# Estimation of instant solar radiation by using of instant temperature

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*An attempt has been made to correlate the recorded instant temperature and corresponding instant solar radiation of different days in hot season of Lucknow, India. The obtained graph for these data and also the obtained equation relating temperature and corresponding instant radiation have good correlation and are useful in predicting of solar radiation from instant temperature.*

**Key words:** *Instant solar radiation, Instant temperature, regression analysis.*

## Introduction

Instant solar radiation is considered as the most important parameter in the performance prediction of various solar devices. It may prove an important parameter for a building of design and agriculture. But the availability of such important data is very scarce and often not readily available. As a result, design of solar systems may not be proper for its efficient functioning [1, 2, 3]. Various relations have been developed to measure monthly mean global solar radiation with the help of different parameters. For example - the first attempt at estimating of solar radiation was due to Angdtrom, who suggested that it could be related to the amount of sunshine by a simple linear relation in following:

$$H_g/H_c = a + b(S/S_{max}) \quad (1)$$

where,

$H_g$= Monthly Average of the daily global radiation on a horizontal surface at a location in (KJ/m$^2$-day),
$H_c$= Monthly Average of the daily global radiation on a horizontal surface at the same location on clear day (KJ/m$^2$-day),
S= Monthly Average of the sunshine hours per day at the location (h),
$S_{max}$= Monthly Average of the maximum possible sunshine hours per day at the location, that is the day length on a horizontal surface (h), and
a, b= Constant obtained by fitting data.
J.K. Page [4] suggested a modification in this relation and replaced $H_c$ by $H_o$ - the monthly average of the daily extra-terrestrial radiation which would fall on a horizontal surface at the location under consideration.

$$H_g/H_o = a + b(S/S_{max}) \quad (2)$$

Values of a and b have been obtained frm many cities in the world by Lof et al [5] and many other researchers. Further, various equations were introduced for many estimation of average value of solar radiation. Various modifications were made for these relations by introducing different parameters. Reddy's correlation [6] and Gopinathan's correlation [7] are very important relation for the estimation of monthly average of daily global solar radiation.

Variation of monthly global solar radiation throughout the year and the relation of monthly global solar radiation with monthly mean temperature have also been studied as it is given by Kovacs et al [8].

But the functioning of solar devices at any time depends on the solar radiation at that time i.e. the instant solar radiation. Some times when we want to get the value of instant solar radiation to test the functioning of the solar devices at that instant, the instruments for measuring solar radiation are not found. The main aim of this paper is to solve this kind of problems. Here an attempt has been made to obtain a relation between instant solar radiation and instant temperature, so that instant solar radiation can be estimated by measuring instant temperature using simple devices.

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### Development of correlation between instant solar radiation and instant temperatures

As stated earlier, there are a number of apparatus, working at instant solar radiation. So, to estimate the working of such apparatus, value of instant solar radiation is required. But all the time resources are not found to measure the solar radiation. To solve such problems we may have tried to develop empirical relation between instant temperature and instant solar radiation.

The radiation of the sun reaching the earth surface has different values during the day. This fluctuation results from the earth's spin about its axis. There are a number of factors affecting the total solar radiation. For example these factors may be – wind velocity, cloud-cover, humidity, etc. Aim of the studies made here is to find out variation of instant solar radiation with temperature only. So, the dependence of instant solar radiation on different factors except instant temperature is neglected. To develop relation of instant solar radiation with instant temperature, data for instant solar radiation and instant temperature are needed.

So, the instant solar radiation and corresponding instant temperature for a number of days in the hot period at Lucknow has been recorded. Instant solar radiation has been recorded by using solarimeter and instant outside air temperature has been recorded using digital thermometer. General variation in radiation and temperature has been observed to be same for all the days. As an example, we are taking the observations of one particular day in the month of May.

Due to dependence on various factors the radiation is different for the same temperature on different day. Neglecting the dependence of radiation on other factors, we are giving here relation between temperature and radiation. The relation given here is for May 27, 2007. But the similar relations have been developed for other days of hot period for Lucknow. Table 1 gives the data for May 27, 2007 for Lucknow.

*Tab. 1. Instant solar radiation and instant temperature data.*
*$T_{MAX}$=40.6°C, $T_{MIN}$=26.1°C, $H_{MAX}$=51 %, $H_{MIN}$=35 %, Sun Rise =05:14, Sun Set =06:53*

| Time | Instant Temperature [°K] | Instant Solar Radiation [W/ m$^2$] |
|---|---|---|
| 7 : 30 AM | 304.5 | 240 |
| 8 :00 AM | 305.5 | 380 |
| 8 :30 AM | 306.5 | 460 |
| 9 :00 AM | 307.5 | 560 |
| 9 :30 AM | 308.5 | 600 |
| 10 :00 AM | 308.5 | 700 |
| 10 :30 AM | 309.5 | 760 |
| 11 :00 AM | 309.5 | 780 |
| 11 :30 AM | 310.0 | 840 |
| 12 :00 Noon | 310.0 | 840 |
| 12 :30 PM | 310.5 | 840 |
| 1 :00 PM | 312.0 | 840 |
| 1 :30 PM | 311.5 | 800 |
| 2 :00 PM | 312.5 | 680 |
| 2 :30 PM | 312.5 | 620 |
| 3 :00 PM | 312.5 | 500 |
| 3 :30 PM | 312.5 | 500 |
| 4 :00 PM | 312.5 | 360 |
| 4 :30 PM | 312.0 | 260 |
| 5 :00 PM | 311.5 | 160 |
| 5 :30 PM | 311.5 | 100 |
| 6 :00 PM | 310.5 | 40 |

The corresponding Radiation Vs Temperature graph for the data is given in fig. 1.

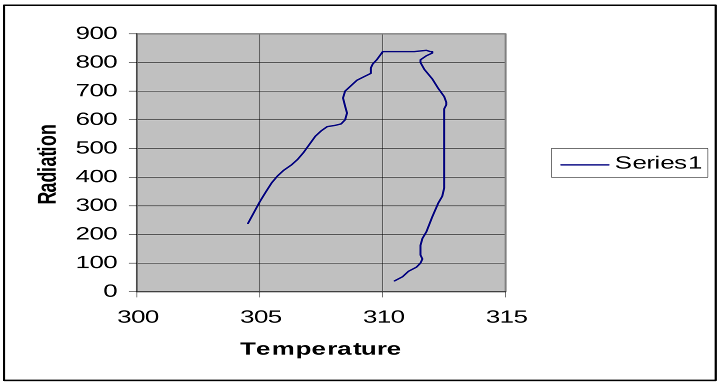


*Fig. 1. Instant solar radiation versus instant temperature for May 27, 2007.*

As it is clear from the graph, there are two values of radiation for some given temperature. So, we can not get the radiation as a single valued function of temperature for these data. To get the radiation as a function of temperature, we break the data at the turning point and get relation of instant solar radiation with instant temperature for morning hours and evening hours separately.

### Relation for morning hours

To develop relation of instant solar radiation with instant temperature for morning, data from 7.30 AM to 11.00 AM are taken. These data are given in tab. 1. The radiation Vs temperature graph for morning hour data (from 7.30 AM to 11.00 AM) is given in fig. 2.

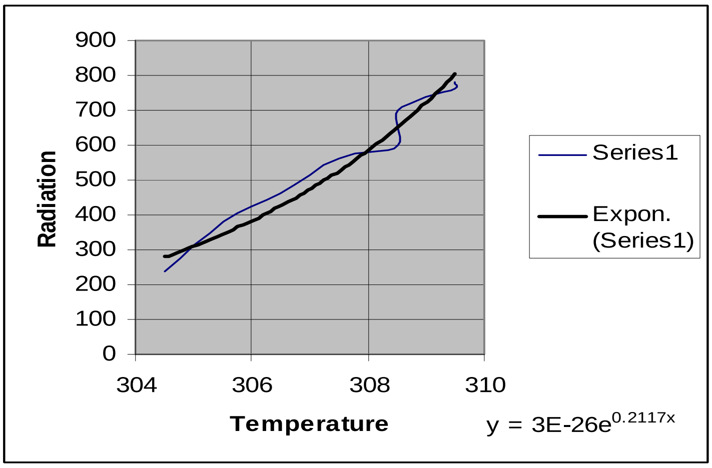


*Fig. 2. Variation of instant solar radiation and instant temperature from 7.30 AM to 11.00 AM.*

The corresponding equation (radiation Vs temperature) obtained from the computer is

$$R=3E\text{-}26e^{0.2117T} \qquad (3)$$

where R is the instant solar radiation and T is the instant temperature.

For manual calculation of the relation, we have used the process of regression analysis as it is given by the exponential relation of the type:

$$y=AB^{x} \qquad (4)$$

where A and B are constants.

Taking log on both sides of Equation (4), we get,

$$\log y = \log A + x \log B \qquad (5)$$

Putting log y = Y, log A = a, log B = b in Equation (5), we get,

$$Y = a + xb \qquad (6)$$

From Equation (6) we get,

$$\Sigma Y= \Sigma a + \Sigma bx$$

or $$\Sigma Y= na + b\,\Sigma x \qquad (7)$$

and $$\Sigma xY=\Sigma ax + \Sigma bx^{2}$$

or $$\Sigma xY= a\Sigma x + b\Sigma x^{2} \qquad (8)$$

Taking x = Temperature = T and y = Radiation = R, we get the required data for $x, y, Y, x^2$ *and* $Yx$ from tab. 2.

*Tab. 2. Data for x, y, Y, $x^2$ and Yx from 7.30 AM to 11.00 AM for n=8*

| Time | Instant Temperature (T=x) [°K] | Instant Solar Radiation (R=y) [W/m²] | $Y=\log_{10} y$ | $x^2$ | Yx |
|---|---|---|---|---|---|
| 7 : 30 | 304.5 | 240 | 2.380211 | 92720.25 | 724.7743 |
| 8 :00 | 305.5 | 380 | 2.579784 | 93330.25 | 786.1239 |
| 8 :30 | 306.5 | 460 | 2.662758 | 93940.25 | 816.1353 |
| 9 :00 | 307.5 | 560 | 2.748188 | 94556.25 | 845.0678 |
| 9 :30 | 308.5 | 600 | 2.778151 | 95172.25 | 857.0597 |
| 10 :00 | 308.5 | 700 | 2.845098 | 95172.25 | 877.7127 |
| 10 :30 | 309.5 | 760 | 2.880814 | 95790.25 | 891.6118 |
| 11 :00 | 309.5 | 780 | 2.892095 | 95790.25 | 895.1033 |
| | Σx=2460 | Σy=4480 | ΣY=21.7671 | $\Sigma x^2$=756474 | ΣYx=6695.589 |

Substituting the values from table 2 in Equation (7) we get

$$21.7671 = 8a + 2460\,b \tag{9}$$

Substituting the values from table 2 in Equation (8) we get

$$6695.589 = 2460a + 756474\,b \tag{10}$$

From Equations (9) and (10) respectively, we get,

$$2.720888 = a + 307.5\,b \tag{11}$$

$$2.721784 = a + 307.5098\,b \tag{12}$$

Subtracting Equation (12) from Equation (11) will be

$$0.0009 = 0.00976\,b$$

So, $b = 0.091906$

Substituting value of b in equation (11) we get

$$a = 2.720888 - 307.5\,(0.091906)$$
$$= -25.5403$$

So,

$$Y = -25.5403 + x\ (0.091906)$$

Now,

$$\log_{10} A = a$$
$$A = 10^a$$
$$A = 2.88204\,(10^{-26})$$

and

$$\log_{10} B = b$$
$$B = 10^b$$
$$B = 1.23567995$$

We get,

$$y = 2.88204\,(10^{-26})\,(1.23567995)^x$$

or

$$y = 2.88204\,(10^{-26})\,e^{0.211622755x} \tag{13}$$

Substituting x = T and y = R in Equation (13).

we get,

$$R = 2.88204\,(10^{-26})\,e^{0.211622755T} \tag{14}$$

Table 3 gives the value of Y measured and calculated from the equation and percentage error. This is an effort to test the validity of the equation.

*Tab. 3. Value of Y measured and calculated from the equation and percentage error.*

| Y (from measured values) | Y (calculated from equation) | Difference of the two Y values | Percentage Error |
|---|---|---|---|
| 2.380211 | 2.445077 | -0,062967 | -2.72522 |
| 2.579784 | 2.536983 | 0,042801 | 1.659092 |
| 2.662758 | 2.628889 | 0,033869 | 1.271952 |
| 2.748188 | 2.720795 | 0,027393 | 0.996766 |
| 2.778151 | 2.812701 | 0,03455 | -1.24363 |
| 2.845098 | 2.812701 | 0,032397 | 1.138695 |
| 2.880814 | 2.904607 | -0,023793 | 0.82591 |
| 2.892095 | 2.904607 | 0,012512 | -0.43263 |

As seen from the table 3, the percentage error is very small; the equation obtained may be taken as valid equation. We may also test the validity of equation by curve tracing process, as shown in fig. 3.

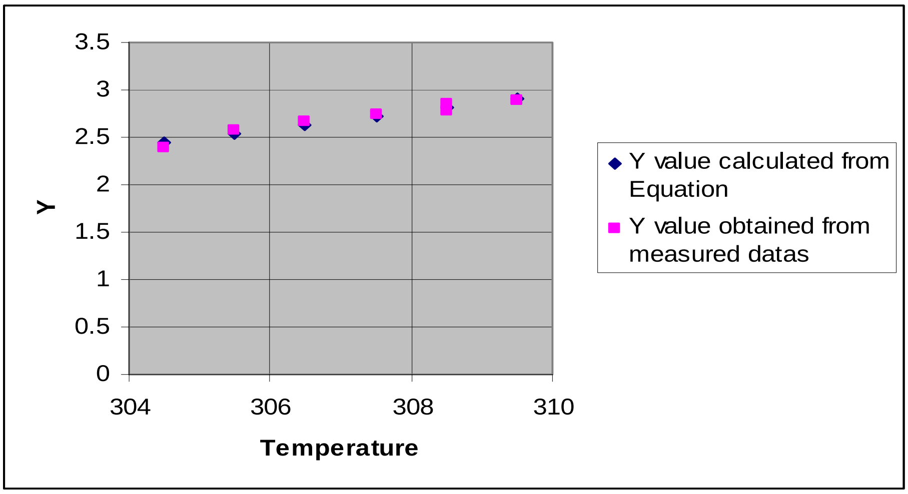


*Fig. 3. Value of Y calculated from equation and obtained from measured data from 7.30 AM to 11.00 AM.*

From fig. 3, it is clear that equation is valid for the calculation of instant solar radiation by using the known values of instant temperatures.

### Relation for afternoon hours

To develop relation of instant solar radiation with instant temperature for evening hours, data from 2:00 PM to 6:00 PM are taken. These data are given in tab. 1. The radiation Vs temperature graph for evening hour data (from 2:00 PM to 6.00 PM) is given in fig. 4.

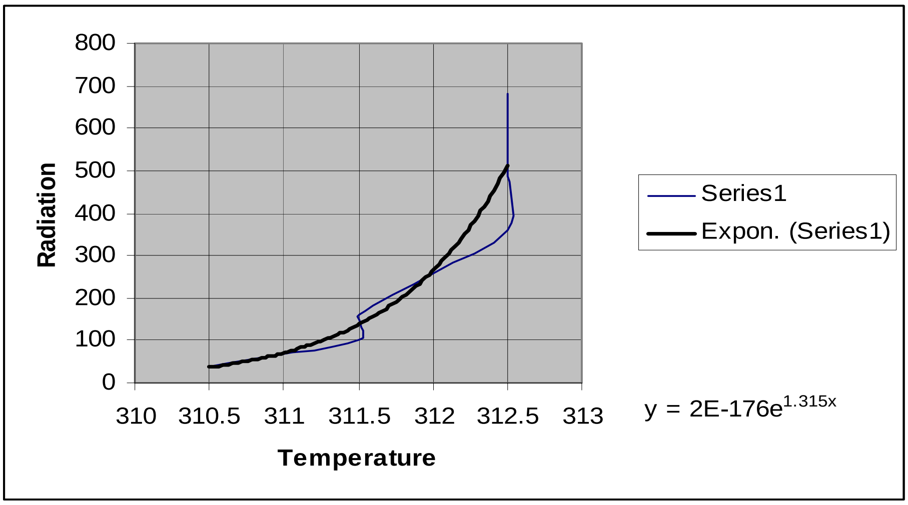


*Fig. 4. Variation of instant solar radiation and instant temperature from 2.00 PM to 6.00 PM.*

The corresponding equation (radiation Vs temperature) obtained from the computer is

$$R = 2E\text{-}176e^{1.315T} \tag{15}$$

Where R is the instant solar radiation and T is the instant temperature.

For manual calculation of the relation, we have used the process of regression analysis. As, it is clear from the studies for morning hour data, for development of relation there is need of data *for x, y, Y,* $x^2$ *and Yx*. These data are given in tab. 4.

*Tab. 4. Data for x, y, Y, x2 and Yx from 2.00 PM to 6.00 PM for n=9.*

| Time | Instant Temperature (T=x) [°K] | Instant Solar Radiation (R=y) **[W/m²]** | $Y=\log_{10} y$ | $x^2$ | Yx |
|---|---|---|---|---|---|
| 2 :00 | 312.5 | 680 | 2.832508913 | 97656.25 | 885.1590352 |
| 2 :30 | 312.5 | 620 | 2.792381689 | 97656.25 | 872.4281265 |
| 3 :00 | 312.5 | 500 | 2.698970004 | 97656.25 | 843.4281264 |
| 3 :30 | 312.5 | 500 | 2.698970004 | 97656.25 | 843.4281264 |
| 4 :00 | 312.5 | 360 | 2.556302501 | 97656.25 | 798.8445315 |
| 4 :30 | 312.0 | 260 | 2.414973348 | 97344.00 | 753.4716849 |
| 5 :00 | 311.5 | 160 | 2.204119983 | 97032.25 | 686.5833746 |
| 5 :30 | 311.5 | 100 | 2.000000000 | 97032.25 | 623.0000000 |
| 6 :00 | 310.5 | 40 | 1.602059991 | 96410.25 | 497.4396273 |
| | Σx=2808 | Σy=3220 | ΣY=21.80029643 | $\Sigma x^2$=876100 | ΣYx=6803.976909 |

Substituting the values from Table 4 in Equation (7) we get

$$21.80029643=9\,a + 2808\,b$$

or $$2.422255159= a + 312\,b \tag{16}$$

Substituting the values from Table 4 in Equation (8) we get

$$6803.976909 = 2808\,a + 876100\,b$$

or $$2.4230687 \;= a \;+\; 312.001 \tag{17}$$

Subtracting Equation (17) from Equation (16)

$$0.000813541 = 0.001424501\,b$$

so, $$b= 0.57110571$$

Substituting value of b in Equation (16) will be

we get,

$$a = -175.7627264$$

*so,*

$$Y= -175.7627264 + (0.57110571)\,x$$

Now,

$$\log_{10}A = a$$
$$A = 10^a$$
$$A = 1.7269\,(10^{-176})$$

and

$$\log_{10}B = b$$
$$B = 10^b$$
$$B = 3.724823598$$

we get,

$$y = 1.7269\,(10^{-176})\,(3.724823598)^x$$

or

$$y = 1.7269\,(10^{-176})\,e^{1.315028008x} \tag{18}$$

Substituting x =T and y = R in Equation (18)

we get,

$$R = 1.7269\ (10^{-176})\ e^{1.315028008\ T} \qquad (19)$$

Table 5 gives the value of Y measured and calculated from the equation and percentage error. This is an effort to test the validity of the equation.

*Tab. 5. Values of Y measured and calculated from the equation and percentage error.*

| Y (from measured values) | Y (calculated from equation) | Difference of the two Y values | Percentage Error |
|---|---|---|---|
| 2.832508913 | 2.707807975 | 0.124700938 | 4.402490568 |
| 2.792381689 | 2.707807975 | 0.084583714 | 3.029077719 |
| 2.698970004 | 2.707807975 | -0.008837971 | -0.327457165 |
| 2.698970004 | 2.707807975 | -0.008837971 | -0.327457165 |
| 2.556302501 | 2.707807975 | -0.151505474 | -5.926742793 |
| 2.414973348 | 2.42225512 | -0.007281772 | -0.301525979 |
| 2.204119983 | 2.136702265 | 0.067417718 | 3.058713599 |
| 2.000000000 | 2.136702265 | -0.136702265 | -6.83511325 |
| 1.602059991 | 1.565596555 | 0.036463436 | 2.276134389 |

As seen from the table 5, the percentage error is very small; the equation obtained may be taken as valid equation. We may also test the validity of equation by curve tracing process, as shown in fig. 5.

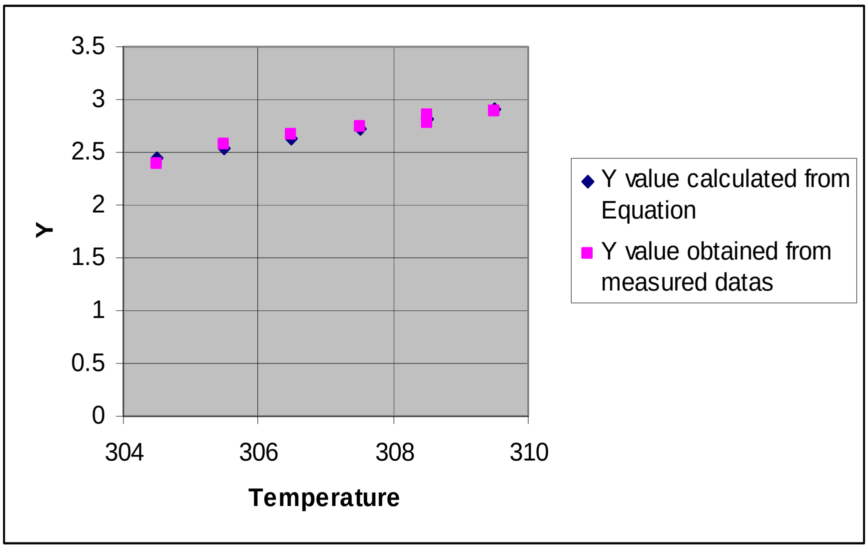


*Fig. 5. Values of Y calculated from equation and obtained from measured data from 2.00 PM to 6.00 PM.*

From fig. 5, it is clear that equation is valid for the calculation of instant solar radiation by using of known values of instant temperatures.

For subsequent development of such type of empirical relations, the effects of sky clearness index, cloud cover and wind velocity may also be taken into account in developing the relationship.

## Conclusion

Solar radiation including its instant values and sunshine hours are important data for design and efficient functioning of various solar thermal and photovoltaic devices. For Lucknow, India, values of instant solar radiation and instant outside air temperature have been recorded for a number of days throughout the year. An attempt has been made to develop equations for morning and evening hours to calculate instant solar radiation from instant temperature data for sunny hot periods. The developed equations show very good correlation with measured results for almost every day of the hot periods. This is clear from calculated percentage error and also from Y vs temperature curves.

Efforts are being made to evolve such equations for all round the year. Also, the effects of sky clearness index, cloud cover and wind velocity will be taken into account in developing further relationships. These developed equations may be useful for estimation of instant solar radiation from the known values of instant temperatures and other meteorological parameters.

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