BNL 50939
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NORMAL INCIDENT SOLAR RADIATION MEASUREMENTS AT UPTON, NEW YORK

J.G. COTTINGHAM

August 23, 1979

ACCELERATOR DEPARTMENT

**BROOKHAVEN NATIONAL LABORATORY
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**UNDER CONTRACT NO. EY-76-C-02-0016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY**

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BNL 50939
Second Edition
AGS DIV. 79-1
UC-62
(Solar Thermal - TID-4500)

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ABSTRACT

Normal incident solar energy measurements made at Upton, L.I., New York are reported and analyzed relative to the total energy received on a horizontal surface. A new method for estimating normal incident solar radiation is developed and used to determine average values for other east coast locations.

The northeastern part of the United States is not the sunniest part of the country. And for this reason much of the solar energy research and demonstration is planned and conducted in the southwest. This is particularly true for energy concentrating type systems. These systems collect energy only from the normal incident beam which is reduced by atmosphere scattering. Collecting systems that respond to scattered light recollect some of this scattered energy and therefore are less affected.

Nevertheless concentrating type systems must not be eliminated from the Northeast region of the country since their high temperature output is essential to certain application. Most cooling, mechanical and electrical generating systems fall into this application set. The northeast is also unique in that this region of the country has an in-place steam utilization technology with many building systems completely motivated by steam for both heating and cooling purposes.

As part of the heliostat development project at Brookhaven National Laboratory normal incident solar radiation measurements were made at Upton, N.Y. which is located on Long Island 70 miles east of New York City. For this purpose an Eppley Normal Incident Pyrheliometer was mounted on the roof of the Atmospheric Science Building and operated by that group. Daily data was digitally recorded and processed by R.M. Brown. This data together with pyranometer reading giving the radiations received on a horizontal surface was processed by D. White and C. Henderson under the able direction of J. Tichler. This report is now updated to include data collected over the 25 month period from June 1977 through June 1979.

In order that total incident energy be reported, missing and erroneous data must be restored. Missing data results principally from two causes, failure in the recording equipment and tracking errors.

Mr. Paul Vosganian joined our staff in the summer of 1978 and addressed this data restoration problem. Mr. Michael Falco continued the data analysis in the summer of 1979. The normal incident readings were plotted versus the pyranometer reading for each month. Plots thus made display a general smooth relationship. Data points far removed from this smooth curve were considered

erroneous and were eliminated. Missing and erroneous pyraheliometer readings were replaced by values read from the curve fit; if pyranometer readings were available. If no readings were available, the pyraheliometer value was assumed to be equal to the average for the month. Table I summarizes these results. For comparison long term values for solar radiation measured on a horizontal surface copied from Reference 1 are also included in Table I.

It is clear from examining Table I that the period over which these measurements were made was not typical, and in general contain less solar insolation than reported as average for this location.

In an effort to relate this brief set of normal incident solar radiation measurements to that of other time periods two ratios were defined:

$$K_H, \frac{\text{daily total solar energy received on a horizontal surface}}{\text{same total received outside the atmosphere}}$$

$$K_L, \frac{\text{daily total normal incident solar radiation}}{\text{same total received outside the atmosphere}}$$

These parameters were computed for each day for which good data was available and grouped into small bins and averaged. From these groupings three data sets were formed. One covering the first season from June 1977 through May 1978, the second covering the same season of the following year and the final set covers the total period. Each data set was fit with a third order polynomial and the resulting coefficients are tabulated in Table II. Figure I shows the data and the fit for the two single year periods.

This curve fit appears to be seasonally invariant. Data from widely spaced months are shown plotted superimposed with the curve of the total period polynomial in Figures 2 through 5 and almost no seasonal effects are evident.

If the relationship between these two atmospheric transmissions coefficients is seasonally invariant, then it is reasonable to expect it to be approximately invariant over the long term. This relationship is in major part a comparison between two methods for measuring the transmission of solar energy through the atmosphere which explains this invariant character.

TABLE I
Daily Average Solar Radiation Upton, N.Y. (BTU/ft²)

	Received on a Horizontal Surface			Normal Incident Solar Radiation	
	Long Term				
	1977-1978	1978-1979	Lui-Jordan	1977-1978	1978-1979
June	1856	2067	2159	1270	1624
July	2015	1871	2045	1626	1421
Aug	1468	1322	1790	1023	824
Sept	1156	1416	1473	915	1404
Oct	820	1082	1103	618	1082
Nov	473	590	687	313	706
Dec	439	558	551	649	817
Jan	548	479	583	800	632
Feb	994	927	873	1517	1132
Mar	1239	1193	1280	1241	1166
Apr	1527	1584	1610	1280	1096
May	1506	1605	1892	1148	1014
Yearly Total	4.27x10 ⁵	4.47x10 ⁵	4.89x10 ⁵	3.76x10 ⁵	3.92x10 ⁵
Heating Season, Oct-May	2.29x10 ⁵	2.44x10 ⁵	2.61x10 ⁵	2.28x10 ⁵	2.32x10 ⁵

TABLE II
Polynomial Fit $K_L = AK_H^3 + BK_H^2 + CK_H + D$

	A	B	C	D
First Year	1.044	.2236	-.0516	.0013
Second Year	1.080	.1327	-.0447	.0017
Total Period	.9952	.2389	-.0615	.0018

With the assumptions of a fixed relationship between horizontal and normal incident transmission coefficients, methods for estimating normal incident for other time periods and other locations are made possible using existing horizontally measured data.

The method proceeds as follows:

$A_{\perp}$, the annual total solar energy received at normal incidence is given by

$$A_{\perp} = \sum_{\text{year}} I_{Dn}$$

where

I_{Dn} = daily insolation received at normal incidence

define. $K_{\perp} = \frac{I_{Dn}}{I_{on}}$

where

I_{on} = daily insolation received at normal incidence outside atmosphere which is given by

$$I_{on} = \frac{24}{\pi} w_s r I_{sc}$$

where

w_s = 1/2 daylight (radians)

$w_s = \cos^{-1} (-\tan L \tan \delta)$

L = latitude

δ = declination

r = ratio solar intensity to mean solar intensity outside the atmosphere

$I_{sc} = 428.38 \text{ BTU-hr}^{-1} - \text{ft}^{-2}$

$K_{\perp}$ is related to K_H through the measured polynomial $K_{\perp} = F(K_H)$

K_H can be determined from existing measured data

$$K_H = \frac{H(\text{measured})}{H_o}$$

where

H_0 = daily total solar radiations received on a horizontal surface outside the atmosphere which is given by

$$H_0 = \frac{24}{\pi} r I_{sc} [\cos L \cos \delta \sin w_s + w_s \sin L \sin \delta]$$

from the definition of $K_{\perp}$

$$I_{Dn} = I_{on} K_{\perp} = I_{on} F(K_H) = \frac{24}{\pi} w_s r I_{sc} F(K_H)$$

then

$$A_{\perp} = \frac{24}{\pi} I_{sc} \sum_{\text{year}} r w_s \cdot F(K_H)$$

The $\sum_{\text{year}}$ can be evaluated in segments, where each segment is made small enough to approximate a linear segment. Within this segment $F(K_H) = C_i$, where C_i is a constant that varies from segment to segment and is determined from the polynomial. The contribution to $A_{\perp}$ from any segment becomes

$$\frac{24}{\pi} I_{sc} \sum_{\text{year}} r w_s C_i = \frac{24}{\pi} I_{sc} C_i \sum_{\text{year}} r w_s$$

The term $\sum_{\text{year}} r w_s$ is a weighted count of days occurring in the chosen K_H segment with rw_s as the weighting factor. With this weighted count the contribution of this segment to the quantity $A_{\perp}$ can be determined. Summing over all segments yields the total $A_{\perp}$.

Figure 6 shows the weighted K_H occurrence frequency for Upton for two different time periods and illustrates the effect of climatic changes upon this weighted sum. Figure 7 shows the long term occurrence frequency of K_H for four other locations and shows the variation in this parameter with location along the eastern seaboard.

Using this method for computing A_1 and the results shown in Figure 7, long term average values for A_1 can be determined for these four locations. Results are summarized in Table III.

TABLE III

Locations	Long Term Annual Solar Energy Receiver at Incidence
Boston, MA	3.32×10^5 BTU-ft ⁻² -year ⁻¹
New York, NY	3.08
Sterling, VA	3.51
Cape Hatteras, NC	4.29
Greensboro, NC	4.10
Charleston, SC	3.78

Table IV shows values of A_1 as computed by William Dickinson and reported in Reference 4.

TABLE IV

Locations	Long Term Annual Solar Energy Received at Normal Incidences (Ref. 4)
Phoenix, AZ	7.98×10^5 BTU-ft ² -year ⁻¹
Albuquerque, NM	8.19
Fort Worth, TX	5.45
Omaha, NB	5.17
Nashville, TN	4.17
Blue Hill, MA	3.78

Annual normal incident solar radiations received at Upton, NY can also be computed for each year for which good horizontal data is available. Figure 8 presents these results and includes the recent direct normal incident measurements. Upton, NY can anticipate receiving an average of 3.65×10^5 BTU-ft²-year⁻¹ solar radiation at normal incidence.

Acknowledgments

The author wishes to acknowledge the invaluable assistance and enthusiastic cooperation which he received from the Meteorology group under the direction of Dr. Paul Michaels. The computer analysis by J.L. Tichler, data reduction by Robert M. Brown, Paul Vasgianian and Michael Falco was essential to this work.

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2. Constance M. Nagle, Climatology of Brookhaven National Laboratory 1949 through 1973, report BNL 50466.
3. Constance M. Nagle, Climatology of Brookhaven National Laboratory 1974 through 1977, report BNL 50857.
4. William C. Dickinson Annual Available Radiations for Fixed and Tracking Collectors, Solar Energy, Vol. 21, No. 3, 1978.

Figure 1. Measured values of K_H versus K_L grouped into bins and averaged for Upton, NY for two time periods

Figure 2. Curve fit versus data from January 1978 and 1979

Figure 3. Curve fit versus data from March 1978 and 1979

Figure 4. Curve fit versus data from June 1977, 1978 and 1979

Figure 5. Curve fit versus data from September 1977 and 1978

Figure 6. Weighted $\bar{K}_H$ occurrence frequency for Upton, NY for time period 1950-58 and 1970-78

Figure 7. Long term weighted K_t occurrence frequency for Boston, Mass; New York, NY; Sterling, VA; Charleston, SC

Figure 8. Computed annual normal incident solar radiation received at Upton, NY