

9.2 Where the properties of compression parallel to grain and horizontal shear have not been evaluated at elevated temperatures for a species, the *CLT* determined for bending and for tension parallel to grain, whichever is greater, shall be used in Eq 4 to determine treatment adjustment factors for these properties.

9.3 Where a property shows no strength loss when exposed at elevated temperature ($CLT = 0$), the property treatment adjustment factor, *TF*, for all thermal load zones shall be equal to $(1 - IT)$, or R_o.

9.4 A treatment adjustment factor for applications involving service temperatures up to 100°F (38°C) shall be $(1 - IT)$, or R_o, for all properties.

9.5 Compression perpendicular to the grain design values are based on a deformation limit which is related to specific gravity. Although reductions in specific gravity are generally not observed at 150°F (66°C) temperature exposure, a *TF* of 0.95 shall be used for this property for both normal temperature and roof framing applications.

9.6 Connection design values for lumber are related to both specific gravity and compression properties. The treatment adjustment factor for lumber connections shall be either the compression parallel to grain treatment factor or 0.90, whichever is lower.

NOTE 7—The 0.90 factor has been used in practice for many years as a conservative adjustment for connection design loads for fire-retardant treated lumber.

9.7 If the effect of a fire-retardant treatment on southern pine, Douglas fir and white spruce (or spruce-pine-fir from which pine species have been removed) have been evaluated at normal and elevated temperatures in accordance with Test Method D 5664, the lowest of the treatment factors calculated for the three species under this practice is applicable to other untested softwood lumber species.

NOTE 8—Use of test results for southern pine, Douglas fir and white spruce (or equivalent) to establish treatment factors for untested species is recognized in Note 1 of Test Method D 5664.

9.8 Treatment adjustment factors calculated in accordance with this practice are to be applied to design values for

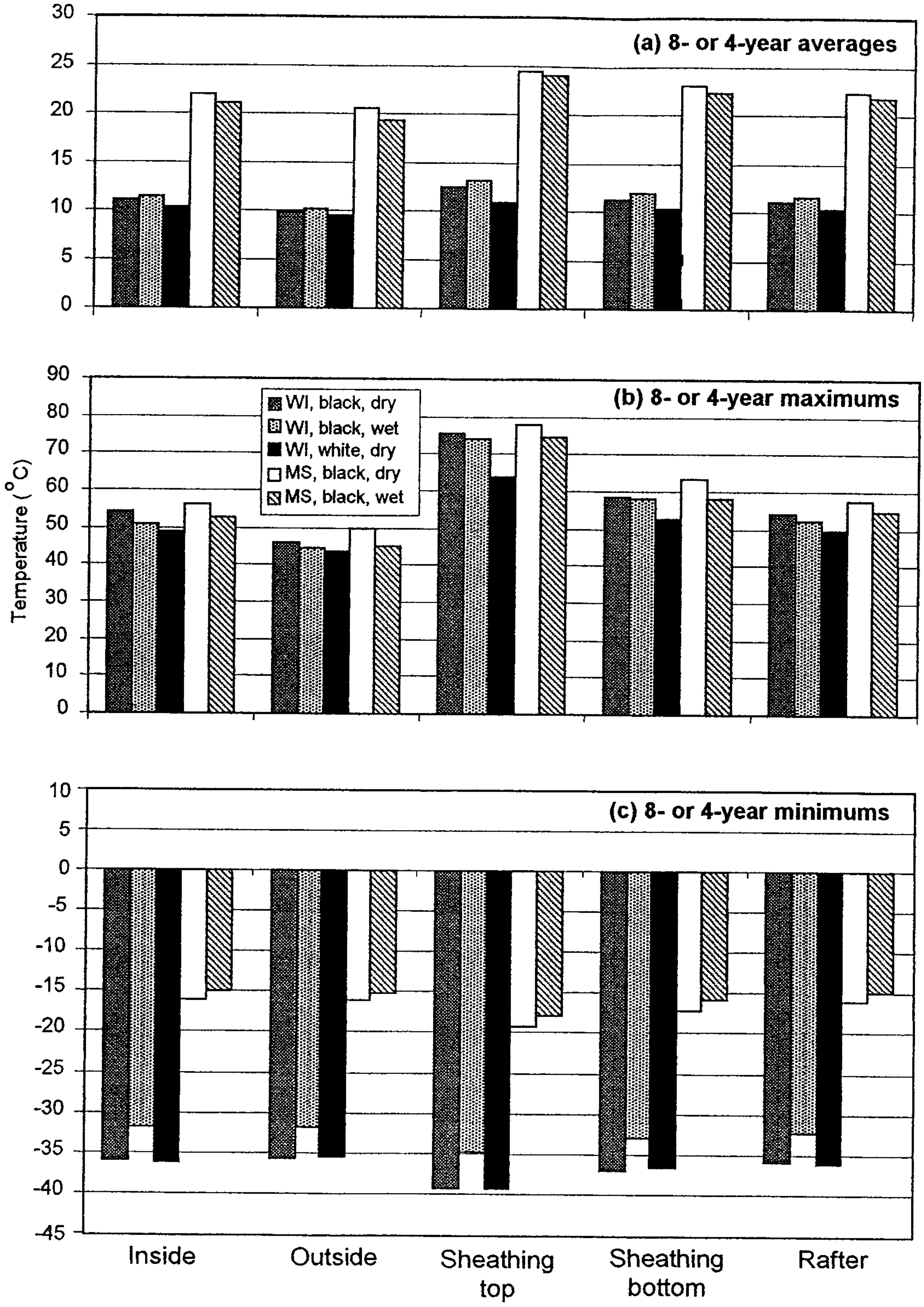

FIG. 1 Average, Maximum, and Minimum 8- or 4-Year Temperatures for Exposure Structures in Wisconsin and Missippi (Ref 5).

untreated lumber published by lumber grading agencies and in the National Design Specification for Wood Construction.

10. Keywords

10.1 design values; fire-retardant; fire-retardant treatment; lumber; mechanical properties; strength property; thermal effects

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE CALCULATIONS

X1.1 Test data and property loss rates for this example are summarized in Table X1.1. Properties of extreme fiber in bending (MOR), modulus of elastcity (MOE), tension parallel to grain (UTS), compression parallel to grain (UCS) and horizontal shear (USS) were evaluated at room temperature [75°F (24°C)] and at 150°F (66°C) for 36, 72 and 108 days.

X1.2 The relative humidity of the test exposure at 150°F (66°C) averaged 75.4 percent. Adjusted strength loss rates, k_{50}, for properties having a negative k_t in Table X1.1 are:

MOR = –0.0004733
UTS = –0.0007332
UCS = –0.0002487
USS = –0.0002100

X1.3 Strength loss rates for bin mean temperatures from Eq 3 are given in Table X1.2.

X1.4 Capacity loss per year by property for Zone 1B are given in Table X1.3. Loss values are the product of the thermal loads given in Table 1 and the rates (k_2) given in Table X1.2.

X1.5 Treatment adjustment factors for the example data are given in Table X1.4.

TABLE X1.2 Strength Loss Rates (k_2) by Property and Bin Mean Temperature

Bin Mean Temperature, °F (°C)	Strength Loss Rate (k_2) per day at 50 % RH			
	MOR	UTS	UCS	USS
105(41)	0.000036	0.000055	0.000019	0.000016
115(46)	0.000066	0.000103	0.000034	0.000029
125(52)	0.000118	0.000183	0.000062	0.000052
135(57)	0.000209	0.000323	0.000110	0.000093
145(63)	0.000362	0.000560	0.000190	0.000160
155(68)	0.000616	0.000954	0.000324	0.000273
165(74)	0.001031	0.001597	0.000542	0.000457
175(79)	0.001698	0.002630	0.000892	0.000753
185(85)	0.002752	0.004264	0.001446	0.001221

TABLE X1.1 Example Data

Property	Exposure °F (°C)-days	Average Untreated (Unt)	Average Treated (Trt)	Ratio Trt./Unt	Strength Loss Rate, k_t
MOR, psi (MPa)	75 (24)	14 647 (101)	12 640 (87)	0.863 = R_o	-0.0007138
	150(66)-36	15 772 (109)	13 240 (91)	0.839	
	150 (66)-72	14 735 (102)	11 810 (81)	0.801	
	150 (66)-108	15 394 (106)	12 155 (84)	0.790	
MOE, 1000 psi (GPa)	75 (24)	1 925 (13)	1 835 (13)	0.953 = R_o	+0.0000639
	150 (66)-36	1 981 (14)	1 880 (13)	0.949	
	150 (66)-72	1 957 (13)	1 879 (13)	0.960	
	150 (66)-108	2 003 (14)	1 917 (13)	0.957	
UTS, psi (MPa)	75 (24)	19 487 (134)	15 999 (110)	0.821 = R_o	-0.0011056
	150 (66)-36	18 941 (130)	14 566 (100)	0.769	
	150 (66)-72	19 126 (132)	14 009 (96)	0.758	
	150 (66)-108	18 368 (127)	12 766 (88)	0.692	
UCS, psi (MPa)	75 (24)	9 554 (66)	8 847 (61)	0.926 = R_o	-0.0003750
	150 (66)-36	9 678 (67)	9 010 (62)	0.931	
	150 (66)-72	9 043 (62)	8 256 (57)	0.931	
	150 (66)-108	9 309 (64)	8 257 (57)	0.887	
USS, psi (MPa)	75 (24)	1 547 (11)	1 440 (10)	0.931 = R_o	-0.0003167
	150 (66)-36	1 709 (12)	1 583 (11)	0.926	
	150 (66)-72	1 674 (12)	1 505 (10)	0.899	
	150 (66)-108	1 748 (12)	1 577 (11)	0.902	

TABLE X1.3 Capacity Loss per Year for Zone 1B

Temperature, °F (°C)	Thermal Load, days		Capacity Loss, k_2 times load[A]			
	MOR, UCS, USS	UTS	MOR	UCS	USS	UTS
105 (41)	25.584	22.720	0.000921	0.000486	0.000409	0.001250
115 (46)	9.326	5.236	0.000616	0.000317	0.000270	0.000534
125 (52)	3.097	--	0.000365	0.000192	0.000161	--
135 (57)	0.947	--	0.000198	0.000104	0.000088	--
145 (63)	0.024	--	0.000009	0.000005	0.000004	--
Capacity Loss per year, CLT			0.00209	0.001104.	0.00093	0.001784

[A] Example: MOR loss for 125 bin = 3.097 × 0.000118 = 0.000365.

TABLE X1.4 Treatment Adjustment Factors

Property	Service Temperature[A] ≤ 100°F (38 °C)	Roof Framing, Zone 1B[B]
MOR	0.86	0.80
UTS	0.82	0.77
UCS	0.93	0.89
USS	0.93	0.90
MOE[C]	0.95	0.95

[A] See 9.4.
[B] See 9.1 and Eq 4.
[C] See 9.3.

REFERENCES

(**1**) Pasek, E. A. and McIntyre, C. R., Heat Effects on Fire-Retardant Treated Wood, *J. Fire Sci.*, 8, Nov.-Dec. 1990, pp. 405-420.

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(**3**) Lebow, P. K., and Winandy, J. E., “Verification of Kinetics-Based Model for Long-Term Effects of Fire Retardants on the Bending Strength at Elevated Temperatures,” *Wood and Fiber Science*, (31)1, 1999, pp. 49–61.

(**4**) Tenwolde, A., “FPL Roof Temperature and Moisture Model: Description and Verification,” USDA Forest Service, Forest Products Laboratory, Madison, WI, FPL-RP-561, 1997.

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