SHADING EFFECTS OF DECIDUOUS TREES[1]

by Robert J. Youngberg

The shading impact of trees on the energy consumption of buildings, and in particular solar systems is not easy to estimate. With support from the Lincoln Electric system and the U.S. Department of Energy a project was started to monitor deciduous trees, both summer and winter for two years. The project was designed to provide data on widely used tree species in the Midwest. At the present time, information on the effectiveness of deciduous trees to provide shade in the summer but also allow sunlight penetration in the winter is minimal.

This project measured solar radiation penetration through the canopy of six trees twice a year for two years. Sites were selected which contained 'modern' healthy tree species which were currently popular and available from nurseries. They were also selected for uniformity in size, age and accessability for monitoring. Both the Lincoln and state forestries were very helpful in the selection and location of these trees.

It is essential when monitoring sunlight penetration through the tree canopy that the measurement reflect the average condition. Wide variations in measurements were experienced due to bare branches, wind, sun flecks and reflection from the surroundings. A mobile, track mounted thermopile type pyranometer was used to measure a grid 9 readings wide and 7 readings long each hour under the tree canopy. Another pyranometer was located in the full sun outside the tree canopy and a battery powered data logger intercepted three readings over 30 seconds for each sensor. A battery powered 'tank' programmed to stop every 4.3 ft. for 30 seconds provided the locomotion. In this fashion, 63 readings in a grid pattern were obtained each hour for 6 to 8 hours per day. The track was moved after each 'run' (9 readings) through the shade or 7 times each hour. The readings were recorded on an audio tape recorder connected to the data logger. Each day's data was then played through an analog to digital converter and stored on computer tape for further analysis.

The data were analyzed from three viewpoints both summer and winter. First was how many watts per square meter was being blocked by the tree. This varied continuously from tree to tree, time of year, time of day and location within the tree itself. Although this information is in itself of great value to plant scientists it was not of central concern to the project. The following charts show the amount of solar radiation blocked by a sycamore tree in the full leaf condition (Fig. 1). These figures show a blockage of about 700 watts per square meter during the summer. A similar hour for the winter shows a 350-450 w/m^2 blockage. Of interest is the general uniformity (except for sun flecks) of blockage both top to bottom and side to side within the tree canopy.

What we are more interested in for design purposes, however, is the amount of solar radiation penetrating the canopy. Figure 2 and 3 show these figures are in the range of 500-600 w/m^2 during the bare branch condition and typically less than 100 during the full leaf condition. Of even more interest for designers in applying this information to other locations with trees of this type is a percentage figure.

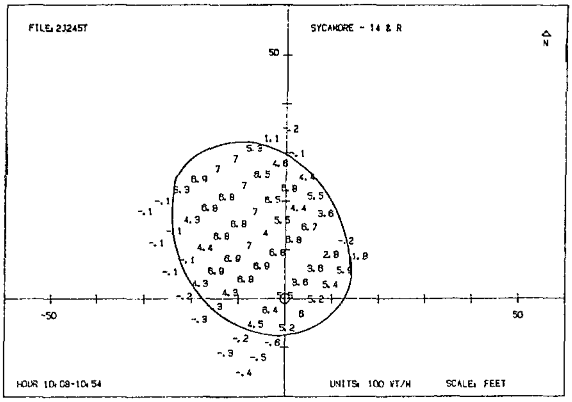

Figure 1

1. Presented at the Trees for Nebraska Conference in 1982.

REC NO.	SOLAR TIME	SR#1 WT/M	SR#2 WT/M	RUN DIST FT.	X FT.	Y FT.	Z1 WT/M	Z2 %
127	1008	770	727	-5	-8.73	-15.64	-43	-5.92
128	1008	778	727	-5	-5.67	-12.62	-51	-7.00
129	1009	794	730	-5	-2.66	-9.59	-64	-8.83
130	1009	209	731	-5	.42	-6.58	522	71.37
131	1010	129	732	-5	3.47	-3.60	603	82.37
132	1010	211	731	-5	6.57	-.61	521	71.22
133	1011	187	732	-5	9.67	2.32	545	74.51
134	1011	140	732	-5	12.78	5.29	592	80.84
135	1012	550	733	-5	15.94	8.18	183	25.01
136	1014	772	738	0	-12.64	-11.67	-34	-4.61
137	1015	767	738	0	-9.53	-8.70	-30	-4.01
138	1015	281	738	0	-6.35	-5.80	457	61.93
139	1016	95	740	0	-3.19	-2.88	645	87.15
140	1016	185	741	0	0.00	0.00	556	75.05
141	1017	378	742	0	3.21	2.86	364	49.04
142	1017	380	741	0	6.42	5.73	361	48.74
143	1018	461	741	0	9.68	8.53	281	37.86
144	1018	766	742	0	12.90	11.38	-24	-3.19
145	1023	783	745	8	-18.34	-4.84	-38	-5.14
146	1023	781	746	8	-15.03	-2.09	-35	-4.68
147	1024	312	747	8	-11.72	.72	435	58.26
148	1024	63	749	8	-8.40	3.45	686	91.61
149	1025	57	750	8	-5.04	6.21	694	92.47
150	1025	65	751	8	-1.70	8.92	686	91.41
151	1026	66	751	8	1.71	11.62	685	91.20
152	1026	74	753	8	5.06	14.31	679	90.20
153	1027	385	754	8	8.52	16.95	369	48.93
154	1030	778	755	13	-21.56	-.09	-23	-3.09
155	1030	320	757	13	-18.14	2.52	438	57.77
156	1031	67	758	13	-14.69	5.22	691	91.15
157	1031	61	760	13	-11.25	7.80	699	91.96
158	1032	60	760	13	-7.75	10.43	701	92.16
159	1032	354	761	13	-4.30	13.00	408	53.55
160	1033	207	762	13	-.75	15.57	555	72.83
161	1033	320	763	13	2.71	18.11	443	58.03
162	1034	211	763	13	6.31	20.62	552	72.31
163	1037	774	758	18	-24.40	4.96	-17	-2.18
164	1037	774	758	18	-20.87	7.41	-16	-2.08
165	1038	312	759	18	-17.28	9.98	447	58.91
166	1038	74	760	18	-13.73	12.41	687	90.33
167	1039	82	762	18	-10.09	14.91	681	89.27
168	1039	61	764	18	-6.53	17.32	702	92.00
169	1040	109	765	18	-2.84	19.75	656	85.75
170	1040	80	765	18	.73	22.13	685	89.55
171	1041	323	765	18	4.47	24.49	442	57.76
172	1043	780	763	24	-27.42	10.94	-17	-2.18
173	1044	777	763	24	-23.72	13.42	-14	-1.80
174	1044	326	765	24	-20.09	15.71	439	57.38
175	1045	79	766	24	-16.32	18.11	687	89.71
176	1045	76	766	24	-12.67	20.38	690	90.04
177	1046	64	769	24	-3.87	22.71	705	91.74
178	1046	112	771	24	-5.20	24.96	659	85.47
179	1047	312	772	24	-1.36	27.21	460	59.64
180	1047	784	773	24	2.32	29.44	-12	-1.49
181	1050	789	775	30	-29.89	17.39	-13	-1.70
182	1050	792	776	30	-26.16	19.54	-16	-2.02
183	1051	444	777	30	-22.29	21.84	333	42.84
184	1051	86	778	30	-18.55	23.96	693	88.98
185	1052	75	779	30	-14.64	26.19	704	90.42
186	1052	74	780	30	-10.38	28.29	706	90.56
187	1053	243	782	30	-6.92	30.43	540	68.99
188	1053	664	784	30	-3.16	32.50	120	15.27
189	1054	812	785	30	.85	34.57	-27	-3.47

This is a typical one hour recording of data from 10:08 to 10:54 in September. SR#1 is the sensor reading in the shade of the canopy and SR#2 is the full-sun reading in immediate area. The run distance is the track position from the tree trunk. 'X' and 'Y' are calculated coordinates for plotting purposes and Z1 is the unit difference between the two readings in watts per square meter and Z2 is the percentage difference. Negative differences are due to local reflections and will be minimized after calibration constants are applied to the data.

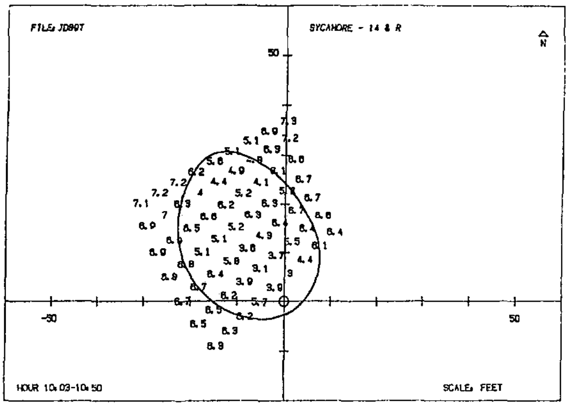

Figure 2

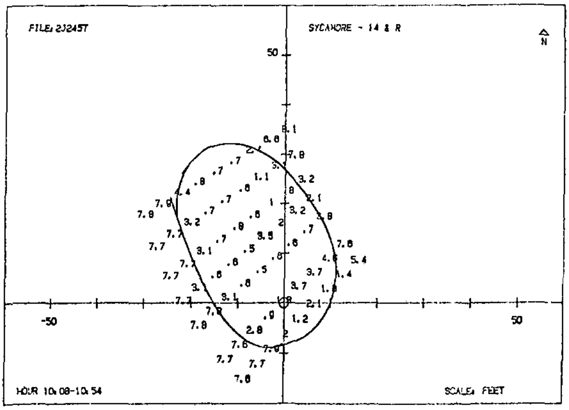

Figure 3

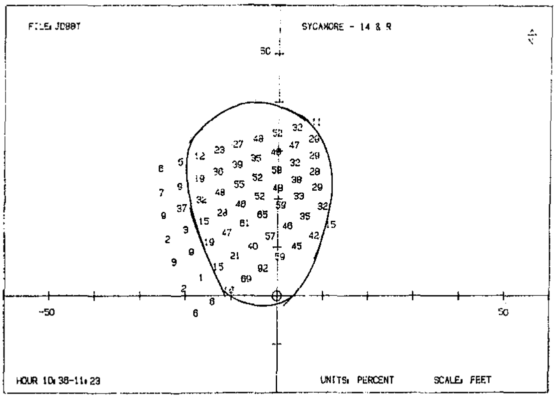

Figure 4

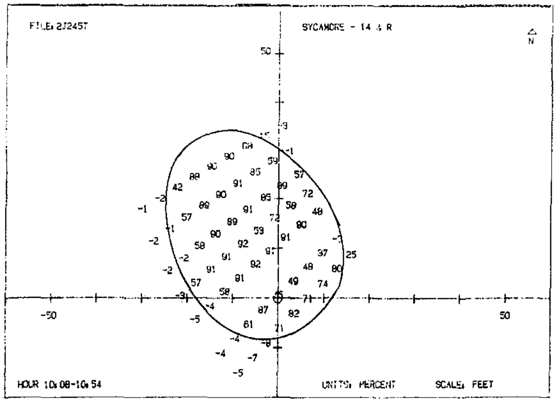

Figure 5

Figure 4 shows this tree to block 40-50% of the solar radiation in the bare branch winter condition and in the full leaf condition block an almost uniform 90%. It is interesting to note that this is very close to the expected diffuse component (vs. direct) of total solar radiation. Figure 5 shows this information for the full leaf condition.

Preliminary analysis of the other monitored trees show a typical 90% blockage during the summer months and a winter blockage ranging from 25 to 60%. A statistical analysis including curve fitting will be performed on the data to derive a model by which this information can be applied to other locations.