Studies on Measurement and Estimation of Solar Radiation*  
(1st Report, Process and Analysis of Measurements of Solar Radiation)  
at Kitami Institute of Technology

by Hiroshi BABA** and Kimio KANNAYAMA***

Measurements of solar radiation in the past five years from 1978 to 1982 at Kitami Institute of Technology were processed and analyzed, and it was then proved that there was a high correlation between the total solar radiation on a horizontal surface and the direct solar radiation on a normal surface to incidence which were both normalized by dividing by extraterrestrial solar radiation. From the frequency distribution of a number of days which was obtained by grading the daily total radiation on a horizontal surface every 2 MJ/m²·d of intensity, a limit value of the direct solar radiation on a normal was introduced in order to define a clear day on which it was possible to use solar energy and a cloudy day on which it was impossible to use solar energy. According to the results of data analysis, the limit value of the direct radiation on a normal, H* lim, on the borderline between such clear and cloudy days as above was about 3 MJ/m²·d, and the limit value of the total radiation on a horizontal, H* lim, which corresponded to H* lim, and the ratio of clear days to total days could be obtained as a monthly average over five years.

Key Words: Heat Engineering, Solar Energy, Total Radiation, Direct Radiation, Scattered Radiation

1. Introduction

To utilize solar energy, it is essential to clarify the characteristics of solar radiation sufficiently, and to do so it is necessary to continuously measure the solar radiation over a long period. Until now, global insolation has been observed at several meteorological observatories all over the country as a meteorological item. However, the measurements of only such global insolation as above are insufficient for heat engineering for using solar energy. In order to remedy this situation, and in connection with the Sunshine Project, the observation system of solar radiation was greatly improved. Consequently, an equation for estimating the total solar radiation on a horizontal surface from the number of sunshine hours has been presented, and then based on these results insolation maps have been made for the whole country. In the field of solar radiation observation, the direct radiation and the scattered solar radiation in addition to the total solar radiation on a horizontal surface are being measured at several places in Japan. As part of a program of research of solar energy, the authors (4), (5) have made hourly measurements of the total solar radiation on a horizontal surface (horizontal-total solar radiation in short), the direct solar radiation on a normal surface to the incidence (normal-direct solar radiation) and the total solar radiation on a tilted surface with 60 deg inclination angle from the horizontal surface (inclined-total solar radiation) on the roof of the heat engineering laboratory at Kitami Institute of Technology since the autumn of 1977. These measurements were useful for the performance evaluation of a number of solar heating systems. At the same time, focusing on the relation between the horizontal-total solar radiation and the normal-direct solar radiation of those three measurements, the measured results have been processed and analyzed in order to calculate the total solar radiation incident upon any tilted surface with various angles of inclination and direction. Since the measurements in the five years from 1978 to 1982 could be well processed and analyzed with the aid of a computer, the results are presented in this paper.

Nomenclature
h: solar altitude angle, deg  
A: solar direction angle, deg  
\( \phi \): latitude, deg  
\( \delta \): solar declination, rad  
\( \omega \): day angle of the earth from January 1st on revolution orbit,
rad

t : hour angle, rad
T : time, h
W : equation of time due to a longitude, h
e : equation of time due to revolution of the earth, h
Ip : solar constant (nearly equal 5023 kJ/m²h)

\( I_{HR} \) : hourly total solar radiation on a horizontal surface, kJ/m²h
\( T_{HR} \) : monthly average hourly total solar radiation on a horizontal surface, kJ/m²h

\( I_{ND} \) : hourly direct solar radiation on a normal surface to incidence ray, kJ/m²h

\( I_s \) : hourly scattered solar radiation, kJ/h

P : transmittance of atmosphere

\( K_{Dc} \) : ratio of normal direct radiation to solar constant (\( R = I_{ND}/I_p \))

\( K_{Te} \) : ratio of horizontal total solar radiation to extraterrestrial horizontal solar radiation

\( H_{ND} \) : daily direct solar radiation on a normal surface, MJ/m²d

\( H_{HR} \) : daily total solar radiation on a horizontal surface, MJ/m²d

\( R_{ND} \) : monthly average daily direct solar radiation within the rank, MJ/m²d

\( H_{HR} \) : monthly average daily horizontal total solar radiation within the rank, MJ/m²d

\( H_{ND} \) : limit value of daily normal direct solar radiation, MJ/m²d

\( H_{HR} \) : limit value of daily horizontal total solar radiation within the rank, MJ/m²d

Subscripts

\( I_{ND} \) : average value of the data of which direct solar radiation is more than zero

5 days : average value of the data for the upper five days in each month

max : maximum value in the rank

mean : average value in the rank

2. Fundamental Equation on the Solar Radiation

In order to introduce a relation equation for treating the solar radiation as an energy quantity, it is essential and also important to get the latitude and direction of the sun at any location and time, and to separate two components of the direct radiation and the scattered radiation from the total solar radiation, i.e., separation of the direct and scattered components.

In terms of latitude, solar declination and hour angle, the solar altitude and solar direction angle \( A \) are given by

\[
\sin h = \sin \delta \sin \phi + \cos \delta \cos \phi \cos t
\]

and

\[
\sin A = \cos \delta \sin t / \cos h
\]

where, solar declination \( \delta \) is

\[
\delta = 0.00098 \times \cos \omega - 0.000852 \\
+ 0.011635 \cos \omega - 0.001172 \cos^2 \omega \\
+ \sin \omega (0.048888 + 0.001208 \cos \omega \\
- 0.012897 \cos^2 \omega)
\]

Based on a number of the days \( n \) counted from January 1st on revolution orbit of the earth measured from the vernal equinox, \( \omega \) is obtained by Eq. (4).

\[
\omega = 2\pi (n - 80)/365 \quad (n > 80)
\]

\[
\omega = 2\pi (285 + n)/365 \quad (n < 80)
\]

The hour angle \( t \) is given by Eq. (5) to be equal to zero at southing time of the sun at the location, and assuming the hour angle for one hour to be equal to 15 deg (= 360 deg/24 h).

\[
t = \pi (T - 12 + W_e + e)/12
\]

where, sign of \( t \) is negative in the morning and positive in the afternoon, and \( T \) denotes time at the location.

In terms of the longitude, the equations of time due to longitude and revolution of the earth are given by Eq. (6) and Eq. (7) respectively.

\[
W_e = (L - 135)/15
\]

and

\[
e = 0.006938 + \cos \omega / 0.134940
\]

\[
- 0.014434 \cos \omega - 0.021273 \cos^2 \omega
\]

\[
+ \sin \omega (0.03087 + 0.330601 \cos \omega + 0.002474 \cos^2 \omega)
\]

The relation between solar altitude and solar direction on 21st each month at Kitami (43° 49'N, 143° 55'E) is shown in Fig. 1 as the result of calculation by Eq. (1) to Eq. (7).

Next, in terms of the direct and scattered components, the horizontal-total solar radiation is

\[
I_{HR} = I_{ND} \sin h + I_s
\]

Fig. 1 Solar altitude and solar direction at Kitami City
radiation and \( I_0 \) denotes the scattered solar radiation. The scattered solar radiation is widely changed by weather conditions, especially by a state of the cloud, and, assuming that the sky on a clear day has a characteristic of uniform scattering in accordance with Rayleigh's law, the scattered solar radiation can be calculated by Berlage's equation as follows:

\[
I_s = \frac{I_0 \sin h(1 - \frac{\sin \alpha}{\sin h R})}{2(1 - 1.4 \ln R)}
\]

where, the solar constant \( I_0 \) can be obtained by

\[
I_0 = 4.186 \text{W/m}^2 (1154 - 39 \sin \omega + 9 \cos \omega)
\]

where, \( R \), which is a function of transmittance of atmosphere, can be obtained by

\[
R = \frac{\sin \alpha}{\sin h R}
\]

Substituting Eq. (9) into Eq. (8), the horizontal-total solar radiation, \( I_{HT} \), yields

\[
I_{HT} = I_{HS} \sin h + \frac{I_0 \sin h(1 - R)}{2(1 - 1.4 \ln R)}
\]

If the correlation between \( I_{HT} \) and \( I_{ND} \) is known, the normal-direct solar radiation, \( I_{ND} \), can be obtained from data of \( I_{HT} \) which is easily available. And since the so-called direct-scattered separation can be done, it is possible to calculate the total solar radiation on a tilted surface, \( I_{HT} \). From this point of view, Figure 2 shows the relation between \( I_{ND} \) and \( I_{HT} \) which was calculated from Eq. (12) as a parameter of \( h \) and \( R \).

3. Measurement Method of Solar Radiation

On the roof of a one-storied building of our laboratory, since the autumn of 1977, three sorts of the solar radiation; the horizontal-total solar radiation, normal-direct solar radiation and inclined-total solar radiation on a tilted surface \( (\theta = 60^\circ, \alpha = 0^\circ) \) have been measured continuously. With respect to an instrument for the measurement, prior to July of 1981, two EKO pyranometers (MS-60) were used and, after August of 1981, two NICO pyranometers (MS-42) have been used for total radiation on the horizontal and the tilted surfaces respectively. For the measurement of the direct solar radiation, EKO pyrheliometer (MS-51) which was overhauled in August of 1981, has been used until now. These instruments are set on a table whose height is about 1 m above
the roof, and the results measured may slightly be affected by a shade of the surrounding buildings. Outputs from the pyranometers are led to an automatically balanced penrecorder (Tokokawa 3066) and to a digital recorder (Chino Procos V) through an integrator set in parallel, and then they are recorded as both analogue and digital values. Only the digital number is stored on the magnetic tape as an hourly value for the data-analysis aided by a computer in the following process.

For routine maintenance, a worker climbs the roof once a day at least to adjust the pyrheliometer for total radiation. In spite of such attention, the lead-wire breaks due to snow and freezing in winter and trouble due to stoppage of electric power is unavoidable. When no data of solar radiation can be obtained on account of integrator trouble, data integrated by a planimeter from a curve on the recorder chart are employed. In the data processing for five years, when an unusual number appears on the data, the value is checked by going back to the original chart recorded, and the data are treated as precisely as possible.

4. Results and Discussion

Figures 3 (a) and (b) show the original data of (1) the horizontal-total solar radiation, (2) total solar radiation on the tilted surface and (3) normal-direct solar radiation throughout the day on November 27th and 29th in 1980. On the 27th, a clear day, three sorts of the solar radiances are shown smoothly curved, but on the 29th, a cloudy day, they are violently changed by the influence of the cloud. With respect to the difference between the days, solar radiances on the 27th were 7982.0 kJ/m²d in horizontal-total radiation and 1664.7 kJ/m²d in normal-direct radiation, but, those on the 29th were 5241.8 kJ/m²d in horizontal-total and 3965.9 kJ/m²d in normal-direct radiation. That is, the horizontal-total radiation and normal-direct radiation on the 29th decreased to 65.7 % and to 23.8 % respectively of the values on the 27th.

Figure 4 (a) shows the total measurements of the horizontal-total and normal-direct radiations in January of the five years from 1978 to 1982, which were classified into five ranks according to solar altitude and plotted on the graph in Fig. 2. Due to low solar altitude in January, they are only plotted in a range of sin h < 0.5. ICOTY denotes the total number of the measurements and TOREL denotes a number of lost data because of power stoppage. The total number of measurements is 1625, so the measuring time averages 10.5 hours per day. The horizontal-total solar radiation is less than about 1750 kJ/m²h, the normal-direct solar radiation is also less than 3000 kJ/m²h, and the measurements are concentrated in the ranges of 0.3 < sin h < 0.5 of solar altitude and 0.7 < P < 0.8 of transmittance of the air. From this fact, it is known that there are many clear days in January with high transmittance. In the range of 0.1 < sin h < 0.3, there are a lot of measurements at P > 0.8, but at this rank of lower solar altitude, there are likely to be errors in the measurements. Similarly, Figure 4 (b) shows the results measured in June over the five years. The maximum possible number of sunshine hours in June is greater than this value in January, and there are a lot of data in the range of sin h > 0.7.

Fig. 5 Relation of the normalized radia-
tions Kc and Kd classified by sin h for one year

Fig. 6 Monthly average of the hourly horizontal total radiation for all the days
We can roughly see some relation between the horizontal-total and normal-direct radiations. However, no exact correlation between them can be recognized because of the broad scatter of the data.

Next, the relations between the hourly horizontal-total and the hourly normal-direct radiations divided by the extraterrestrial solar radiation are shown in Fig. 5 as a normalized value. The value of K_HF on the ordinate is the same as R given by Eq. (11), and K_HM on the abscissa is called a clear day index [2].

In Figures 5 (a) to (e), the measurements are divided into five ranks by the solar altitude similarly to the case of Fig. 4. Figure 5 (a) shows data measured just after sunrise and just before sunset, the values being very small. The measured K_HM becomes larger than unity affected by a scattered ray just after sunrise and just before sunset, and in this case the direct radiation equals mostly zero. Figure 5 (b) shows the solar radiations relatively early in the morning and relatively late in the afternoon. It seems that at the range K_H > 0.5 the value of K_HM is more than zero, and at the range K_H < 0.3, K_HM equals zero. At the range K_H > 0.3, good correlation between K_HR and K_HM is also recognized, the deviation being smaller than in the other cases.

Even when solar altitude approaches the maximum, K_HM is 0.75 constantly, and K_H increases with an increasing solar altitude, such as 0.5 in Fig. (b), 0.6 in Fig. (c) and 0.63 in Fig. (d). In Fig. (e), the deviation of the measurements decreases and the correlation is shown by a curve. When the results were checked, because of a large deviation on the data, the points distributed to the left or upper side in Figs. (b) and (c) were considered to have been caused by the influence of snow (i.e., the sensor of the pyranometer was affected by shading due to the snowfall on the glass-dome in the previous night), and on the contrary, the points distributed to the right or lower side were caused by the rapid motion of cloud in spite of the day being clear. In Figs. (c), (d) and (e), the data concentrate in the range 0.4 < K_H < 0.6 in the center of the figures and found the abscissa of K_H.

Figure 6 shows the hourly average of the horizontal-total solar radiation every month. The energy of the radiation increases in January, February and March successively. The values of April and May are smaller than those of March because the radiation does not increase as much in the daytime from 10 am to 1 pm. This fact means that there are many fine days in winter as a characteristic of the weather in Kitami district. In summer, the radiation in June is smaller than the value in July, and the radiation decreases gradually as the season changes from July to December. In the morning from 7 to 9 am, however, the solar radiation in September is slightly larger than that in August. From January to June, the time when the radiation reaches its maximum slightly lags from the time in July to December. This fact occurs because of an equation of time due to the revolution of the earth, and there is a time lag of about 30 minutes on the equation of time between February and October.

Figure 7 (a) shows the average value of the horizontal-total radiation over the five years excluding for the data whose direct radiation is zero. Fig. (b) shows the ratio of the number of the data used for the average of N(H/ND(INDO)) to total number of data N(H/ND(INDO)).

For positive use of solar energy, Fig. 7 (a) shows the quantity of the total solar radiation whose direct radiation is more than zero, and Fig. 7 (b) shows the rate at which such an amount of radiation can be expected each month. In this case, January becomes a value proportional to the solar altitude in each month, and is about 10% larger than the value averaged for all the data at peak time (11:00 - 12:00) as shown in Fig. 6.

In a time-range from 8 am to 3 pm, the rate that direct solar radiation larger than 0 kJ/m²·h appears is about 90 to 94% as the maximum in February, and, followed by 80 to 90% in March, and then by 70 to 85% in September, July, August,
October and November. The lower rate than the values as mentioned above is about 77 % in March, June, April and December, and the weather in these months must be less good. According to these results, the direct solar radiation appears with a probability of more than 75 % during 8 hours in the daytime, and the horizontal-total radiation shown in Fig. 7 (a) could be expected as a total energy.

Figure 8 shows the horizontal-total radiation for the upper 5-day in every month, i.e., a standard clear day. The solar radiation on the standard clear day is 40 ~ 50 % larger than the average solar radiation on all the days in the month shown in Fig. 6.

Figure 9 shows the average value of transmittance of the air on the standard clear day and on the upper 3-day in each month for the five years since 1978, whose horizontal total solar radiation is large. The transmittance of the air on the standard clear day is shown by a solid line and one on the upper 3-day by a dashed line. The transmittance from March to September is smaller than 0.7 and one from October to February is 0.7 ~ 0.8, on the standard clear day. The transmittances of the standard clear day and on the upper 3-day are close to each other in winter from October to March, but a difference between both values appears in summer. This fact means that good days such as clear days are a few in summer.

Figure 10 shows the frequency when distributing the daily horizontal-total solar radiation \( H_{\text{mt}} \) to each scale rank classified by every 2 MJ/m²d over five years, and the normal-direct solar radiation \( H_{\text{mr}} \) averaged in each scale rank. The abscissa indicates the scale rank of the horizontal-total solar radiation in each month by a unit of the ranges \( 0 < H_{\text{mt}} < 2.0, 2.0 < H_{\text{mt}} < 4.0, \ldots \), and the ordinate indicates the number of days and the value of \( H_{\text{mt}} \). Focusing on the frequency of distribution of \( H_{\text{mt}} \) in each month, the number of the scale ranks in winter is as small as five ranks in November and December, six ranks in January and February and nine ranks in March, and consequently, the frequency of the distribution concentrates in a specified rank of a higher position than the middle rank. This fact means kitami district has a favorable weather in winter. On the other hand, two peaks in the frequency of the distribution between April and October are found. Assuming that the scale rank at the boundary of two peaks corresponds to that of one grade lower rank than one half of the maximum rank, \( H_{\text{mt}} \) at the boundary can be defined as the limit value, \( H^*_{\text{mt}} \), of the horizontal-total solar radiation.

At the ranks of range \( H_{\text{mt}} < H^*_{\text{mt}} \), the amount of direct solar radiation is very small, and conversely, at the range \( H_{\text{mt}} > H^*_{\text{mt}} \), the direct solar radiation increases suddenly with an increasing grade of the rank. By the way, when the direct radiation is very small, there is no solar energy useful in the field of heat engineering. Hence, the cloudy day (the day of useless solar energy) when \( H_{\text{mr}} < H^*_{\text{mr}} \) and the clear day (the day of useful solar energy) when \( H_{\text{mr}} > H^*_{\text{mr}} \) will be defined.

Next, focusing on the normal-direct

![Fig. 9 Transmittance of the air on a standard clear day and on the upper 3-day](image-url)

![Fig. 10 Distribution frequency of the horizontal total radiation graded by MJ/m²d each and the average normal direct radiation for every rank](image-url)
solar radiation \( R_{ND} \) averaged in each rank, the maximum \( R_{ND} \) of these values is 17.6 MJ/m²d as the smallest value in January and 30.2 MJ/m²d as the largest value in July. This disagreement of \( R_{ND} \) values both in winter and summer comes from the difference in the maximum possible sunshine hours; for instance, in July it is 1.7 times as great as \( R_{ND} \) horizon. Hardly any difference among \( R_{ND} \) values from April to August can be seen, and \( R_{ND} \) averaged for this period is 28.9 MJ/m²d.

The values of \( R_{ND} \) in February, March, September and October are in the range 25.4 - 26.6 MJ/m²d, averaging 26.0 MJ/m²d. \( R_{ND} \) in August and September appears on the range of one rank under the maximum possible sunshine hours (This means that \( R_{ND} \) on a slightly cloudy day in the first half of the month is larger than that on a clear day in the latter half of the same month). This is an example in which the day of the maximum value of \( R_{ND} \) does not always correspond to the clearest day within the same month, and this special phenomenon is likely to happen in August and September.

If we intend to distinguish a cloudy day from a clear day according to the magnitude of \( R_{ND} \), in Fig. 10, the value of \( R_{ND} \) on the cloudy day is smaller than about 3 MJ/m²d. It seems that, judging from the results that the hourly normal-direct radiation on a clear day equals about 3 MJ/m²h as shown in Fig. 4, such an amount of solar radiation must also be available for use as the daily solar energy. Based on Figure 10 with this standpoint, the limit value of the horizontal-total radiation which is standard daily solar radiation available for use, the rate of clear days (ratio of the number of clear days to the total number of days in the month) and several kinds of solar radiations are respectively shown in Table 1. Assuming the limit value of the normal-direct radiation, \( R_{ND} \), equals 3 MJ/m²d, the limit value of horizontal-total radiation, \( R_{H} \), which corresponds to \( R_{ND} \), seasonally varies from 4 MJ/m²d in November and December to 14 MJ/m²d in June. In January, the rate of clear days is 0.627, and the horizontal-total and normal-direct radiations are 7.7 MJ/m²d and 11.2 MJ/m²d on average respectively. Through one year, it seems rather unrealistic that the rate of clear days in January is the minimum. Since the maximum possible sunshine hours in January are so short that their total number of the ranks are few, by lowering the value of \( R_{ND} \) to 2 MJ/m²d, the value of \( R_{H} \) as marked with a sign \( \Delta \) becomes 14.1 MJ/m²d, the rate of clear days is 0.813 and the horizontal-total radiation is 9.1 MJ/m²d on average. The values described above are not so different compared with the values of November and December, and this is more typical of the weather in the Kitami district. On clear days through the year, 21.3 MJ/m²d of the monthly average horizontal-total radiation, \( R_{H} \), in June is 3.6 times as great as 5.9 MJ/m²d in December, although, 17.1 MJ/m²d of the monthly average normal-direct radiation, \( R_{ND} \), in June is twice the value of 8.5 MJ/m²d in December. On the other hand, on a cloudy day, there is only a little difference between \( R_{ND} \) measured in the season centered around summer during March to September and one in winter during October to February, and thus the value of \( R_{ND} \) is a nearly constant small value through the year.

Figure 11 shows the monthly average horizontal-total radiation (solid line) and the monthly average normal-direct radiation (dashed line) every year. The horizontal-total solar radiation during March and September is about 450 MJ/m²mon, on average. The horizontal-direct and normal-direct radiations are almost the same; therefore, we may consider that the mean of the ratio of horizontal-direct and normal-direct radiations is about 1.

### Table 1

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan.</th>
<th>Jan²</th>
<th>Jan³</th>
<th>Jan⁴</th>
<th>Jan⁵</th>
<th>Jan⁶</th>
<th>Jan⁷</th>
<th>Jan⁸</th>
<th>Jan⁹</th>
<th>Janⁱ⁰</th>
<th>Jan¹¹</th>
<th>Jan¹²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit total radiation on a horizontal ( R_{H} )</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>Number of days ( N_{ND} )</td>
<td>94</td>
<td>125</td>
<td>116</td>
<td>123</td>
<td>92</td>
<td>103</td>
<td>92</td>
<td>106</td>
<td>90</td>
<td>97</td>
<td>113</td>
<td>116</td>
</tr>
<tr>
<td>Rate of clear days ( R_{ND} )</td>
<td>0.627</td>
<td>0.833</td>
<td>0.859</td>
<td>0.837</td>
<td>0.630</td>
<td>0.687</td>
<td>0.723</td>
<td>0.736</td>
<td>0.677</td>
<td>0.729</td>
<td>0.785</td>
<td>0.847</td>
</tr>
<tr>
<td>( R_{H}^{(mean)} )</td>
<td>7.7</td>
<td>7.0</td>
<td>10.3</td>
<td>14.7</td>
<td>17.9</td>
<td>19.0</td>
<td>21.3</td>
<td>19.2</td>
<td>17.7</td>
<td>15.5</td>
<td>11.2</td>
<td>7.7</td>
</tr>
<tr>
<td>( R_{ND}^{(mean)} )</td>
<td>11.2</td>
<td>9.1</td>
<td>12.7</td>
<td>12.5</td>
<td>15.0</td>
<td>13.8</td>
<td>17.1</td>
<td>17.0</td>
<td>15.1</td>
<td>16.9</td>
<td>13.1</td>
<td>11.1</td>
</tr>
</tbody>
</table>

### Figure 11

Monthly normal direct and monthly horizontal total radiation in every year.

\[ \text{Fig. 11 Monthly normal direct and monthly horizontal total radiation in every year} \]

\[ \text{\( R_{ND} = 3 \text{ MJ/m}^2 \text{d} \)} \]

\[ \text{\( \Delta R_{H} = 2 \text{ MJ/m}^2 \text{d} \)} \]

\[ \text{\( R_{ND} \): Normal-direct radiation} \]

\[ \text{\( R_{H} \): Horizontal-total radiation} \]

\[ \text{\( \text{Jan}^2, \text{Jan}^3, \text{Jan}^4, \text{Jan}^5, \text{Jan}^6, \text{Jan}^7, \text{Jan}^8, \text{Jan}^9, \text{Jan}^{10}, \text{Jan}^{11}, \text{Jan}^{12} \): Data for different months} \]
and this is about twice 220 MJ/m²/mon, the average for October and February. On the other hand, about the normal-direct solar radiation, 330 MJ/m²/mon for March and September is not so different from 260 MJ/m²/mon for October and February. This fact means that the horizontal-total radiation is seasonally affected by the solar altitude, but the normal-direct radiation is scarcely affected by the solar altitude. The yearly variation of the solar radiation in summer is more violent than in winter. As a special feature over the years, it can be seen that the horizontal-total radiation in July, 1978, is extremely large, the value for May and August of 1979 is pretty small, and the value for April and August of 1980 is relatively small.

In general, the yearly variation of the normal-direct radiation is larger than one of the horizontal-total radiation. The normal-direct radiations in August of 1980 and in June of 1981 are pretty small. On the former, the horizontal-total radiation also is small, and on the latter, only the normal-direct radiation is small and no horizontal-total radiation is different from that in the other year. This means that there were many slightly cloudy days and few clear days. Measurements of the normal-direct solar radiation on August 25th and on September 12th in 1981, failed due to the instrument being under repair.

5. Conclusions

From a point of view of heat engineering, the measured results of the solar radiation during the five years from 1978 to 1982 at Kitami Institute of Technology were processed, particularly focusing on the relation between the horizontal-total radiation and the normal-direct radiation, and the obtained results are as follows:

(1) No correlation between the hourly horizontal-total solar radiation and hourly normal-direct solar radiation could be clearly seen. However, the correlation between both values normalized by an extra-terrestrial solar radiation could be clearly seen.

(2) The monthly average daily horizontal-total solar radiation, $I_{ht}$, for five years was small in April, May and June, and, therefore, it seems generally that there were a lot of cloudy days in these seasons.

(3) The monthly average hourly horizontal-total radiation, $I_{ht}$, is except when the normal-direct radiation, $I_{nd}$, was zero, larger than that for all the data, $I_{ht}$, at peak on a daytime. There were many days whose $I_{nd}$ was more than zero, in January, February and March, and few of such days in April, May, June and December. The probability of is seasonally different from the days whose $I_{nd}$ is more than zero can be expected to be more than 75% through the year.

(4) The monthly average hourly horizontal-total radiation, $I_{ht}$, 5 days on the standard clear day, was $I_{ht} = 34$ & larger than the average value for all the days, $I_{ht}$, and the transmittance of the atmosphere on the standard clear day is in a range of 0.6 - 0.8.

(5) From the frequency distribution when processing the relation between the daily horizontal-total radiation, $I_{ht}$, and the daily normal-direct radiation, $I_{nd}$, if the $I_{nd}$ was classified into ranks ranged by every 2 MJ/m², then all the days every month could be divided into clear days or cloudy days in terms of the value of $I_{ht}$ on the day. The limit value of the horizontal-total radiation, $I_{ht}$, which corresponds to the limit value of the normal-direct radiation, $I_{nd}$, and the ratio of the number of clear days to all the days every month was obtained. As a result, even from the daily average horizontal-total radiation, the possibility of using solar energy on the day could be estimated.

(6) On the monthly average solar radiation measured over five years, the solar radiation in July of 1978 was very large, and, in contrary, that in August of 1980 was very small. The yearly variation of the normal-direct radiation was more violent than that of the horizontal-total radiation. From this fact, we can recognize that the former more sensitively reflects the weather conditions.

Processing the measurements with attention to the relation between the horizontal-total radiation and the normal-direct radiation, it is considered that in the field of heat engineering the procedure of dividing all the days into cloudy days and clear days must be significant, and could be applied in the use of solar energy.

References