Radiation On Collector Program

1 - Introduction

The Radiation On Collector program is used to estimate the solar radiation energy incident on a collector based on: 1)the direction the collector is aimed, 2) time of year, 3) position on the earth, 4) altitude of the collector, and 5) the area of the collector.

The tool is best used for determining the effect of changing the orientation (tilt and azimuth) of the collector on the radiation received.

Examples of the kind of problems this tool can help with:

> How much less radiation energy will fall on a collector that is aimed SE than a collector that is aimed in the ideal due south direction? And, how does this vary with collector tilt angle and season of the year?
>
> How much energy will I lose if the collector is shaded from 11 am to noon?
>
> How will tilting the collector more steeply effect the solar energy available in each month of the year?
>
> Which collector will have the most solar energy incident on it over a year: A horizontal collector, or a collector tilted at an angle equal to latitude?
>
> If my collector only gets sun from 11 am to 3 pm, how much energy will I lose compared to a full day?

The program provides two reports:

> **Day Report** – This shows the hour by hour radiation on the collector for the date you input.
> **Year Report** – Shows the total radiation on the collector for one day of each month.

Note that Radiation On Collector shows radiation for a fully sunny day. It does not account for clouds, pollution, fog, …

This manual and the program are written with the northern hemisphere in mind. If you live in the southern hemisphere, you probably already know how to adapt to north centric tools?

2 - Installing the Program

The program runs on Windows computers.

No installation is really necessary.

Download the program executable from this page:
www.builditsolar.com/Tools/RadOnCol/radoncol.htm

Place the executable file in any convenient directory,

Run the program by double clicking the executable.

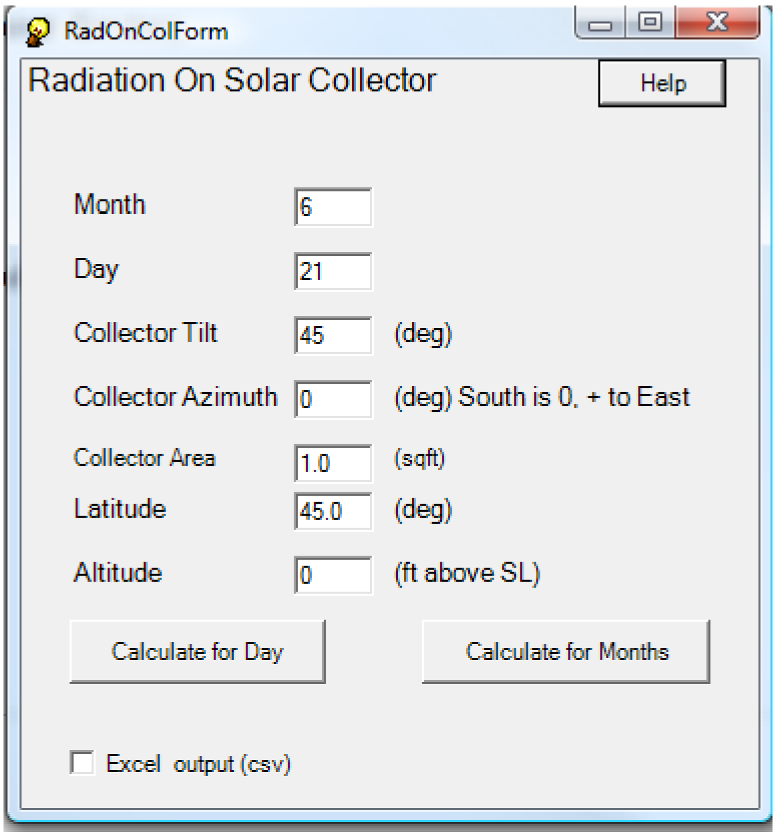
> Note 1: If you do not already have the "dot Net" package from Microsoft on your computer, you will need to download and install this from Microsoft.
> You can find it here ... But, most computers will already have it installed.

Note 2: Under Vista, you will get a message saying that the publisher (thats me) could not be verified, and asking if you still want to run the program. This is because I am not registered with Microsoft (and have no idea how to register). Uncheck the "always ask" box, and click the "run anyway" box (or not).

3 - Running the Program

To run Radiation On Collector, just double click it the program file you downloaded.

This input form will come up:



Fill in the required inputs (see below for more explanation of the inputs).

Then click on "Calculate for Day" to produce hourly output for the date entered.

Or, click on "Calculate for Months" to produce output by month for the year.

You will be asked for the file name you want the output to go to. The output file is a standard text file, and its best to use the file extension ".txt" – for example: "MyCollector.txt" – this way it will be associated with a program on your system to display text files.

You can look at the output with any text editor (e.g. NotePad, Word, ...).

Note that there is also a check box to produce output for a spread sheet. This allows you to easily graph the output in any spreadsheet that accepts .csv (Comma Separated Values) files.

4 - Explanation of Inputs

These are the inputs required to run Radiation On Collector

Month: The month of the year as a number from 1 (January) through 12 (December).

Day: The day of the month as a number from 1 to 31

Collector Tilt: The tilt of the collector in degrees **from horizontal**

Examples: For a vertical collector, enter 90 degrees, for a horizontal collector, enter 0 degrees, and for a collector tilted at 60 degrees to the ground, enter 60 degrees.

Collector Azimuth: This is the direction that the collector faces.

Due south is 0 degrees

Directions to the East of South are entered as plus numbers, and directions to the West of south are entered as negative numbers.

Examples: Due south = 0, SE = +45, SW = -45, East = +90, West = -90

Collector Area: This is the collection area of the collector in square feet.

Example, for a 4 ft by 10 ft collector, enter 40.

Latitude: This is the latitude of the collector location in degrees.

Example: If you live in Bozeman, MT enter 46 degrees

Look up latitudes of cities...

Altitude: The altitude of the collector above sea level in feet

The most common input errors made are:

Entering the collector azimuth. This must be the angle between south and the direction the collector is aimed with eastern directions being positive and western directions being negative.

A collector aimed due south is entered as 0, a collector aimed due east is entered as 90, and a collector aimed due west as -90.

Entering the tilt of the collector as the angle from vertical instead of horizontal. A vertical collector has a tilt angle of 90 degrees (not 0 degrees). Tilt is the angle between the ground and the collector.

5 - Explanation of Outputs

There are quite a few outputs provided, but the one you usually are interested in is the last column, ITotal. This is the total radiation on the collector surface.

The other outputs are provided to give a better understanding of why ITotal is what it is.

Day Report Outputs:

Time Hour – The hour of the day. This is solar time – that is, the sun will always be due south at noon. This will differ some from your local time – you can find your local time for solar noon here ...

SUN OUTPUTS **(The sun position and solar radiation intensity throughout the day)**

Sun Azimuth – The azimuth angle to the sun. South is 0, and the azimuth angle at solar noon will will always be zero.
Angles to East of South are positive (due East is +90 degrees), angles to the west of South are negative (due West is -90 degrees).

Sun Elevation – The angle of the sun above the horizon in degrees.
Negative values in the early or late day indicate that the sun is below the horizon.

Direct Radiation– The direct radiation from the sun in BTU per hour per square foot of area. Direct radiation is the radiation that is within 5 degrees of the direction of the sun.

Diffuse Radiation – The radiation coming from sky – this is light scattered by the atmosphere. In BTU per hour per square foot.

Total Radiation – The sum of the Direct and Diffuse radiation in BTU per hour per square foot.

COLLECTOR OUTPUTS **(Radiation energy incident on the collector surface throughout the day)**

Horizontal Total Radiation – The total radiation falling on a horizontal surface in BTU per hour per square foot. This is included because the energy incident on a horizontal surface is often used as a reference.

Incidence Angle – The angle that direct radiation from the sun makes with a normal to the collector surface in degrees. This angle is 0 if the sun rays come in perpendicular to the collector surface.

Direct Radiation – The direct solar radiation incident on the collector in BTU per hour per square foot. This value is equal to the cosine of the incidence angle times direct solar radiation.

Diffuse Radiation – The diffuse radiation that incident on the collector surface in BTU per hour per square foot. The diffuse radiation comes from the whole sky, so the diffuse radiation incident on the collector depends on the fraction of the sky that the collector can "see" – for a vertical collector this is half of the sky, and for a horizontal collector it is the full sky.

Total Radiation (ITotal) – The sum of the Direct Radiation and the Diffuse Radiation in BTU per hour per square foot. This is usually the output of most interest in that it is the total solar energy that is incident on the collector surface.

Year Report Outputs:

The Year Report shows the total energy incident on the collector for one full day for each month. Where the day of the month is the "Day" value you input on the input form.

Month – The month of the year numbered 1 (January) through 12 (December)

Day – The day of the month for which the incident energy totals are shown.

SUN OUTPUTS **(providing the position of the sun in the sky and the intensity of the solar radiation)**

Direct Normal Radiation – The total direct radiation from the sun for the full day in

BTU per sqft.

Diffuse Radiation – The total diffuse radiation from the sun for the full day in BTU per square foot.

Total Radiation – The sum of the Direct and Diffuse radiation for the full day in BTU per square foot.

COLLECTOR OUTPUTS **(providing the radiation levels on the collector surface)**

Direct Radiation – The total direct solar radiation energy incident on the surface of the collector for the full day in BTU per square foot.

Diffuse Radiation – The total diffuse solar radiation energy incident on the surface of the collector for the full day in BTU per square foot.

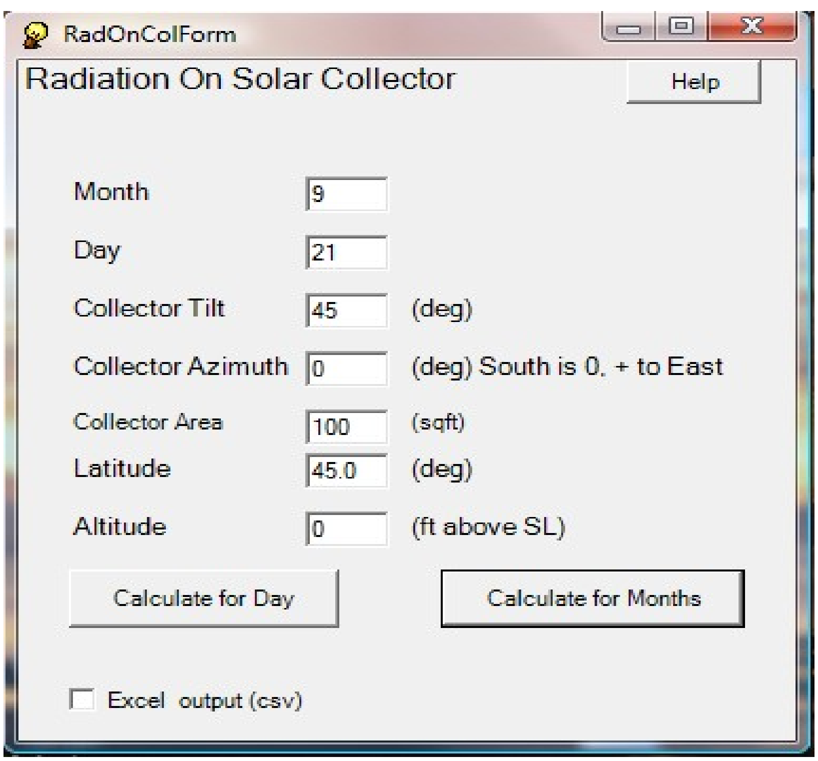
Total Radiation – The sum of the Direct and Diffuse radiation for the full day in BTU per square foot. This is often the column you will be most interested in because it is the total energy incident on the collector surface for the full day.

6 - Examples

This section provides a couple examples for the program.

Example 1: A simple south facing collector tilted at latitude:

This is for a collector at latitude 45 degrees.
The day report will be for 9/21 (September 21) – the fall equinox.
The collector is tilted up 45 degrees from the ground plane, and is facing due south (0 azimuth).
The collector area is 100 square foot.
The collector is located near sea level.
This is the filled in input form for example 1:



Day Report:

Solar Radiation on Collector for day of: 9/21

Collector Area: 100.0 (sqft)

Collector Azimuth: 0.0 (deg) measured from South, + is to East

Collector Tilt: 45.0 (deg) measured from horizontal

Latitude: 45.0 (deg)

Altitude: 0.0 (ft) Above Sea Level

Sun Rise: 6.0 (hr) Sunrise in solar time

Time	Sun					Collector				
Hour	Az	Elev	DirNormal	Diffuse	Total	HorzTot	IncidAng	Direct	Diffuse	ITotal
4	112.5	-20.4	0	0	0	0	90	0	0	0
5	101.0	-10.3	0	0	0	0	90	0	0	0
6	90.3	0.3	0	0	0	0	90	0	0	0
7	79.6	10.8	142	13	155	3977	75	3665	1123	4788
8	68.1	21.0	222	21	243	10023	60	11102	1761	12863
9	55.0	30.3	256	24	280	15328	45	18129	2034	20163
10	39.5	38.1	273	25	299	19414	30	23673	2168	25841
11	20.9	43.5	282	26	308	21985	15	27196	2233	29429
12	0.0	45.4	284	26	310	22863	0	28403	2253	30655
13	-20.9	43.5	282	26	308	21985	15	27196	2233	29429
14	-39.5	38.1	273	25	299	19414	30	23673	2168	25841
15	-55.0	30.3	256	24	280	15328	45	18129	2034	20163
16	-68.1	21.0	222	21	243	10023	60	11102	1761	12863
17	-79.6	10.8	142	13	155	3977	75	3665	1123	4788
18	-90.3	0.3	0	0	0	0	90	0	0	0
19	-101.0	-10.3	0	0	0	0	90	0	0	0
20	-112.5	-20.4	0	0	0	0	90	0	0	0
			-----	------	------	-----		-----	-----	-----
Day Total			2634	245	2879	164316		195932	20891	216823

Angles in degrees, Radiations in BTU/hr, DayTotal in BTU/day

1 BTU/hr-ft^2 = 3.152 W/m^2

The first column gives the hour of the day in solar time (sun due south at noon).

The columns 2 through 6 give the sun position in the sky and the direct, diffuse, and total solar radiation intensities.

Column 7 gives the radiation on a collector of the same size that is oriented horizontally (as a reference).

Columns 8 through 11 columns give the direct, diffuse, and total radiation on the collector.

The definitions of the individual outputs are given in the Explanation of Outputs section above.

The final column (11) gives the total radiation on the collector in BTU per hour. In many cases this is the only number you will be interested in, but the other outputs allow you to check that everything makes sense.

Just some random notes on the above output table:

> The sun elevations and azimuths are (and will always be) symmetric about solar noon.
>
> Since the date of the report is an equinox, the noon time solar elevation is equal to the latitude, and the day length is 12 hours – everywhere on earth!
>
> Since the collector faces due south, the incidence angles and radiation levels are symmetric about solar noon.
>
> Since this is the equinox, and the collector is tilted at an angle equal to the latitude, the incidence angle at noon is 0 (the sun is perpendicular to the collector surface). What would the noon incidence angle on this collector be at the winter solstice?

Year Report:

```
Month by Month Summary of Sun on Collector
(100% sunny weather)
  Collector Area:      100.0 (sqft)
  Collector Azimuth:     0.0 (deg) measured from South
  Collector Tilt:       45.0 (deg) measured from horiz
  Latitude:             45.0 (deg)
  Altitude above SL:     0.0 (ft) Above Sea Level
```

Date ----		Sun ----------------			Collector -----------------------		
Month	Day	Direct Normal	Di-fuse	Total	Direct	Difuse	Total
1	21	1933	112	2045	154013	9580	163593
2	21	2407	144	2551	189902	12300	202202
3	21	2838	201	3039	209850	17197	227047
4	21	3090	301	3391	203099	25695	228794
5	21	3217	390	3608	191256	33323	224580
6	21	3268	437	3706	184105	37328	221433
7	21	3117	424	3541	185151	36165	221317
8	21	2906	353	3260	192351	30149	222501
9	21	2634	245	2879	195932	20891	216823
10	21	2241	162	2404	178264	13866	192130
11	21	1856	117	1973	148325	9958	158283
12	21	1632	94	1726	131614	8003	139617
Sum		31140	2981	34121	2163862	254457	2418319

Radiation in BTU/day

The first column is month: 1 (January) through 12 (December)

The 2nd column is the day of the month for which output is shown.

Columns 3 through 5 give solar direct, diffuse and total radiation for *one full day*.

Columns 6 through 8 give the direct, diffuse and total radiation on the collector surface for *one full day*.

Note that the outputs are the incident solar energy for ***one sample day*** in each month, not for the full month.

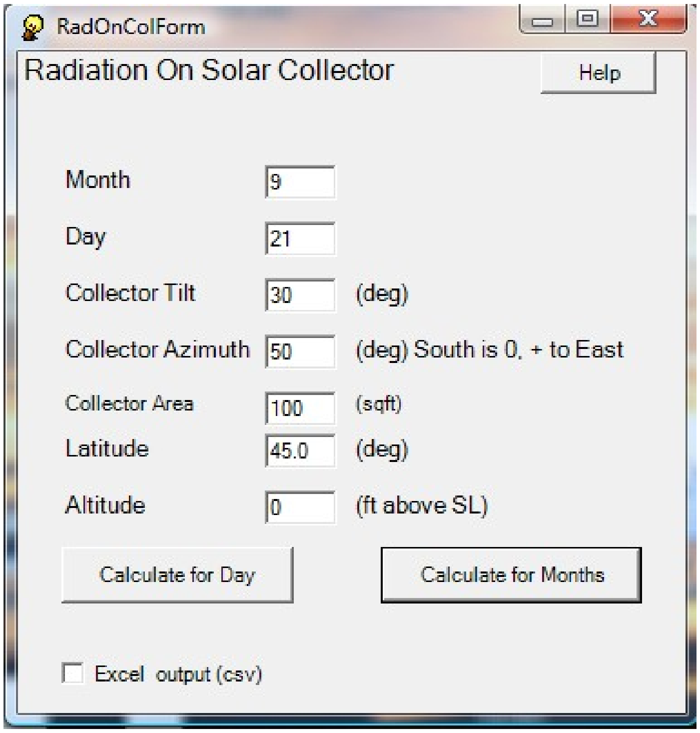
Looking at this example, you might wonder why the incident energy is not the same for the spring and fall equinox. They differ a bit because the earth to sun distance varies through the year, making the sun a bit more intense on the spring equinox than the fall equinox.

Example 1 was a south facing collector and is very straightforward. The radiation levels could be looked up in the tables provided in many solar books. Example 2 looks at a case that is not nearly as easy to tackle with tables or rules of thumb.

Example 2: A more complex situation

Using the same location as Example 1, suppose your roof faces 50 degrees east of south, and has a slope of 30 degrees. You would like to place the collector flat on the roof so that you don't have to build a fancy rack to give the collector the ideal azimuth and tilt, and so your neighbors don't have to look at a not so pretty installation. The question is how much less energy would you collect with this non-optimal azimuth and tilt?

Looking at the same 9/21 date as was used in example 1 – the inputs are:



The Day Report for Example 2:

Solar Radiation on Collector for day of: 9/21

```
  Collector Area:         100.0 (sqft)
  Collector Azimuth:       50.0 (deg) measured from South, + is to East
  Collector Tilt:          30.0 (deg) measured from horizontal
  Latitude:                45.0 (deg)
  Altitude:                 0.0 (ft) Above Sea Level
  Sun Rise:                 6.0 (hr) Sunrise in solar time
```

Time	Sun					Collector				
Hour	Az	Elev	DirNormal	Diffuse	Total	HorzTot	IncidAng	Direct	Diffuse	ITotal
4	112.5	-20.4	0	0	0	0	90	0	0	0
5	101.0	-10.3	0	0	0	0	81	0	0	0
6	90.3	0.3	0	0	0	0	67	0	0	0
7	79.6	10.8	142	13	155	3977	54	8355	1228	9582
8	68.1	21.0	222	21	243	10023	41	16748	1925	18673
9	55.0	30.3	256	24	280	15328	30	22236	2223	24459
10	39.5	38.1	273	25	299	19414	23	25186	2370	27556
11	20.9	43.5	282	26	308	21985	24	25702	2441	28143
12	0.0	45.4	284	26	310	22863	33	23924	2463	26386
13	-20.9	43.5	282	26	308	21985	44	20119	2441	22560
14	-39.5	38.1	273	25	299	19414	57	14714	2370	17084
15	-55.0	30.3	256	24	280	15328	71	8345	2223	10568
16	-68.1	21.0	222	21	243	10023	85	2015	1925	3940
17	-79.6	10.8	142	13	155	3977	90	0	1228	1228
18	-90.3	0.3	0	0	0	0	90	0	0	0
19	-101.0	-10.3	0	0	0	0	90	0	0	0
20	-112.5	-20.4	0	0	0	0	90	0	0	0
			-----	------	------	-----		-----	-----	-----
Day Total			2634	245	2879	164316		167342	22836	190178

Angles in degrees, Radiations in BTU/hr, DayTotal in BTU/day

1 BTU/hr-ft^2 = 3.152 W/m^

Comparing the Example1 and Example 2 runs for 9/21:

The ITotal incident radiation is down from 216,823 BTU/day to 190,178 BTU/day, a drop of about 12%. It may well be more cost effective and look better to just increase the collector size rather than building a fancy rack to mount the collectors at the optimal angle.

Now lets see if the results are the similar for the other months by looking at the Year Report for Example 2:

Month by Month Summary of Sun on Collector

```
(100% sunny weather)
  Collector Area:       100.0 (sqft)
  Collector Azimuth:     50.0 (deg) measured from South
  Collector Tilt:        30.0 (deg) measured from horiz
  Latitude:              45.0 (deg)
  Altitude above SL:      0.0 (ft) Above Sea Level
```

Date ----		Sun ----------------			Collector -----------------------		
Month	Day	Direct Normal	Di-fuse	Total	Direct	Difuse	Total
1	21	1933	112	2045	104557	10472	115029
2	21	2407	144	2551	142615	13445	156061
3	21	2838	201	3039	178647	18798	197445
4	21	3090	301	3391	199349	28087	227436
5	21	3217	390	3608	207122	36425	243548
6	21	3268	437	3706	207899	40803	248702
7	21	3117	424	3541	201157	39532	240689
8	21	2906	353	3260	188992	32956	221948
9	21	2634	245	2879	167342	22836	190178
10	21	2241	162	2404	133298	15157	148455
11	21	1856	117	1973	100495	10885	111380
12	21	1632	94	1726	85622	8748	94370
Sum		31140	2981	34121	1917096	278145	2195240

Radiation in BTU/day

You can compare each month to the Example 1 Report. The winter months take the biggest hit – as much as 32% at the Winter Solstice. You can look at the Day Report for a winter month to get an idea why the drop is larger. It is primarily due to the low 30 degree tilt angle.

For a solar domestic water heating system, which collects its heat year round, the flat on the roof orientation is likely to be quite acceptable. For a winter space heating system, this orientation is getting questionable.

The usual rule of thumb for collector orientation is to face the collector due south, and for best year round collection, tilt it at an angle equal to the local latitude. For best winter collection add 15 degrees to the tilt and for summer applications, subtract 15 degrees from the tilt.

If you have a nice straightforward situation like Example 1, the the rules of thumb will serve you well. But, if you deviate very far from the optimal aiming, my experience is that its best to run Radiation On Collector rather than guess with rules of thumb. The results for orientations other than the recommended aiming angles can be quite surprising. For example, horizontal collectors (which are well off the rule of thumb orientation) do very well for summer applications.

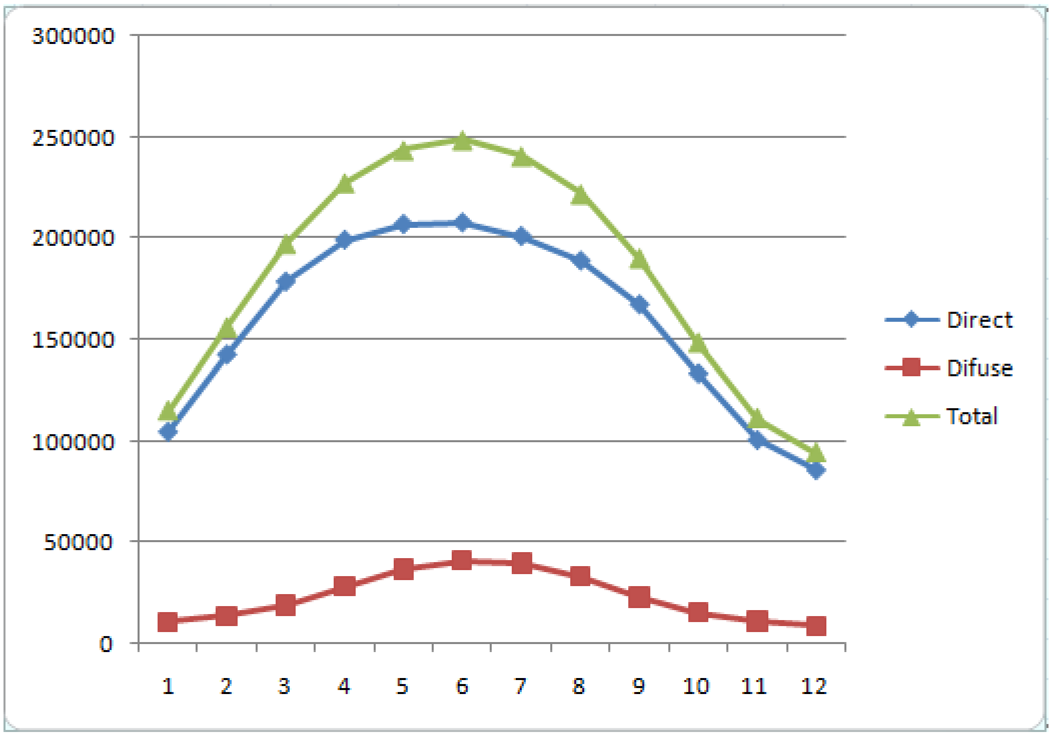
7 - Spreadsheet Graphs:

To graph the reports in a spreadsheet, check the "Excel Output (csv)" box, and then click on either the "Calculate for Day" or "Calculate for Months" button.

When asked for a file name, use .csv as the file name extension – for example: MyPlot.csv

If your computer has .csv files associated with your spreadsheet program, you can just double click your .csv file, and it will open in the spreadsheet. Then select the columns you wish to graph, and use the line chart spreadsheet tool to do the plot.

An example spreadsheet graph:



Other Examples:

There are lots of problems that Radiation on Collector can help with:

How much less radiation energy will fall on a collector that is aimed SW than a collector that is aimed in the ideal due south direction? And, how does this vary with collector tilt angle?

How much energy will I lose if my collector is shaded by a nearby building from 11 am to noon? Or, if my collector will only get sun from 11 am to 3 pm?

To figure out how much nearby buildings, mountains or trees will block sun on your collector, use the Solar Site Survey – Very Important!

How will tilting the collector more steeply effect the solar energy available in each month of the year?

Which collector will have the most solar energy incident on it over a year: A horizontal collector, or a collector tilted at an angle equal to latitude?

How much of a gain will I get if I manually adjust the tilt of the collector a few times a year?

Will a horizontal collector work well for heating my swimming pool?

If my roof ridge runs North-South, how well will I do if I place half my collector area on the East slope and half on the West slope?

8 - Metric Conversions

For the part of the world not stuck in the past like US, here are some conversions:

```
1 BTU/hr-ft^2 = 3.152 W/m^2
1 square foot = 0.093 square meters
```

9 - Limitations

- The program estimates SUNNY day radiation only.
- The effects of clouds, fog, pollution are not included.
- The program does not account for any obstructions (trees etc.) that might block the sun.
- The program does not take into account reflections off the ground (or anything else). This can make a significant difference for vertical or very steeply tilted collectors with a snow field in front of them. This is a reason to favor vertical or very high tilt collectors for winter space heating applications where snow cover is common.

The program is not for estimating the radiation an actual collector will receive over time, as it does not account for the effects of cloudy days.

10 - Origins

The algorithms used in the program come almost entirely from:

"Solar Thermal Engineering" by Peter J. Lunde
A good reference for people interested in solar energy.

11 - Validation

While I don't guarantee in any way that there are no bugs in the program, I have checked a number of cases against tables of radiation on tilted surfaces provided in the Lunde book and in other references, and the program has been in use for a couple years by many users.

I am interested in hearing about any anomalies you find – gary@BuildItSolar.com

12 - Disclaimer

I take no responsibility whatever for any errors in this program or the output it produces, or for any consequences of those errors to you. It is your responsibility to you to make sure the data you use is correct.

Legal Disclaimer...

13 - Source Code

The source code for this program is available subject only to the provisions of the GNU General Public License as published by the Free Software Foundation. The source can be downloaded here:

http://www.builditsolar.com/References/Source/sourcecode.htm

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