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NORMAL INCIDENT SOLAR RADIATION MEASUREMENTS AT UPTON, NEW YORK

J.G. COTTINGHAM

MASTER

October 24, 1978

ACCELERATOR DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
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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 computing normal incident solar radiation is developed and used to study long term variations in this energy source at Upton and to estimate 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 system collect energy only from the normal incident beam and it is this energy form that is most effected by atmosphere scattering. Collecting systems that respond to scattered light recollect some of the energy scattered from the direct beam.

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 based on data collected over the 13 month period from June 1977 to June 1978.

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. 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. The remaining data was fit with a curve of the form $y = ax^n$ using a least squares method. 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 1.

It is clear from examining Table 1 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. Figure 1 plots this monthly average atmospheric transmission coefficient $\bar{K}_H$, the daily average ratio of solar energy received on a horizontal surface to that outside the atmosphere, for the long term Lui and Jordan data and for the months recently measured. The 1977 time period is notably below the average. Figure 2 shows the horizontal insolation as reported by additional references^{1,2,3}.

Figure 2 clearly shows changes in the averages measured for different time periods. It is believed that the Lui and Jordan work¹ is based in part on data from the 1950 time period and is therefore higher than indicated by later measurement.

In an effort to relate this brief set of normal incident solar insolation measurement to that of other time periods two parameters were defined, $\bar{K}_H$, defined as before and $\bar{K}_I$ the same ratio measured at normal incidence.

These parameters were computed for each day for which good data was available and grouped into small bin and averaged. The resulting data set was fit with a third order polynomial. The result is shown in Figure 3a and the equation for the fit is:

$$\bar{K}_I = .5548(\bar{K}_H)^3 + .9949(\bar{K}_H)^2 - .4218 \bar{K}_H + .0526$$

Figure 3b shows the daily data superimposed on this polynomial.

This curve fit appears to be seasonally invariant. Data from widely spaced months are shown plotted superimposed with the curve of the polynomial in Figures 4 through 7 and no seasonal effects are evident. Time will test this invariant assumption.

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

Table 1
Solar Radiation Upton, N.Y. (BTU/ft²)

Total-Horizontal Surface Upton, N.Y.				Normal Incident Solar Radiation		
<u>Long Term</u> <u>Lui-Jordan</u>		<u>Measured</u> <u>Daily Average</u>	<u>Monthly</u> <u>Total</u>	<u>Measured</u> <u>Daily Average</u>		<u>Monthly</u> <u>Total</u>
2159.0	June '77	1856.0	55680.	June '77	1270.0	38100
2044.6	July '77	2014.8	62459.	July '77	1626.0	50406
1789.6	Aug '77	1467.5	45493.	Aug '77	1022.5	31698
1472.7	Sept '77	1156.0	34680.	Sept '77	914.6	27438
1102.6	Oct '77	820.4	25432.	Oct '77	618.2	19164
686.7	Nov '77	473.1	14193.	Nov '77	313.4	9402
551.3	Dec '77	439.0	13609	Dec '77	649.0	20119
583.0	Jan '78	547.6	16976	Jan '77	800.0	24800
872.7	Feb '78	993.5	27818	Feb '78	1517.2	42482
1280.4	Mar '78	1239.1	38412	Mar '78	1241.0	38471
1609.9	Apr '78	1526.9	45807	Apr '78	1279.5	38385
1891.5	May '78	1506.7	46708	May '78	1148.0	35588
2159.0	June '78	2067.1	62013	June '78	1624.4	48732
Yearly Total 7/77-7/68			4.34×10^5	Yearly Total 7/77-6/78		3.87×10^5

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

The method proceeds as follows:

A_1 , the annual total solar energy received at normal incidence is given by

$$A_1 = \sum_{\text{year}} I_{Dn}$$

where

I_{Dn} = daily insolation received at normal incidence

$\bar{K}_1$ is defined as

$$\bar{K}_1 = \frac{I_{Dn}}{I_{on}}$$

where

I_{on} = daily insolation received at normal incidence outside atmosphere

and

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

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

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

$\bar{K}_1$ is related to $\bar{K}_H$ through the polynomial, and is equal to

$$.5548(\bar{K}_H)^3 + .9949 (\bar{K}_H)^2 - .4218 \bar{K}_H + .0526 = F(\bar{K}_H)$$

$\bar{K}_H$ can be determined from existing data

$$\bar{K}_H = \frac{H(\text{measured})}{H_o}$$

where

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

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

since

$$I_{Dn} = I_{on} \bar{K}_1 = I_{on} F(\bar{K}_H) = \frac{24}{\pi} w_s r I_{sc} F(\bar{K}_H)$$

then

$$A_1 = \frac{24}{\pi} I_{sc} \sum_{\text{year}} r w_s \cdot F(\bar{K}_H)$$

The $\sum_{\text{year}}$ can be evaluated in segments, where each segment is made small enough to approximate a straight line. Within this segment $F(\bar{K}_H) = C_i$, where C_i is a constant that varies from segment to segment and is determined from the polynomial. The contribution to A_1 from any segment becomes

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

The term $\sum_{\text{year}}^{\text{segment}} r w_s$ is a weighted count of days occurring in the chosen $\bar{K}_H$ segment. With this weighted count the contribution of this segment to the quantity A_1 can be determined. Summarizing over all segments yields the total A_1 result.

Figure 8 shows the weighted $\bar{K}_H$ occurrence frequency for Upton for two different time periods and illustrates the effect of climatic changes upon this weighted sum. Figure 9 shows the long term occurrence frequency of $\bar{K}_H$ 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 9 long term average values for A_1 can be determined for these four locations. Results are summarized in Table 2.

Table 2

Locations	Long Term Annual Solar Energy Receiver at Nominal Incidence
Boston, Mass.	$3.51 \times 10^5 \text{ BTU-ft}^{-2}\text{-year}^{-1}$
New York, N.Y.	3.27
Sterling, VA	3.63
Charleston, S.C.	3.95

Table 3 shows values of A_1 as computed by William Dickinson and reported in reference 4.

Table 3	
Location	Long Term Annual Solar Energy Received at Normal Incidences (ref. 4)
Phoenix, AZ	7.98×10^5 BTU-ft. ² -yr. ⁻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, N.Y. can also be computed for each year for which good horizontal data is available. Figure 10 presents these results. Data for the 1960's is not computer accessible. A smooth curve has been passed through the data of Figure 10 suggesting long term seasonable changed. During the next decade Upton, N.Y. might anticipate receiving an average of 5.0×10^5 BTU-ft.²-yr.⁻¹ solar radiation at normal incidence.

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

Figure 1. $\overline{K_H}$, the ratio of daily average radiation measured on a horizontal to that received outside the atmosphere, versus time.

Figure 2. Solar radiation measured on a horizontal surface at Upton, N.Y. report by various authors and time periods.

Figure 3a. Measures values of $\overline{K_H}$ versus $\overline{K}$ grouped into bins and averaged for Upton, N.Y. 6/77 through 6/78 with least squares fit polynomial of 3rd order.

Figure 3b. Daily values of $\overline{K_H}$ and $\overline{K}$ plotted against fit polynomial from Figure 3.

Figure 4. Curve fit versus data from January 1978.

Figure 5. Curve fit versus data from March 1977.

Figure 6. Curve fit versus data from June 1977 and 1978.

Figure 7. Curve fit versus data from September 1977.

Figure 8. Weighted $\bar{K}_H$ occurrence frequency for Upton, N.Y. for time period 1950-58 and 1970-78.

Figure 9. Long term weighted $\bar{K}_H$ occurrence frequency for Boston, Mass; New York, N.Y.; Sterling, Va.; Charleston, S.C.

Figure 10. Computed annual normal incident solar radiation received at Upton, N.Y.