Estimating the Fuel Moisture Content of Indicator Sticks from Selected Weather Variables

Theodore G. Storey

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Contents

THE AUTHOR

THEODORE G. STOREY has specialized in forest fire research since shortly after joining the Forest Service at Berkeley, Calif., in 1949. In 1955 he transferred to the Southeastern Station, Asheville, N.C. He worked at the Forest Fire Laboratory in Macon, Ga., for 3 years before returning to the Pacific Southwest Station in 1962. The field work for the study reported in this paper was done while he was at the Macon laboratory. Storey is a forestry graduate of the University of California (1948). Since 1963 he has been assigned to the Pacific Southwest Station's Forest Fire Laboratory at Riverside, Calif.

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Every day during the fire season some 2,250 trained observers take certain measurements of the existing fire danger at selected points in forested areas throughout the United States. More than 2,000 of these observers carefully weigh specially prepared fuel moisture indicator sticks and record their moisture content. These measurements are important in assessing fire danger because they represent the relative dryness of fire-carrying fuels in the forest area—a factor that is directly related to the ignition and spread of fire.

When exposed under actual or simulated typical forest conditions, the sticks reveal the effects in one simple measurement of all weather variables affecting moisture content, such as precipitation, humidity, temperature, evaporation, solar radiation, and wind. Basswood slats $^1/_8$ by 2 $^3/_8$ by 18 inches are used at fire danger stations in the East and South, where fine fuels predominate (Nelson 1955b). In the West and Northwest, where fuels are of larger diameter, ½- by 19-inch ponderosa pine dowels are used (Hardy, *et al.* 1955).

Although sticks are satisfactory, there are problems associated with their use. They require lengthy processing, including, for slats, preweathering and calibration (Hardy 1953; Nelson 1955); they must be replaced twice a year, and they must be exposed on a special support. Screen shading, used to simulate natural shading, must be changed in spring and in fall. A special scale and shelter for weighing the sticks must be provided.

In the South the requirement for changing from six-screen shading over the slats in the summer to one-screen in the winter is questionable. Pine trees lose very few needles in winter, and the shade they cast changes very little throughout the year. Also, the change from one screen to six screens in spring may be too abrupt, resulting in too sudden an apparent increase in fine fuel moisture content and decrease in fire danger. In fall, the reverse sometimes happens. One amount of screen shading yearlong seems more reasonable.

If the moisture content of the sticks could be estimated accurately from the weather variables controlling their moisture content, weather instruments could be substituted for sticks at fire-danger stations. Stick moisture content under one or more amounts of shading could be determined from suitable graphs or tables. Meteorologists could predict the pertinent weather variables as well as stick moisture. Furthermore, fire danger ratings could be computed currently or for historical periods in areas where weather records are available but where no fire danger stations exist.

Information on shading and radiation effects on stick moisture content should be particularly pertinent to the national fire danger study (Keetch 1959). The estimating equations for slat moisture content described in this paper are the basis for the fine-fuel moisture tables in the national fire danger rating system, developed by the U.S. Forest Service for Service-wide use.

For several years fire weather forecasters in the East have used various tables to estimate the moisture content of basswood slats from psychrometric variables (Hood).[1] These estimates are used for short-term forecasts. None of these tables has proved completely satisfactory, probably because each was based on uncontrolled data. And no indication of statistical accuracy is given.

The present study was planned to (a) develop a more accurate system for estimating slat moisture content, (b) to devise a system for estimating dowel moisture content, and (c) determine whether one amount of screen shading for slats could be used yearlong in the South. This paper reports the results of work on the first two goals. Work on the third objective was not completed because the development of a national fire danger rating system appeared imminent (Keetch 1959).

[1] Hood, F. C. *Indicated average moisture content of thin basswood slats in relation to temperature on sticks and dewpoint temperature.* 1954. (Unpublished report on file at U.S. Weather Bureau, Asheville, N.C.)

Study Procedure

Sticks were exposed unshaded and under artificial shade in the form of one, three, four, and six layers of 14-by 18-mesh aluminum wire window screen. Each amount of shading was replicated three times. The 15 frames were spaced 5 feet apart, forming a rectangular block with the number of screens randomized within the block (fig. 1).

Each frame included a set of three slats, a set of four dowels, a single slat, and a single dowel exposed side-by-side on a standard fuel moisture slat support (fig. 2). A weathering study was conducted concurrently with the main study to determine weathering correction factors to apply to sticks.

Surface temperature of the single sticks was measured by a mercury-in-glass thermometer attached to the stick and by a thermocouple imbedded within the stick. The thermometers were read directly, and the thermocouples remotely with a potentiometer. Other weather variables measured included dry bulb (air) temperature, wet bulb temperature, relative humidity, and maximum and minimum temperatures (at 4 ½ feet above the ground in a thermoscreen), wind speed and direction (at 15 feet above ground), precipitation, solar radiation, and current weather. Temperature, humidity, solar radiation, and precipitation were recorded automatically on strip charts.

The sticks were weighed and weather readings were taken at 2 p.m. daily from May 1959 through April 1960. One day a week readings were taken at 8 a.m., 10 a.m., 12 noon, 2 p.m., and 4 p.m. No readings were taken while rain was falling or when the moisture content of the basswood slats exceeded 50 percent. Sticks in the study were changed after six months' exposure to conform to standard practice at fire danger stations (Nelson 1955). The old sticks were oven-dried and weighed to determine their weight loss.

Sticks in the weathering study were dried and weighed every 2 weeks to determine their weight loss and to obtain corrections for application to test sticks. A daily average correction was computed and applied to the weight of the test sticks for each day in the 2-week period.

Moisture Relations in Wood

The sorption curve of moisture content over relative humidity for wood is characteristically S-shaped (Stamm 1952). For a given relative humidity, the equilibrium moisture content is higher when equilibrium is approached by desorption than when it is approached by adsorption (Masson and Richards 1906). This phenomenon is known as sorption hysteresis.

Seborg (1937) showed that the hysteresis ratio obtained by dividing the adsorption by the desorption moisture content is almost constant over most of the range of relative humidities. At 0- and 100-percent humidities, the hysteresis ratio is near unity.

The area bounded by the hysteresis loop represents an area of equilibrium (Urquhart and Eckersall 1930). At any point in this area, equilibrium moisture content may occur depending on preliminary and conditioning treatments of the material. The maximum hysteresis effect is only obtained when working under very carefully controlled conditions.

Investigators, each working under controlled laboratory conditions, differ as to the effect of specimen size on hysteresis. Stamm and Loughborough (1935) found that hysteresis was essentially eliminated when working with large specimens. On the other hand, Sergovskii (1951), found that hysteresis increased as specimen size increased, up to pieces 0.31 inches thick, after which it remained fairly constant. Schniewind (1956) concluded that whatever influence thickness may have, it was very slight.

Drying Rate and Timelag

Time is required for wood to come to equilibrium within a given set of conditions. When drying, a sample of wood will approach equilibrium moisture content at a rate that decreases exponentially with time. Byram [2] called this rate a timelag. It is the time required for a wood sample in an atmosphere of constant temperature and humidity to lose about 63 percent of the moisture it would lose if left there for an infinite time (until it reached equilibrium). For any given material, timelag interval depends only on the size and temperature of the specimen.

[2] Byram. G. M. *An analysis of the drying process in forest fuel material.* 1963. (Unpublished manuscript on file at Southeastern Forest Expt. Sta.. Forest Fire Lab., U.S. Forest Serv., Macon. Ga.)

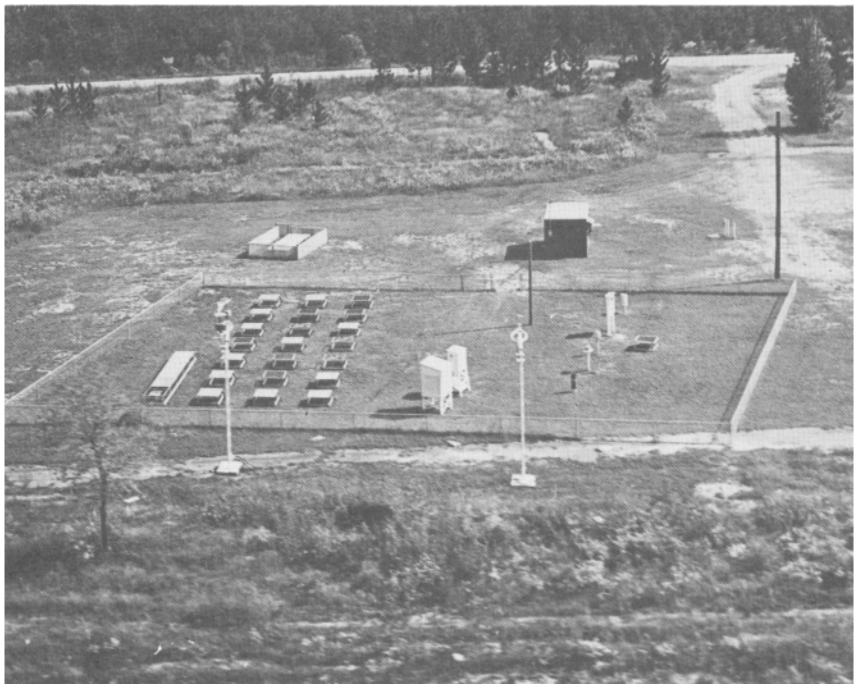

Figure 1. — *Replicated stick exposures are shown at left inside the enclosure. The long frame at the extreme left held the weathering study sticks and screens. Instruments for recording the weather variables occupied the rest of the enclosure. The stick weighing shelter is shown at top right.*

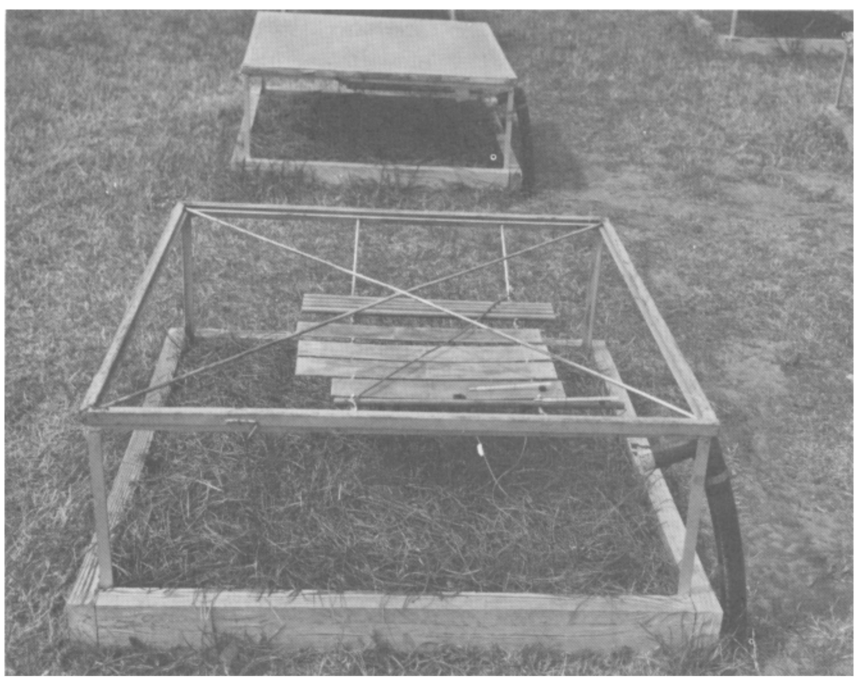

Figure 2. — *Sticks exposed under no screens were placed on supports. The tube leading into the ground carried the thermocouple lead-in wires to the potentiometer in the weighing shelter. Sticks were also exposed under one, three, four, and six layers of screen.*

At an air temperature of 80° F. under full shade the timelag interval is about 1.4 hours for basswood slats and about 5 hours for ½ -inch pine dowels. Under the shading of one layer of screen these intervals drop to about 1 hour and 3 hours, respectively.

Moisture Content of Wood in Service

Wood in service, such as fuel moisture sticks exposed outdoors, is seldom at exact equilibrium because neither the humidity nor temperature of the air remain constant for long. Direct or reflected solar radiation may raise the surface temperature of the sticks above the temperature of the surrounding air, reducing the stick moisture content below what would be indicated based on air temperature and relative humidity (Byram and Jemison 1943; Jemison 1935). Wind, if present, may cool the sticks (Byram 1940). Rain falling directly on the sticks may increase their moisture content greatly. However, because the timelag interval of slats is short, their moisture content probably is very nearly in balance with the surrounding weather conditions most of the time on drying days, particularly at the customary 2 p.m. reading time at fire danger stations. Air temperature usually is near the daily maximum and relative humidity near the daily minimum about then. Although dowels have a longer timelag than slats do, there would appear to be enough daylight hours before 2 p.m. on most rainless days for dowels to come to some degree of balance with the surrounding weather conditions.

Analysis and Results

There were 208 days with usable data covering a wide range of stick moisture content and weather conditions (tables 1 and 2). Of the 24 weather variables determined from the weather factors measured, 17 were functions of weather factors observed during preceding time intervals of various lengths; these variables were intended to reflect the cumulative effect of the antecedent weather on stick moisture.

Slats

Sorting Out the Variables

In a preliminary analysis, we studied 10 weather variables: ST, DBT, DPT, WBD, $(DPD)^2$, RH, $T_x–T_m$ W, AR_2, and AH_8.

Coefficients of determination for 2 p.m. slat moisture content under one-screen and six-screen shading were computed for all possible combinations of the 10 independent variables. Data for the period May to September were used. The strongest single variables and strongest two-, three-, four-, and five-variable combinations were determined by inspection (table 3). As a result, the weather variables $T_x–T_m$ W, AR_2, and AH_8 were eliminated. $(DPD)^2$ was correlated with AR_2, the solar radiation variable. The two variables were equally usable in the analysis, but $(DPD)^2$ proved easier to determine in practice.

Coefficients of determination were also calculated for slat moisture content under zero, three, and four screens using all possible combinations of the six independent variables selected above. The strongest single variables and combinations of variables up to three were determined by inspection (table 3). Many combinations were of limited value for prediction because certain variables were alternate expressions of the same factor; for example, DPT, RH, and WBD all reflected humidity.

One of the three best three-variable combinations was DBT, DPT, and $(DPD)^2$. This combination can be put into the form of a two-way table for ease of use because the third variable is the square of the difference of the first and second variables. A statistical analysis showed that there was a significant gain in information by adding successively DPT and $(DPD)^2$ to DBT. Adding successively a fourth and a fifth variable increased R^2 by slight but significant amounts. However, four- and five-variable equations are cumbersome to use. A three-variable equation is about the practical limit.

Regression equations containing the three strongest independent variables were computed from the 91 data using the model:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3$$

Table 1.--*Range in moisture content and surface temperature of fuel moisture indicator sticks (Basis: 208 data of readings at 2 p.m.)*

MOISTURE CONTENT

Screens (number)	Slats			Dowels		
	Symbol	Range	Average	Symbol	Range	Average
		- - - - *Percent* - - - - -			- - - - *Percent* - - - -	
0	SM_0	2.4 to 20.3	6.0	DM_0	6.6 to 31.5	12.1
1	SM_1	3.1 to 20.6	6.8	DM_1	7.0 to 34.6	12.4
3	SM_3	3.8 to 20.8	8.0	DM_3	7.2 to 45.0	13.0
4	SM_4	3.9 to 27.0	8.5	DM_4	6.9 to 41.1	13.1
6	SM_6	4.4 to 22.8	8.7	DM_6	7.4 to 29.0	12.6

SURFACE TEMPERATURE (BY THERMOCOUPLE)

Screens (number)	Symbol	Range	Average	Symbol	Range	Average
		- - - - *Degree F.* - - - -			- - - - *Degree F.* - - - -	
0	ST_0	51 to 126	89.2	DT_0	44 to 116	85.7
1	ST_1	44 to 120	85.4	DT_1	44 to 115	82.2
3	ST_3	42 to 116	81.1	DT_3	41 to 112	79.4
4	ST_4	40 to 112	79.7	DT_4	40 to 109	78.7
6	ST_6	41 to 110	79.5	DT_6	41 to 109	78.2

in which, Y is SM_0, SM_1, SM_3, SM_4, or SM_6; a, b_1, b_2, and b_3 are regression coefficients; x_1 is DBT, x_2 is DPT, and x_3 is $(DPD)^2$.

Similar equations were computed from the 117 data for the period October 1959 to May 1960. This is the normal one-screen season at 8-Type fire danger stations during which hardwood trees are without leaves.

Two Seasons' Data Combined

An analysis of variance test applied to the two seasons' data showed that the seasons did not differ significantly. The two sets of data were combined and a new set of equations of the same curve form based on 208 data were computed.

Selecting the Proper Curve Form

An improved curve form for the basic three-variable equation was determined by a series of statistical tests and graphic comparisons. Plotting residuals from the computed equations showed that SM, the dependent variables, should be in the log form ($\log_e SM$).

The third independent variable $(DPD)^2$ also was transformed to the log form ($\log_e DPD$). Curves computed from equations containing the transformed variables better fitted published equilibrium curves for wood (Forest Prods. Lab. 1955; Schniewind 1956) (fig. 3). Because their timelag interval is short [3] slats will reach equilibrium moisture content rather rapidly. It might be expected, therefore, that the computed prediction curves and equilibrium curves would be similar.

Use of the transformed variables resulted in the following regression model:

$$\log_e Y = a + b_1(X1) + b_2(X_2) + b_3 \log_e(X3)$$

in which Y is SM_0, SM_1, SM_3, SM_4, or SM_6; a, b_1, b_2, and b_3 are regression coefficients; X_1 is DBT, X_2 is DPT, and X_3 is DPD.

Values for the regression coefficients, coefficients of determination, and confidence limits calculated using this model were computed (table 4), and selected solutions of the equations were plotted (figs. 4, 5).

A similar analysis of 127 data from a well-run fire danger station in Connecticut afforded an independent check of the estimating equation for slat moisture content under one screen. The two equations were nearly identical. The coefficient of determination was slightly smaller, and the standard error of estimate slightly larger for the check equation — probably because the slats were not as carefully selected and precisely weighed as in the present study.

[3] See footnote 2.

Table 2.--*Ranges in values of weather factors (Basis: 208 data of readings at 2 p.m.)*

Weather factors	Symbol [1]	Units	Range	Average
Dry bulb (air) temp.	D.B.T.	°F.	38 to 101	74.5
Dew point temp.	D.P.T.	°F.	11 to 76	51.8
Wet bulb depression	W.B.D.	°F.	1 to 63	13.8
Dew point depression	D.P.D.	°F.	4 to 47	23.4
Relative humidity	R.H.	Pct.	16 to 87	44.8
Maximum temp.-minimum temp.	T_x-T_m	°F.	10 to 45	27.2
Wind speed (15 ft.)	W	m.p.h.	1.0 to 15.0	6.5
Antecedent solar radiation	AR_1	gm.cal./cm.^{2}	12 to 78	50.4
Antecedent solar radiation	AR_2	gm.cal./cm.^{2}	24 to 188	104.0
Antecedent solar radiation	AR_8	gm.cal./cm.^{2}	--	--
Antecedent relative humidity	AH_4	Pct.-hrs./20	2 to 15	9.5
Antecedent relative humidity	AH_8	Pct.-hrs./20	2 to 26	12.1
Antecedent relative humidity	AH_{24}	Pct.-hrs./20	--	--
Antecedent relative humidity	AH_{48}	Pct.-hrs./20	--	--
Antecedent relative humidity	AH_{72}	Pct.-hrs./20	--	--
Antecedent time at saturation	AS_8	hours	0 to 6	1.6
Antecedent time at saturation	AS_{24}	hours	0 to 20	7.7
Antecedent time at saturation	AS_{48}	hours	--	--
Antecedent time at saturation	AS_{72}	hours	--	--
Antecedent precipitation	AP_4	inches	0 to 0.20	0.001
Antecedent precipitation	AP_8	inches	0 to 1.05	0.007
Antecedent precipitation	AP_{16}	inches	--	--
Antecedent precipitation	AP_{24}	inches	--	--
Antecedent precipitation	AP_{48}	inches	--	--

[1] Numbers in subscript are the number of hours the variable was accumulated.

Dowels

A somewhat similar analysis was made of the 208 dowel data with the two seasons combined. We examined 10 weather variables: DT, DBT, DPT, RH, W, AR_2, AR_3, AH_8, AH_{24}, and AS_{24} (table 1) . More antecedent weather variables were included than in the slat analysis because the time-lag interval is longer for dowels. [4] Weather conditions the preceding night or preceding night and day would be expected to influence dowel moisture content the following day.

Coefficients of determination for $\log_e$ (dowel moisture content) under zero-, one-, three-, four-, and six-screen shading were computed for all possible combinations of the 10 independent variables. The strongest single variables and the strongest two-, three-, four-, and five-variable combinations were determined by inspection (table 5).

[4] See footnote 2.

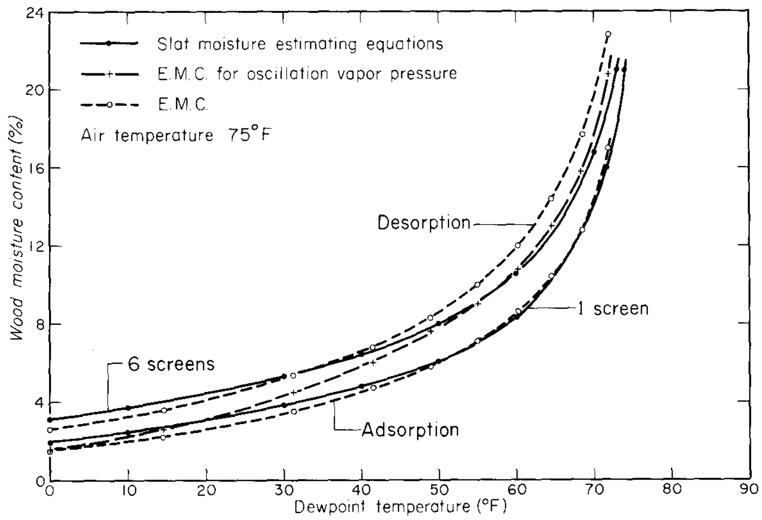

Figure 3. — *Computed estimating curves for slat moisture content plotted on curves of equilibrium moisture content (E.M.C.) for wood (Schniewind 1956) and for oscillation vapor pressure (Forest Products Lab. 1955). The six-screen shading was most similar to shading indoors where the E.M.C. studies were conducted.*

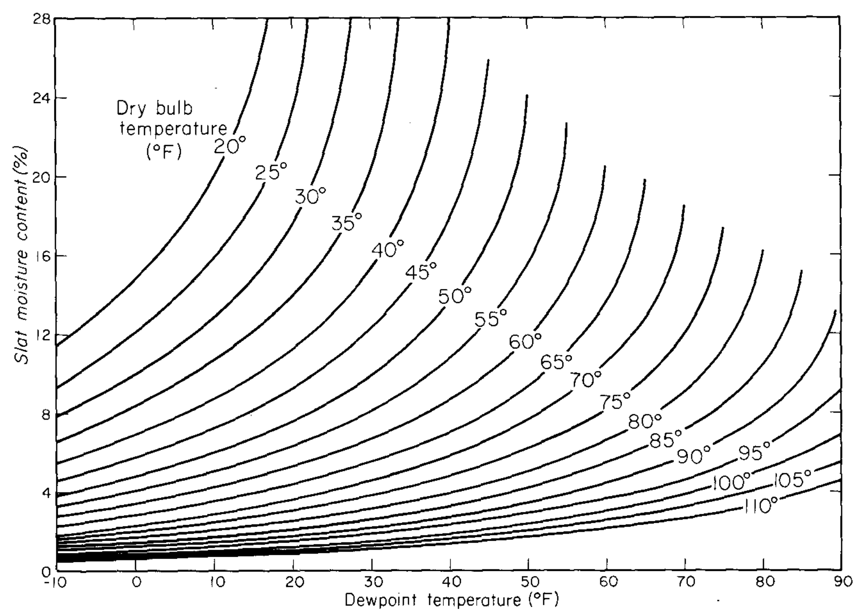

Figure 4. — *Computed curves for estimating slat moisture content under one-screen shading from psychrometric variables.*

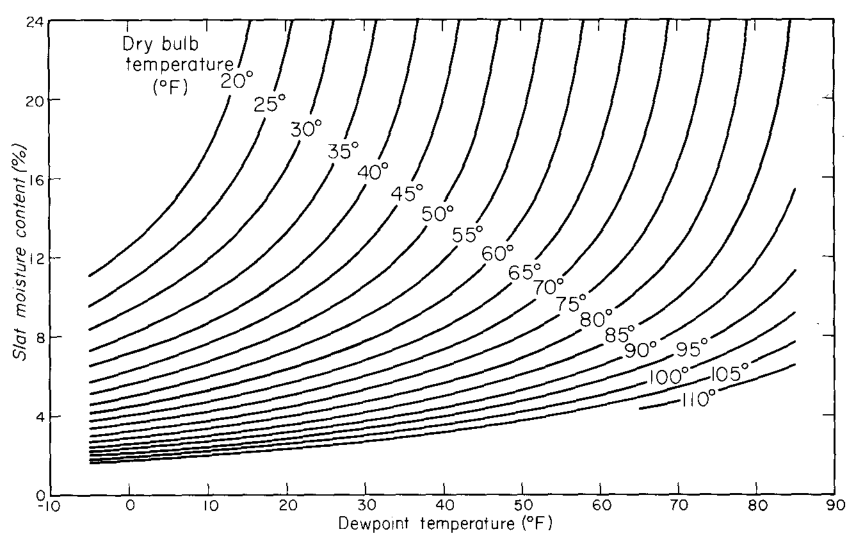

Figure 5. — *Computed curves for estimating slat moisture content under six-screen shading from psychrometric variables.*

Table 3.--*Best single variables and combinations of variables for predicting slat moisture content (Basis: 91 data, May to September 1959)*

Variables in combination	Coefficients of determination (R^2)				
	0-screen	1-screen	3-screen	4-screen	6-screen
1:					
RH	0.677	0.796	0.729	0.647	0.711
WBD	.658	.752	.659	.576	.648
$(DPD)^2$	.517	.595	.518	.453	.536
2:					
ST, RH	.717	.852	.749	.659	.734
DBT, RH	.727	.821	.731	.647	.711
DBT, DPT	.691	.769	.665	.581	.659
3					
ST, RH, $(DPD)^2$	.728	.871	.790	.701	.754
DBT, RH, $(DPD)^2$	.745	.848	.771	.687	.730
DBT, DPT, $(DPD)^2$	.740	.846	.774	.687	.734
4:					
ST, RH, $(DPD)^2$, AH_8	--	.877	--	--	.760
ST, RH, $(DPD)^2$, W	--	.874	--	--	.761
DBT, DPT, $(DPD)^2$, AH_8	--	.855	--	--	.743
5:	--	.877	--	--	.766
ST, RH, $(DPD)^2$, AH_8, W					
DBT, RH, $(DPD)^2$, AH_8, W	--	.853	--	--	.740
DBT, DPT, $(DPD)^2$, AH_8, W	--	.855	--	--	.745

Table 4.--*Regression equation constants, coefficients of determination (R^2), and confidence limits for estimating slat moisture content (SM) (Basis: 208 data for the period May 1959 through April 1960)*

Screens (number)	Regression coefficients					Confidence limits at 95 percent level [1]
	a	b_1	b_2	b_3	R^2	
						Percent [2]
0	4.41028	-0.020188	0.005152	-0.45707	0.816	- 73.9 +135.2
1	3.84924	- .032019	.018703	- .17361	.830	- 76.7 +130.4
3	4.14172	- .016778	.008291	- .40801	.810	- 77.9 +128.4
4	4.05962	- .017926	.010626	- .37790	.777	- 76.1 +131.3
6	3.81922	- .017253	.011504	- .31695	.792	- 79.1 +126.5

[1] For individual (single)estimates of slat moisture content at the mean value of the independent variable (tables 1 and 2).

[2] Of predicted slat moisture.

Table 5.--*Best single variables and combinations of variables for predicting dowel moisture content (DM) (Basis: 208 data)*

Variables in combination	Coefficients of determination (R^2) 0-screen	1-screen	3-screen	4-screen	6-screen
1:					
AR_2	0.311	0.309	0.287	0.280	0.319
AS_{24}	.344	.301	.211	.190	.212
DBT	.289	.255	.181	.158	.178
2:					
DT, AS_{24}	.569	.576	.528	.550	.637
DBT, AH_8	.617	.601	.561	.575	.630
DBT, DPT	.556	.548	.498	.522	.604
3:					
DT, AH_{24}, AS_{24}	.678	.685	.655	.676	.754
DBT, DPT, AH_{24}	.673	.672	.641	.665	.737
DT, DPT, AH_{24}	.672	.671	.638	.654	.642
4:					
DT, AR_8, AH_{24}, AS_{24}	.685	.695	.665	.687	.770
DBT, DPT, AH_{24}, AR_8	.684	.685	.655	.679	.755
DBT, DPT, AH_{24}, AS_{24}	.681	.682	.649	.674	.757
5:					
DT, RH, AR_8, AH_{24}, AS_{24}	.693	.703	.673	.696	.774
DT, W, AR_8, AH_{24}, AS_{24}	.691	.703	.660	.685	.773
DBT, DPT, AH_{24}, AS_{24}, AR_8	.690	.694	.669	.692	.770
All	.722	.724	.691	.710	.786

Table 6.--*Test of gain in precision of estimating dowel moisture content (DM) by adding variables to the estimating equation, 1-screen and 6-screen shading (Basis: 208 data)*

Variables	One-screen F [1]	R^2	Confidence limits (95 percent level [2]	Six-screen F [1]	R^2	Confidence limits (95 percent) level [2]
			Percent [3]			*Percent* [3]
$\log_e DM = f(DBT)$	--	0.255	--	--	0.178	--
$\log_e DM = f(DBT, DPT)$	133**	.548	- 68.9 +145.3	220**	.604	- 77.8 +128.6
$\log_e DM = f(DBT, DPT, AH_{24})$	78**	.672	- 73.2 +136.4	103**	.737	- 81.4 +122.9
$\log_e DM = f(DBT, DPT, AH_{24}, AS_{24})$	6*	.680	- 73.1 +137.0	17**	.757	- 82.1 +121.9
$\log_e DM = f(DBT, DPT, AH_{24}, AS_{24}, AR_8)$	8**	.694	- 73.4 +136.2	11**	.770	- 82.4 +121.4
$\log_e DM = f(\text{all } 10)$	--	.724	--	--	.786	--

[1] F = test for significant gain in information due to adding variables; ** highly significant; * significant.
[2] For individual (single) estimates of dowel moisture content at the mean value of the independent variable (tables 1 and 2).
[3] Of predicted dowel moisture.

Table 7. -- *Regression equation constants, coefficients of determination (R^2) and confidence limits for estimating dowel moisture content (DM) (Basis: 208 data)*

Screens (number)	Regression coefficients					Confidence limits at 95-Percent level)
	a	b_1	b_2	b_3	R_2	
						Percent [2]
0	3.49477	-0.026340	0.014771	0.021947	.673	- 74.4
						+134.2
1	3.45754	- .025716	.015048	.021968	.672	- 73.2
						+136.4
3	3.38792	- .024364	.015228	.023089	.641	- 72.4
						+138.5
4	3.35229	- .023875	.015715	.021814	.665	- 72.0
						+138.8
6	3.20931	- .020265	.013633	.016372	.737	- 81.4
						+122.9

[1]For individual (single) estimates of dowel moisture content at the mean value of the independent variable (tables 1 and 2).
[2]Of predicted dowel moisture.

Table 8.--*Comparative errors of determining slat moisture content by equation and by weighing at fire danger stations*

Screens (number)	Slat moisture content	Error by equation [1]	Error in field practice due to --				Total [6]
			Calibration [2]	Weathering [3]	Scale [4]	Natural variation [5]	
	- - - -	- - - -	- - - -	- - *Percent* - -	- - - -	- - - -	- - - -
1	3.1	(>±0.83)	±0.5	±0.8	±0.2	±0.5	1.09
	6.8	±1.82	± .5	± .8	± .2	± .5	1.09
	20.6	(>±5.52)	± .5	± .8	±1.0	± .5	1.46
6	4.4	(>±1.04)	± .5	± .8	± .2	± .5	1.09
	8.7	±2.06	± .5	± .8	±1.0	± .5	1.46
	22.8	(>±S.40)	± .5	± .8	±1.0	± .5	1.46

[1] Based on an average of the confidence limits at 95-percent level (table 4) and for individual (single) estimates of slat moisture content at the mean values of the independent variables (tables 1 and 2).
[2] Allowable variation in processing slats.
[3] Due to the average weathering correction used in field practice.
[4] Due to reading errors and variation between scales used in weighing.
[5] Due to timelag differences resulting primarily from differences in thickness of slats.

6 Probable error = $\sqrt{\Sigma[(\text{individual sources of error})^2]}$.

The most promising three-variable combination was DBT, DPT, and AH_{24}. A statistical analysis of the one-screen and six-screen dowel moisture data showed that there was a significant gain in information by adding successively DPT, AH_{24}, AS_{24}, and AR_8 to DBT (table 6). However, adding more than two variables had little practical benefit since R^2's were increased only slightly. The small gain in precision of estimating dowel moisture content probably would not be worth the effort to measure AS_{24} and AR_8, in field practice.

Regression equations containing the best three variables were computed (table 7) and portions plotted (fig. 6), as follows:

$$\log_e Y = a + b_1(X_1) + b_2(X_2) + b_3\log_e(X_3)$$

in which Y is DM_0, DM_1, DM_3, DM_4, or DM_6; a, b_1, b_2, and b_3 are regression coefficients; X_1 is DBT, X_2 is DPT, and X_3 is AH_{24}.

By holding the third independent variable (AH_{24}) constant, it is possible to demonstrate the equations by a two-dimensional plot (fig. 6). However, a three-dimensional block diagram would be needed to demonstrate the exact relationships between all three independent variables and dowel moisture content.

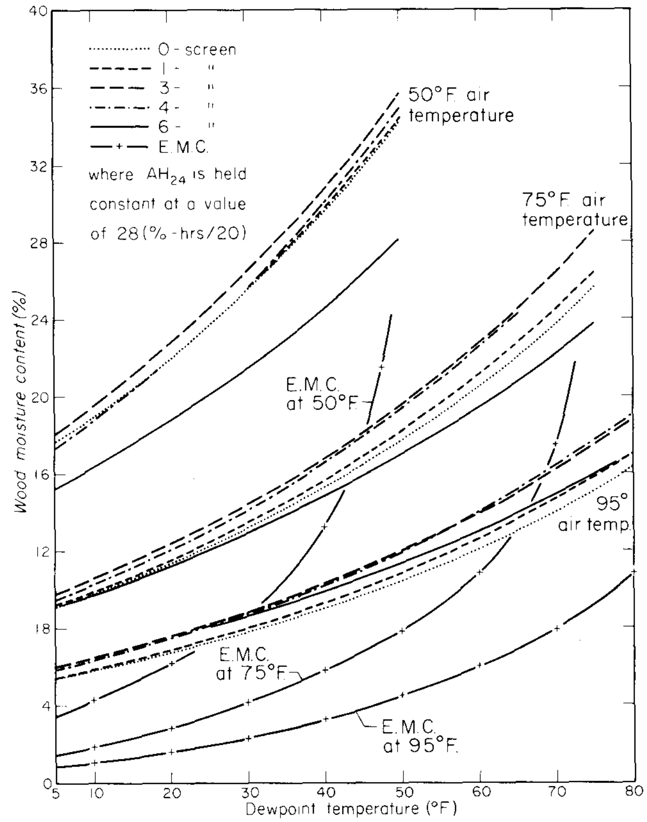

Figure 6. — *Computed curves for estimating dowel moisture content under zero- one-,three-,four-,and six-screen shading from psychrometric variables. Equilibrium moisture content curves (E.M.C.) for wood (Forests Products Lab. 1955) are plotted for comparison.*

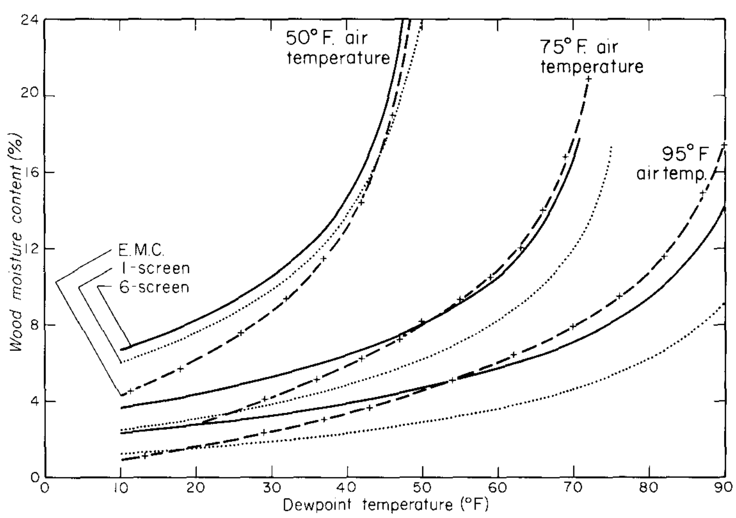

Figure 7. — *Computed slat moisture estimating curves plotted on curves of equilibrium moisture content (E.M.C.) for wood (Forest Products Lab. 1955) for three air temperatures.*

Discussion

Slat Moisture Content

Dewpoint temperature was selected over relative humidity to express humidity in the final equation, although the two variables showed to equal advantage in the analysis (table 3). This choice was made primarily for the benefit of fire weather forecasters who usually prefer to work with dewpoint. However, for those who prefer to use relative humidity or wet bulb depression, the conversion is easily made. It can be done most easily from computed plotting values or graphs of the final equation with the aid of a psychrometric slide rule or tables. Stations that ordinarily take only wet and dry bulb readings would find a tabular form of the equation with wet bulb depression and dry bulb temperature as entries easiest to use. Tables or graphs should be equally accurate in any of the three forms.

Solar radiation has a marked influence on slat moisture content, primarily through surface heating. Less than full shading allows a certain amount of radiation to reach the slats and raise their surface temperature above air temperature (tables 1 and 2). This effect lowers the humidity immediately above the slats and reduces the slat moisture content. The amount that slat moisture content is reduced compared to fully shaded sticks depends on the air temperature and the amount of screen shading (tables 1 and 2, figs. 3 and 7). The reduction is greatest at high temperatures and no shading.

The effect of radiation shading is partially responsible for observed differences between computed slat moisture content and equilibrium moisture content (E.M.C.) for wood (fig. 7). However, timelag is also a factor. The higher the air temperature, the shorter the timelag interval, and the lower the moisture content of slats compared to equilibrium—other things being equal.

The accuracy of estimating slat moisture content by equation, for mean values of the independent variables, approaches that of actual measurement at fire danger stations (table 8). Accuracy of estimation decreases as values of the independent variables depart from their means. The equations are most accurate at low slat moisture content and least accurate at high moisture content. In fire danger measurement work it is considerably more important to be able to estimate stick moisture content accurately in the critical low moisture range, that is, below about 8 percent.

Dowel Moisture Content

The percent of moisture content in dowels can be estimated more closely by equation than that in slats (tables 4 and 7). This is largely because the moisture content of dowels averages from 1½ to 2 times as high as that of slats for similar conditions of weather and shading (table 1).

Solar radiation has at least as much influence on dowel moisture content as on slats as indicated by the spacing between curves for different amounts of screen shading (figs. 6 and 7). As with slats the effect of radiation decreases as temperature and humidity decrease.

At some temperature above 95° F. the curves for zero, one, three, four, and six screens began to reverse order (fig. 6). The slat curves did not show this tendency (fig. 7). At 95° F. the six-screen curve was positioned between the one- and the three-screen curves. At 75° F. the six-screen curve was in the lowest position and the three- and four-screen curve had just reversed order. This tendency continued at lower air temperatures and was most pronounced at higher dewpoint temperatures.

One possible explanation of this phenomenon is on the basis of dew effects and drying rates. Less dew forms at night on shaded dowels than on dowels in the open. However, shaded dowels may be able to retain more of their acquired moisture the next day because they are protected from evaporative effects of the sun. By 2 p.m. the dowels in the open will have lost nearly all of the moisture picked up during the night. On the other hand, unless the day is very hot and bright, the shaded dowels ordinarily will not have lost by 2 p.m. any appreciable portion of the relatively small quantity of moisture they acquired during the night. Dowels dry slowly as is indicated by their long timelag interval, and the interval lengthens rapidly as air temperature decreases. This characteristic probably explains why the reversal becomes more pronounced at low air temperatures. The fact that days with low air temperature usually are shorter, with fewer drying hours before 2 p.m., undoubtedly contributes to this effect.

The reversal is less pronounced at low dewpoint temperatures, probably because less dew is formed at night following days with low dewpoint temperature.

Slats probably pick up relatively more moisture from dew at night than dowels. However, they ordinarily will lose most of it by 2 p.m. the next day because the timelag interval for slats is only about one-fifth as long as for dowels.

Computed moisture content curves for dowels paralleled E.M.C. curves for wood fairly well at high air temperatures, although there was considerable separation (fig. 6). The separation was much greater at low air temperatures, and the computed curves were much flatter than E.M.C. curves.

Summary and Conclusions

Weather factors affecting the 2 p.m. moisture content of two types of fuel moisture indicator sticks exposed under five different amounts of screen shading were studied near Macon, Georgia. Replicated sets of basswood slats and ponderosa pine dowels were exposed under zero, one, three, four, and six layers of aluminum window screen in a randomized block design for 1 year (rainy days were excluded).

Of the 24 weather variables considered in initial trials, 10 showing the most promise were evaluated in detailed multiple regression solutions for each type of indicator stick and amount of shading. All possible combinations of the 10 weather variables were analyzed jointly with stick moisture content.

The resulting equations proved fairly good predicting equations for both slats and dowels. They indicated that for mean values of the independent variables, slat moisture content could be determined with approximately equal precision by equation in the critical low moisture content range or by weighing at fire danger stations. But equations were considerably less accurate than field practice in the high moisture content range. For ease of use the predicting equations can be put into the form of a simple two-way table. This is possible because the third independent variable, dewpoint depression, is composed of the first and second variables, dry bulb temperatures, and dewpoint temperature. Relative humidity or dry bulb depression can be substituted for dewpoint temperature since the three are alternate expressions of humidity.

The percent of dowel moisture content could be determined with slightly greater precision by equation than percent of slat moisture content. Numerically, however, the dowel equations were less precise because dowels averaged one and a half to two times more moisture content than slats for similar weather conditions. Dry bulb temperature, dewpoint temperature, and average relative humidity during the 24-hour period preceding the 2 p.m. reading proved to be significant gauges of dowel moisture content. The variable "antecedent relative humidity" reflected the relatively long timelag interval of dowels. None of the antecedent weather variables was significant in the slat analysis because slats dry rapidly and have short timelag intervals. Three-way tables are required to express the predicting equations for dowel moisture content in tabular form. These are more cumbersome to use in practice than the two-way tables for slats. In addition, humidity must be determined periodically in order to compute the antecedent humidity variable.

Other findings included a close agreement between slat moisture under six screens and equilibrium moisture content for wood at moderate air temperatures and dewpoints; slat moisture under six screens underruns equilibrium moisture content at high temperatures and dewpoints, and overruns equilibrium moisture content at low dewpoints regardless of air temperature; dowel moisture curves parallel equilibrium moisture content curves with considerable separation at very high air temperatures, but the two types of curves resemble one another very little at other air temperatures.

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