EFFECT OF WATER REPELLENTS ON LONG-TERM DURABILITY OF MILLWORK TREATED WITH WATER-REPELLENT PRESERVATIVES

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ABSTRACT

This report describes the long-term effect of water repellents (WRs) on durability of painted window units that were placed outdoors near Madison, Wis., in 1956. It includes the final evaluation of the windows and an analysis of their water repellency during the first 6 years of exposure. Also, swellometer test results for the treating formulations are compared with water repellency and durability of the window units treated with those formulations. The wooden windows were originally treated with several water-repellent preservatives (WRPs) that contained different amounts of WR. Following the WRP treatment, the windows were primed, top coated, and left to weather for 28 years without maintenance. Analysis of the dimensional changes of the WR-treated windows showed that during the first 6 years of exposure, the water-repellent effectiveness (WRE) decreased with time. A least squares fit of this decrease in WRE with time had r^2 values in the range of 0.6 to 0.8 for most treatments. Extrapolation of this trend showed that the effectiveness dropped to zero at about 20 years. There was little correlation between the long-term durability of the windows and the initial swellometer values for the various treatments. There was, however, a slight correlation (r^2 = 0.64) between the original swellometer measurements and the time for the WRE to reach zero.

For more than 50 years, wooden doors and windows have been dipped in water-repellent preservative (WRP) solutions during manufacture to extend their service life (1,2,4,19). Until about 1980, these WRP formulations were composed of about 1 percent water repellent (WR) (i.e., paraffin wax), 5 percent preservative (pentachlorophenol), 10 percent sealer (linseed oil or varnish), and solvent (mineral spirits or turpentine) (6). Although pentachlorophenol was replaced by other preservatives in the early 1980s, many of the solvent-based formulations used today are similar to those developed 50 years ago. In addition to the solvent-borne formulations, waterborne formulations are now available. Solvent- and waterborne formulations continue to protect wooden doors, windows, and other millwork. Where premature decay of wooden windows and doors occurs, the cause is often insufficient treatment with a WRP (7,10,11,12). Quantifying the benefit of such treatments, particularly the effect of the WR, has been elusive because field studies require a long time and the effect of water repellency on durability is often obscured by the inclusion of preservatives in these formulations (3,13). Scheffer and Eslyn (15) evaluated the effectiveness of pentachlorophenol after 22 years with WRs included with the pentachlorophenol, but from their data, it was not possible to determine the effect of the WR without the preservative on durability. The effects of WRs were not clear in other studies of preservatives with and without WRs (17,18). Scheffer and Eslyn (16) did show that formulation of pentachlorophenol with heavy oil gave better efficacy than with light oil or mineral spirits. The heavy oil probably improved the water repellency.

It is well known that WR treatments do not last very long on lateral surfaces exposed to the weather. Voulgaridis and Banks (20) exposed WR-treated Scots pine *(Pinus sylvestris)* and European beech *(Fagus sylvatica)* outdoors for 1 year near Bangor, Wales. They used scanning electron microscopy (SEM) to evaluate the surface degradation, and they reported that the loss of surface water repellency was caused, to a large degree, by the degradation of the wood. Loss of wood from the surface essentially destroyed the structural support for the WR. The loss of water repellency matched that of wood surface degradation. They did not report an effect of the WR on the rate of weathering. Voulgaridis and Banks (2 1) also evaluated the performance of WRs using long wood specimens from Scots pine and European beech. For Scots pine, they showed that

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the water-repellant effectiveness (WRE) of two solvent-borne WRs decreased with depth from the end-grain across 6 to 7 cm. Water absorption ranged from 15 percent at 1 cm to about 55 percent at 7 cm (controls absorbed about 70%). As the specimens were weathered with a 24-hour wet-dry cycle for 40 cycles, the WRE decreased more rapidly at the surface of the end-grain than 2 to 3 cm from the end of the specimen; little change occurred 4 to 5 cm from the end. Although European beech showed quite different water absorption rates compared with Scots pine, the general trend in the change in water repellency with cyclic wetting and drying was the same as for Scots pine. Savory et al. (14) showed a decrease in water repellency during a 4-year outdoor exposure of window joinery.

This report contains the final evaluations of window sashes exposed outdoors for 28 years and compares their performance to evaluations that were conducted after 4 (8) and 20 years (5) of exposure. This study offers a unique opportunity to link initial measurements of water repellency with long-term durability. The report by Miniutti (8) contained outdoor exposure data obtained during the first 4 years. Miniutti evaluated the window units for an additional 2 years, but this information was never published. I analyzed the dimensional changes of the windows from Miniutti's original data for the first 6 years. The dimensional changes during this time were used to determine the decrease in water repellency with time. This decrease in WRE was compared with the final evaluations that were conducted after 28 years of exposure.

BACKGROUND

In 1956, Miniutti et al. (8) began a study of the effect of various solvent-borne WRP dip treatments on the water repellency and service life of window sashes. Three WRP manufacturers supplied three different WRPs each, which totaled nine industry formulations. These test solutions included: three formulations that met the industry standard of 60 percent WRE, three formulations that were above the standard, and three that were below the standard. The actual formulations of these WRPs were not disclosed. Test solutions also included a preservative (5.2% pentachlorophenol) without a WR and a WR (1.5% paraffin wax) without a preservative, totaling 11 treatments plus a control. Window sashes of ponderosa pine sapwood were dip-treated in these solutions for 3 minutes. There were five replicates for each treatment solution and five controls. The windows sashes were glazed, varnished on the interior, painted on the exterior with a primer and top coat, and placed outdoors facing south near Madison, Wis. The windows were installed in casings, typical of those found in normal construction, and had a roof cap and a plywood backing **(Fig. 1).** The casings received the same preservative, WR, or WRP treatment as the sashes, and these treatments were brush-applied before installing the sashes. The casings were primed prior to installing the sashes and top-coated following installation of the sashes. There was minimal overhang of the roof cap. Except for removal from the casings periodically to determine swelling during the first 6 years, the window units (casings and sashes) were left to weather without maintenance until 1984 (for a total of 28 years of exposure).

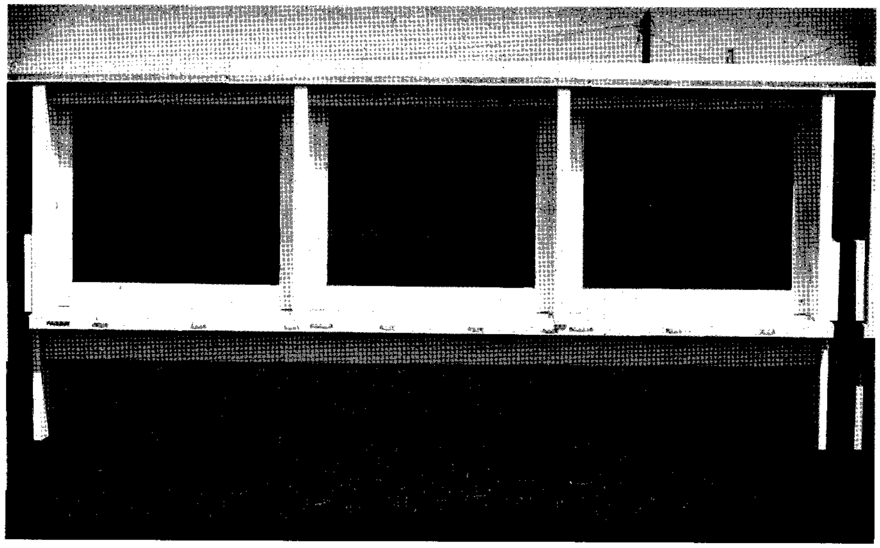

Figure 1. —Window unit on the test fence near Madison, Wis.

A 1961 interim evaluation used dimensional change of the windows as one method to determine the WRE of the solutions. The other methods used were the swellograph, the swellometer, flowing water, water spray, cupping, weight gain at 30 to 80 percent relative humidity (RH), and weight gain at 65 to 97 percent RH (8).

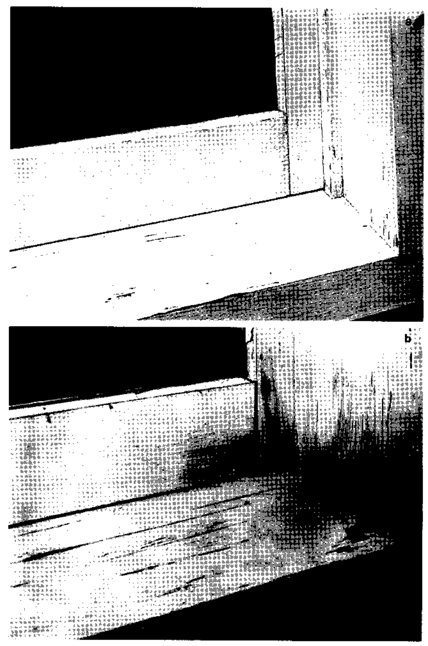

Figure 2.—Window units after 5 years of outdoor exposure; a) window sash and casing treated with a WRP before painting; and b) window sash and casing not treated before painting.

The results of this evaluation showed good correlation between the swelling of the window units and the laboratory methods. The 3-minute dip in solutions that had 60 percent or greater WRE gave good protection during the early years. Miniutti et al. (8) also showed that painted window sashes without a WR

TABLE 1.—Evaluation of windows after 28 years of outdoor exposure near Madison, Wis.

Treatment type	Treatment no.	No. of windows in each visual rating category						Average rating[a]	Standard deviation	Swellograph WRE[b]
		10	8	6	4	2	0			(%)
< 60% WRE[c]	1	1	1	1	1	1		6.0	3.2	6
	2		1	1	2	1		4.8	2.3	28
	3	1	3		1			7.6	2.2	61
HWR[d]	4	4	1					9.6	1.4	61
	5	2	3					8.8	1.1	83
	6	2	3					8.8	1.1	67
Industry standard[e]	7	1	1		2	1		5.6	3.3	77
	8	1	1	2		1		6.4	3.0	53
	9		3	2				7.2	1.1	82
Preservative only	10		1	2	2			5.6	1.7	4
Water repellent only	11				1	4		2.4	1.4	77

[a] Average rating of five window units.
[b] WRE = water-repellent effectiveness. The WRE of the industry-supplied WRP was determined using the swellograph test and reported by Miniutti et al. (8).
[c] Commercially formulated to be below the industry standard of 60 percent WRE.
[d] HWR = high water repellency, Commercially formulated to be above the industry standard of 60 percent WRE.
[e] Commercially formulated to meet the industry standard of 60 percent WRE.

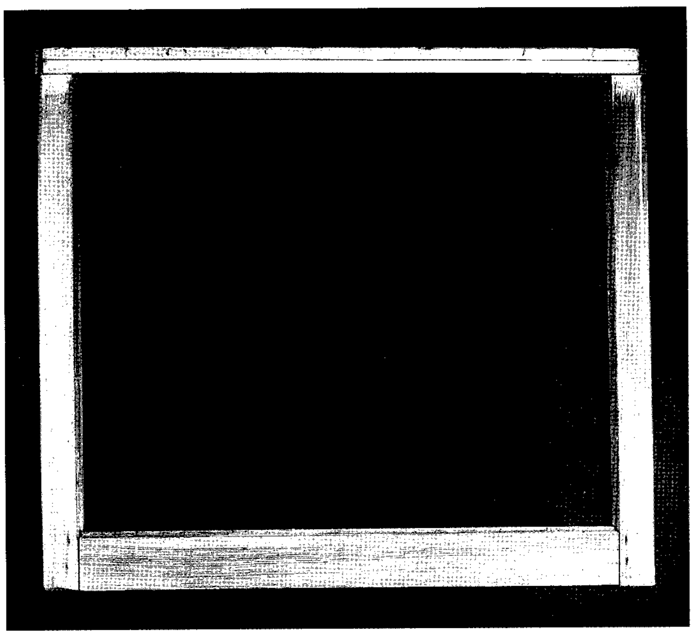

Figure 3. —Window unit after 28 years of outdoor exposure.

trapped moisture. Moisture contents above the fiber saturation point were observed at the mortise and tenon joint at the bottom of the sash **(Fig. 2).** Water could enter the end-grain of the wood through cracks in the paint and move into the interior of the wood where it was trapped by the paint. Premature paint failure was also observed in window casings that were not pretreated with a WRP.

Feist and Mraz (5) evaluated these same window units again after 20 years of exposure. They reported that the windows treated with a WR without the preservative were generally in the same condition as those treated with the WRP.

MATERIALS AND METHODS

The methods used in the original determination of water repellency, dimensional change, and WRE were reported by Miniutti et al. (8). The water repellency of the WRP and WR formulations was determined by several methods including the swellometer test. This method involved submerging treated and matched-untreated specimens in water and measuring the tangential swelling after 30 minutes. The swellograph records the swelling during the entire test (usually 30 min.). The original swelling measurements (swellograph) were done using an instrument that transferred the change in dimension of the wood during the test to a stripchart recorder to obtain a graph of this dimensional change. The swellograph was developed by A.W. Stout and A. Hermann (Western Pine Association Research Laboratory, Portland, Oreg.) and a complete description of the test was forwarded to the Forest Products Laboratory (FPL) in January 1944. This information was documented in an unpublished FPL report by L.E. Downs in 1945. The percentage WRE was calculated by subtracting the swelling of the treated specimens from the swelling of the controls divided by the swelling of the controls times 100, in accordance with the National Wood Window and Door Association swellometer test (9). The water repellency of the window sashes during the first 6 years of exposure was determined by comparing the swelling of the treated window sashes (measured at the rail, close to the mortise and tenon joint) with that of the untreated window sashes. Calculation of the WRE was done in the same way as with the swellometer test.

After 28 years, the windows were removed from the casings and rated for decay on a scale of 0, 2, 4, 6, 8, or 10 **(Table 1)** on the basis of soundness of the wood (10 being most sound). The wood pieces (rails and stiles) at the mortise and tenon joints were the most susceptible to degradation and therefore the windows were inspected most closely at that location. Inspection involved visual examination and probing with a sharp pick. Surface cracking was of secondary importance because all windows were fairly similar with regard to weathering **(Fig. 3).**

For this study, the shrinking and swelling of five replicate window units for each treatment during 6 years was evaluated. This information was obtained from Miniutti's original laboratory notebooks and was compared with rainfall data obtained from the National Weather Service (U.S. Dept. of Commerce). A least-squares fit of the maximum swelling, during periods of high rainfall during the 6 years, was used to determine the drop in WRE with time.

RESULTS AND DISCUSSION

The final evaluation of 55 window units included only the treated windows because the untreated controls had decayed and fallen off the fence 20 years prior to the 28-year evaluation **(Table 1).** The treating solutions that gave the highest average decay rating for the five replicates were those treated with WRP solutions with high water repellency (HWR), with average values of 9.6, 8.8, and 8.8, respectively. The variability in these specimens was considerably less than in most of the other treatments. Those specimens treated with only the WR had the lowest average value (2.4). Windows treated with either the industry standard or the below industry standard (60%) formulations were inconsistent with ratings that varied from a low of 4.8 to a high of 7.6.

Table 1 also lists the original swellograph test results for the solutions used to treat these windows (8). The wood from the actual windows themselves was not measured with the swellograph, but the solutions were evaluated using standard ponderosa pine cross sections in accordance with NWWDA TM-2 (9). The water repellency was reported for the swellograph, which measured tangential swelling with time like the swellometer test. The correlation between the original water repellency of the solution and the final evaluation on the basis of the average water repellency reported for each of these solutions is poor. For example, treatment 1 had a swellograph value of 6 percent, and the visual ratings were 2, 4, 6, 8, and 10 for the live replicate windows to give an "average rating" after 28 years of 6.0. Treatment 7 had a repellency of 77 percent, and its 28-year ratings were 2, 4, 4, 8, and 10 to give an average rating of 5.6. The water repellency measured for the HWR solutions ranged from 61 to 83 percent, and the average ratings after 28 years of exposure ranged from 8.8 to 9.6. The rating of treatment 5 with a water repellency of 83 percent was the same as that of treatment 6 with a water repellency of 67 percent. Treatment 3, which was formulated to be below the industry standard of 60 percent WRE, had 61 percent WRE, and window units treated with this formulation had a higher average rating than those window units treated with the industry standard (7.6 compared with 5, 6, 6, 4, and 7.2).

Comparison of the WRE of the treatment solution with window durability should be viewed in light of several factors. The original water repellency of the industry-supplied treatment formulations was not measured on the windows, but was determined from separate ponderosa pine cross sections that were treated in the same way as the windows. It was not possible to correlate the durability of a particular window with its original water repellency; water repellency was an average from a completely different set of boards. The variability

TABLE 2. — Water repellency values based on dimensions during the first 4 years of weathering of treated and painted window sashes.[a]

Treatment type	Treatment no.	Water repellency by dimension change[b] 1957	1958	1959	1960	Swellograph WRE
		(%)				
< 60% WRE[c]	1	21	37	23	28	6
	2	80	83	65	62	28
	3	78	86	70	66	61
HWR[d]	4	77	85	73	71	61
	5	82	90	78	80	83
	6	86	89	74	71	67
Industry standard[e]	7	82	88	76	77	77
	8	80	81	55	52	53
	9	82	85	72	71	82
Preservative only	10	-1	37	30	37	4
Water repellent only	11	83	90	77	76	77

[a] Reproduced from Mini&i et al. (8).
[b] Water repellency calculated from the swelling of the sash rails near the mortise and tenon joint.
[c] WRE = water-repellent effectiveness. Commercially formulated to be below the industry standard of 60 percent WRE.
[d] HWR = high water repellency. Commercially formulated to be above the industry standard.
[e] Commercially formulated to meet the industry standard of 60 percent WRE.

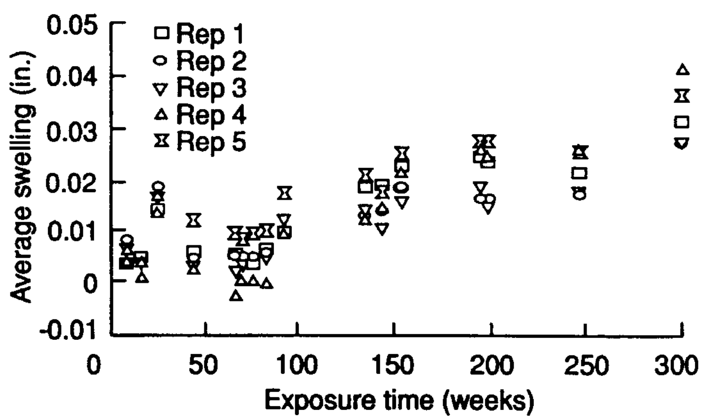

Figure 4. —Average swelling of five replicate windows treated with WRP treatment 7. Each data point is an average of two measurements. The shrinkage during dry periods is not shown (1 in. = 25.4 mm).

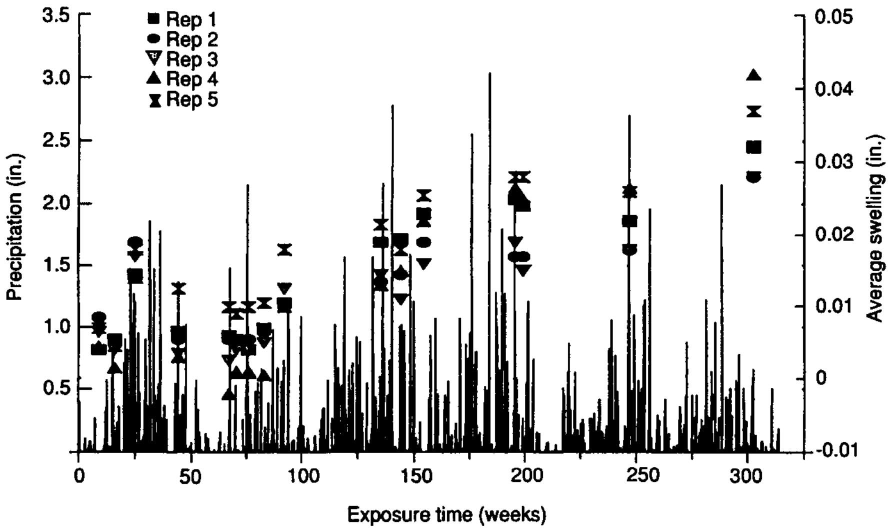

Figure 5. —Average swelling of five replicate windows treated with WRP treatment 7 superimposed on the rainfall during the first 6 years of outdoor exposure. Each data point is an average of two measurements. The swelling was determined during or shortly after periods of wet weather; shrinkage during dry periods is not shown (1 in. = 25.4 mm).

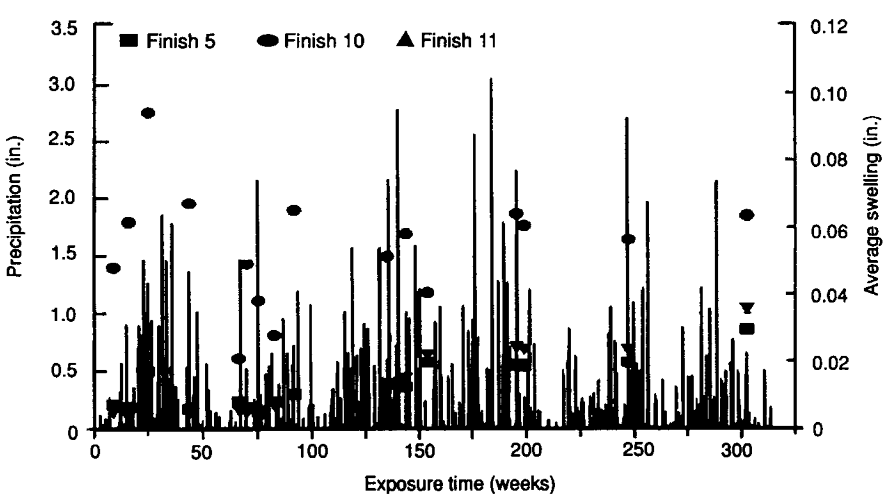

Figure 6. —Average swelling, during wet weather, for WRP treatments 5, 10, and 11 superimposed on the rainfall during the first 6 years of exposure. The swelling was determined during or shortly after periods of wet weather; shrinkage during dry periods is not shown (1 in. = 25.4 mm).

among the swellograph measurements was high even within the same types of formulations. For example, the three WRPs formulated to be less than 60 percent WRE had measured WRE values of 6, 28, and 61 percent **(Table 1).** It is unknown whether they were intentionally formulated to have such a wide range of water repellency.

Miniutti et al. (8) suggested that dimensional changes in the windows should give a realistic appraisal of the effectiveness of the WRs. To calculate water repellencies, they used the average maximum deviations from the original dimensions during the first 4 years of exposure for windows having various treatments. They noted a fairly good correlation during the early years of exposure between these values and the swellograph water repellencies **(Table 2).** A correlation coefficient of 0.922 was reported for the average maximum WRE during the fourth year of exposure and the swellograph test. But, there was little correlation between the dimensional changes reported by Miniutti after 4 years and long-term durability reported here. For example, treatment 11 showed good effectiveness in 1960 (WRE = 76%), but its long-term durability was poor. However, the interim 20-year report indicated WRs without preservatives were as effective as those with preservatives (6). Apparently, WRE was about at its limit at 20 years and substantial degradation took place following the 20-year evaluation.

Information contained in Miniutti's original laboratory notebooks showed considerable variation in shrinking and swelling during any year caused by seasonal changes in RH and differences in rainfall. However, there appeared to be a general trend of increasing swelling during wet periods with exposure time. The maximum swelling during periods of high rainfall tended to be fairly consistent among the five replicates as shown for treatment 7 **(Fig. 4).** The other WR and WRP treatments responded in a similar manner to treatment 7. Swelling coincided with the periods of high rainfall **(Fig. 5),** although there was undoubtedly some minor effect of RH. Average shrinking and swelling values for the various treatments were similar with one exception: the swelling for treatment 10 (preservative only), during wet periods, varied considerably and was greater than that for the WR-treated specimens **(Fig. 6).** The swelling for treatment 11 (WR only) was similar to that of the HWR treatment 5. The trends shown for the two formulations that contain a WR in **Figure 6** (treatments 5 and 11) were representative of the trends for the other formulations that contained a WR.

The least-squares fit of the data for treatment 7 showed a linear decrease in WRE with time, and the fit was extrapolated to zero WRE **(Fig. 7).** Analyses for the other WRP treatments showed similar trends. The least-squares fit gave a calculated WRE (*y* intercept), slope, and years to zero WRE (*x* intercept) **(Table 3).** Although there was some variability in the years to zero WRE for the three types of WRP (i.e., less than 60% WRE, the industry standard of 60% WRE, and greater than 60% WRE), the average years to zero for the three groups was 12, 15, and 18 years, respectively. The years to zero WRE for treatment 11 (the WR only) was 17 years. Although the slope

TABLE 3. —*Least squares fit of the decrease in water-repellent effectiveness (WRE) with time.*[a]

Treatment type	Treatment no.	Calculated WRE[b]	Slope	Years to zero WRE[c]	r^2	Swellograph WRE[d]	28-year rating
		(%)			- - - - - - - - (%)	- - - - - - - -	
< 60% WRE	1	43	-4.8	8	28	6	6.0
	2	94	-8.0	12	80	28	4.8
	3	95	-7.1	16	76	61	7.6
HWR[e]	4	93	-5.8	16	71	61	9.6
	5	94	-4.0	23	60	83	8.8
	6	99	-7.1	14	83	67	8.8
Industry standard[f]	7	95	-4.9	19	70	77	5.6
	8	93	-11.0	8	85	53	6.4
	9	94	-5.6	17	79	82	7.2
Preservative only	10	47	-3.1	15	19	4	5.6
Water repellent only	11	97	-5.7	17	74	77	2.4

[a] The ratings for each individual replicate are shown for each treatment,
[b] Calculated WRE from they intercept of least-squares fit of the 6-year data.
[c] Years to zero WRE values were obtained by extrapolating the linear tit of the WRE of the data for the first 6 years.
[d] Initial WRE obtained from swellograph measurement of the industry-supplied WRPs, preservative only, and the WR only from Miniutti et al. (8).
[e] HWR = high water repellency. Formulated to be above the industry standard.
[f] Commercially formulated to meet the 60 percent WRE.

could be calculated from the data to give 1.5 years to zero WRE for the preservative without a WR (treatment IO), it is probably not valid. A plot of the data showed no trend throughout the exposure period **(Fig. 6).** The r^2 = 0.19 seems to confirm this; there is little dependence of WRE on the time of exposure.

The extrapolation of the WRE data seems to explain the inconsistency between the durability of windows treated with WR without preservatives after 20 years of exposure, as reported by Feist and Mraz (6), and the durability of the windows after 28 years. The data clearly show a decrease of WRE with time. The linear fit of these data seems to be a reasonable approximation considering the actual performance of these window units. The fit predicts complete loss of water repellency at about 20 years, and the degradation of the windows not treated with a preservative increased drastically after 20 years.

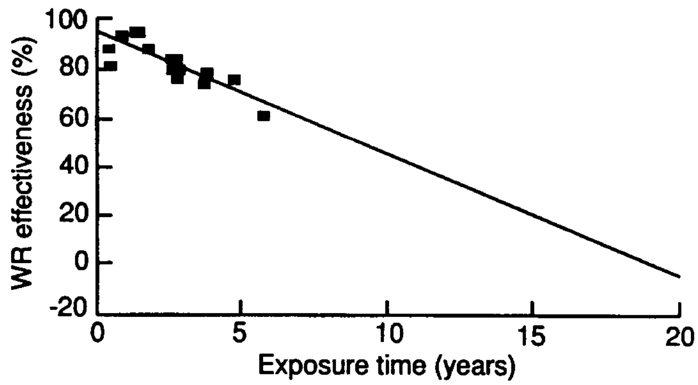

Figure 7. — Average WR effectiveness obtained from swelling of window sashes during wet weather for WRP treatment 7 with the best linear fit superimposed on the data. Each point is an average of 10 observations.

Correlation coefficients were calculated for the parameters listed in **Table 3.** The swellograph-determined WRE from Miniutti et al. (8) (swellograph WRE) was compared with the years to zero WRE. (The years to zero WRE was determined from the least squares fit of the swelling data from the window sashes.) The correlation coefficient obtained from this comparison was 0.64. The other values listed in **Table 3** were also compared; the measured WRE of the solutions (swellograph WRE) was poorly correlated with the 28-year ratings (0.03) and the slope of decreased WRE with time (slope) (0.05). Although there seems to be some correlation between the WRE determined from the swelling of the window sashes (calculated WRE) and the swellograph-determined WRE (swellograph WRE) (0.58), the data for treatment 1 drastically affected the plot. The correlation without this formulation drops to 0.06. The preservative-only formulation was not included in these comparisons. The best correlation with the swellograph WRE seemed to be with the years to zero WRE (0.64). Miniutti et al. (8) reported a much stronger correlation between swellometer values and the maximum swelling during the 4th year of exposure. The correlation coefficient of 0.64 may better approximate the value of the test because it was calculated from a number of WRE observations during 6 years.

CONCLUSIONS

The swellometer test as done according to the standard in 1956 does not appear to be correlated with long-term water repellency. The initial swellometer measurements of the three different treatment groups did not reflect the differences in the formulations. Although the difference in formulation of these WRPs was not disclosed, the long-term performance of the HWR was better than that for the other formulations. The limit to the WRE is about 20 years. After 20 years of exposure, windows treated with both WR and preservative were in better condition because of the preservative.

Swellometer measurements provide a rough idea of the water repellency of formulations, but the test is not sensitive enough, in the present standard, to distinguish between good WRs or to predict long-term performance of formulations that have a preservative. In the absence of a preservative, WRs can improve the durability of wood in aboveground applications and, used with a preservative, they greatly improve preservative efficacy. Predicting durability of WRPs by measuring water repellency, however, may not be appropriate. Water repellency is a parameter that affects, but does not control, the durability of preservative-treated wood.

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