ESTIMATING RADIATION RECEIVED BY A PERSON UNDER DIFFERENT SPECIES OF SHADE TREES

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Abstract. A micrometeorological computer model was used to estimate the radiation that would be received by a person under a range of shade trees. The results provide a relative comparison of tree species in terms of their radiation characteristics for conditions on sunny spring, summer, and winter days. All trees tested provide a significant reduction in the radiation load of a person compared to open conditions. The relative comfort level of the environment under test trees was also determined, using an energy budget 'human thermal comfort' model. These results demonstrate the general value of shade trees in the landscape, and provide a relative measure of the value of different species.

Résumé. Un modèle d'ordinateur pour la micrométéorologie a été utilisé pour estimer la radiation qui serait reçue par une personne sous un couvert d'arbres d'ombrage. Les résultats ont fourni une comparaison entre les espèces d'arbres en terme de leurs caractéristiques radiatives dans des conditions de journées ensoleillées de printemps, de l'été et de l'hiver. Tous les arbres testés procurent une réduction significative dans la charge radioactive d'une personne comparé avec des conditions à découvert. Le niveau de confort relatif de l'environnement sous le test d'arbres était aussi déterminé en utilisant un modèle de budget énergétique du confort thermique humain. Le résultats démontrent la valeur générale des arbres d'ombrage dans le paysage, et fournissent une mesure relative de la valeur de différentes espèces.

Trees provide many amenities, but perhaps none so important as their effect on the thermal comfort of people in the landscape. During hot summer days the filtering of the sunlight by trees produces a welcome, cool, microclimate. Although people sense that the air temperature is lower under trees on sunny days, it is now well known that the air temperature under a single tree is almost exactly the same as the air temperature in the open (1). Although there is considerable cooling power in the evapotranspiration of the canopy, the efficient turbulent mixing of the air nullifies any temperature differences.

The 'cool' feeling people experience is a result of a reduction in radiation received (R). The amount of sunlight intercepted by a tree varies with the species. Many researchers have investigated the porosity, or transmissivity (t) values of tree canopies, in both summer and winter (e.g. 2, 3). This information has seldom been translated, though, into estimates of the amount of radiation a person would receive under a given tree specimen (4) or the thermal comfort amenity of the trees.

Methods

This paper employed a mathematical, micrometeorological model for the estimation of the total radiation load on a person under selected tree species, with no on-site measurements required. The model has been previously validated (5) with data collected for a range of coniferous and deciduous trees.

The model estimates separately all the stream of radiation received by a vertical cylinder (analogous to a person) in test environments. Typically, short wave radiation is received from: a) transmission through the canopy, b) diffuse radiation from the surrounding environment, c) reflections from the tree, and d) reflections from the ground plane. Long wave radiation typically is received from the tree, the sky, and the ground plane.

The model for estimating R requires incoming short wave radiation (K↓), air temperature (T), solar elevation angle, and albedo of the ground plane. Each stream of radiation is modelled and summed to determine the total radiation received by a person in the test environment.

To determine thermal comfort, additional information on wind speed, relative humidity, and activity and clothing levels of the person are also required. Each stream of energy to and from a person is modelled and the resulting balance indicates whether a person would be too cool, comfortable, or too warm in the test environment (6).

Meteorological conditions typical for Southern Ontario in spring, summer, and winter were employed by the model to determine R and S for a range of deciduous trees. Site conditions were held constant from season to season, the only variables being: a) the transmissivities (t) of the test trees, and b) the reflectivity (r) of the ground surface. The values of t and r were estimated from the literature (e.g. 1, 2, 3).

The following experimental conditions were held constant: a) the temperatures of tree branches and trunk were estimated as being equal to air temperature, b) the sky view factor (SVF), the proportion of the sky visible to a person in the test environment, was set at 30% (approximately 70% of the person's sky hemisphere was said to be covered by the tree canopy), c) diffuse radiation was approximately 10% of the recorded solar radiation on the clear, sunny test days (7), and d) a person was considered analogous to a vertical cylinder (6). For the thermal comfort portion of the tests, the person was considered to be standing or walking slowly. Clothing was long pants, heavy sweater and windbreaker in spring and winter conditions; and short pants and T-shirt in summer conditions. A complete listing of the input parameters is available in Table 1.

Table 1. The following input parameters were used in the tests:

K (incoming solar radiation):	Summer = 908 W/m^2 Spring = 620 W/m^2 Winter = 326 W/m^2
Temperature of air, ground, and all objects:	Summer = 28.4°C Spring = 10.5°C Winter = -6.6°C
Albedo of ground: (fresh snow)	Summer = .09 Spring = .09 Winter = .85
Wind speek:	Summer = 1.9 m/s Spring = 1.5 m/s Winter = 1.5 m/s
Solar elevation angle:	*Summer = 53.6°* *Spring = 42.0°* *Winter = 23.9°*
Activity level of person = 100 W/m^2	
Resistance of clothing*:	Summer = 50 s/m *Spring = 250 s/m* *Winter = 250 s/m*
Permeability of clothing:	Summer = 175 Spring =50 Winter =50
Relative humidity = 60%	

*Summer clothing = T-shirt, short pants, socks and running shoes
Spring and winter clothing = shirt, long pants, shoes, sweater and wind breaker.

The computer model was run for the transmissivity value of each test tree, using the data outlined in table 1 and the transmissivity values from tables 2 a, b, and c. A range of trees, with transmissivity values from very low to very high were tested, including Norway maple *(Acer platanoides)*, horsechestnut *(Aesculus hippocastanum)*, European white birch *(Betula pendula)*, shagbark hickory *(Carya ovata)*, Russian olive *(Elaeagnus angustifolia)*, thornless honeylocust *(Gleditsia triacanthos var. inermis)*, black walnut *(Juglans nigra)*, London planetree *(Platanus acerifolia)*, and quaking aspen *(Populus tremuloides)*.

The values of t for individual tree species varies, providing overlap in the estimates of R (Figure 1). The range in the transmissivity values is partially a function of variability in individual trees within a species, but also a result of the instrumentation used in the measurement (8). Within the literature some of the values are derived using pyranometers, which yield reliable estimates of transmissivity. Other values are derived using light meters, which do not yield reliable estimates of transmissivity. Further explanation is offered by

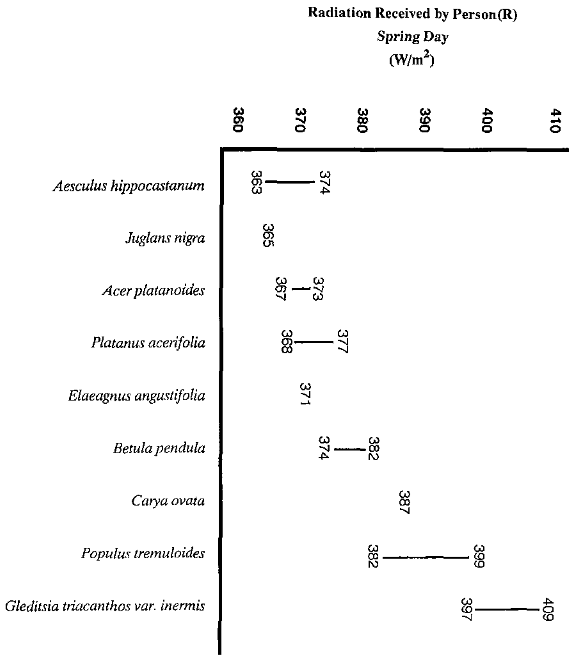

Figure 1. Estimated radiation (R) received by a person under selected shade trees (2, 3).

O'Neill et al (8), as to the inappropriateness of instrumentation used in some studies. This error is avoided in this paper by using only values recorded by pyranometers, and not light meters.

Results

The published values for spring and summer transmissivities of different tree species ranged from a low of 0.08 for horsechestnut, to a high of 0.38 for honeylocust (3). The total (short and long wave) radiation received by a person under those canopies (R) differed by more than 45 W/m^2 in spring conditions and 40 W/m^2 in summer.

The values of winter transmissivity values ranged from 0.46 for London planetree, to 0.85 for honeylocust (3). The estimates of R ranged by more than 120 W/m^2.

Under summer conditions the lowest amount of R, at 378 W/m^2, is estimated for horsechestnut and the highest, at 422 W/m^2, is estimated for honeylocust, with a full range in between (see Table 2). A person in the open would have R of 513 W/m^2. The corresponding energy budget values for a person (S) range from 45 W/m^2 under horsechestnut (comfortable), to 89 W/m^2 in the open (would prefer to be much cooler). Similarly, R values under spring conditions were 290, 332, and 419 W/m^2 respectively, and S values were -52 (would prefer to be warmer), -16 (comfortable), and 59 (would prefer to be cooler) (see Table 2b).

Under winter conditions, with leafless canopies over fresh snow on the ground, the lowest estimate of R was 408 W/m^2 under the London planetree, and the highest was 528 W/m^2 under the honeylocust (see Table 2c). A person in the open would have received 574 W/m^2. These values are higher than the amount received by a person in either spring or summer. This is to be expected due to the high reflectivity of fresh snow, the high transmissivities of canopies, and the low sun angle in winter. The corresponding S values were, respectively, -63 W/m^2 (would prefer to be warmer), 33 W/m^2 (comfortable), and 70 W/m^2 (would prefer to be cooler).

Discussion and Conclusions

This study has modelled the radiation load and the thermal comfort conditions under a range of deciduous trees on sunny spring, summer, and winter days. On cloudy days the short wave radiation is nearly completely diffuse, so the dif-

Table 2. Results of the computer modelling, in terms of Radiation absorbed by a person (R), energy budget of a person (S), and equivalent comfort class.

	Summer conditions				*Spring conditions*				*Winter conditions*			
Species	*t*	*R(W/m²)*	*S(W/m²)*	*Comfort Class* *	*t*	*R(W/m²)*	*S(W/m²)*	*Comfort Class* **	*t*	*R(W/m²)*	*S(W/m²)*	*Comfort Class* ***
Aesculus hippocastanum	.08	378	45	0	.08	363	-52	-1	.73	491	3	0
Juglans nigra	.09	380	47	0	.09	365	-51	-1	.72	488	1	0
Acer platanoides	.10	382	48	0	.10	367	-50	-1	.75	497	8	0
Platanus acerifolia	.11	383	49	0	.11	368	-49	0	.46	408	-63	-1
Elaeagnus angustifolia	.13	386	52	1	.13	371	-46	0	—	—	—	—
Betula pendula	.20	396	63	1	.20	382	-38	0	.52	430	-46	0
Carya ovata	.23	401	67	1	.23	387	-34	0	.66	470	-14	0
Populus tremuloides	.31	412	79	1	.31	400	-24	0	—	—	—	—
Gleditsia triacanthos	.38	422	89	1	.38	409	-16	0	—	—	—	—
(high estimate)	—	—	—	—	—	—	—	—	.85	528	33	0
(low estimate)	—	—	—	—	—	—	—	—	.48	414	-58	-1
Open	1.00	513	179	2	1.00	503	59	1	1.00	574	70	1

*0 = person would prefer no change (comfortable), 1 = person would prefer to be cooler, 2 = person would prefer to be much cooler
**-1 = person would prefer to be warmer, 0 = person would prefer no change (comfortable), 1 = person would prefer to be cooler
***-1 = person would prefer to be warmer, 0 = person would prefer no change (comfortable), 1 = person would prefer to be cooler

ferences in the values of R under various species of trees would be very small. Any differences in comfort levels would be expected to be due to longwave characteristics, and would consequently also be very small.

This study interprets transmissivity values of trees, long available in the literature, into values of radiation received by a person under the trees and into resultant thermal comfort levels. It demonstrates the high value of trees in ameliorating the microclimate for use by people, and also shows that some trees are of more value than others. Although this has long been known on an intuitive level, the quantification in this study should assist landscape planners, designers and arboriculturists in making appropriate decisions, and justifying them to clients.

During times of high temperature and humidity (a common occurrence in Southern Ontario) wind is of little value in cooling a person. The only effective means of creating comfortable outdoor microclimate is to reduce radiation loads. Heavy shade is provided by trees such as the horsechestnut, black walnut, and London planetree. During the shoulder seasons of spring and fall, cool temperatures can make it desirable to provide some solar radiation. Light shade is provided by trees such as shagbark hickory, quaking aspen, and honeylocust. During winter low temperatures require maximum radiation load on a person. Trees with very porous canopies during leafless periods include black walnut, horsechestnut, Norway maple, and honeylocust. When time of use of an area is projected, then the appropriate tree or trees can be determined in a quantitative manner.

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