Online Solar Power Calculator
Prototype Version 0.4

Summary: *This is a preliminary report of an application still in its development phase that can to be used to help people install solar panels anywhere on the earth. The movement of the sun is calculated in the course of a day for any location and any specified date, from which the relative contributions of a set of up to 5 panels with different orientations are calculated between sunrise and sunset. The calculations take account of a number of factors detailed below.*

Such an application should be very useful not just in industrialized countries to cut CO_2 emissions, but in third world countries where many locations are not on a grid and use wood or other local sources of fuel causing pollution.

Introduction: The continuing fall in price of solar panels and associated technology has spurred a rapidly growing industry in solar power generation around the world. In addition to reducing CO_2 emissions, solar power has the advantage of being less intrusive than some other sources of renewable energy such as wind power, as solar panels can be installed on unused and unsuitable terrain, on roofs and in parking areas. In the latter case they also double as shelters for parked vehicles on hot summer days, and at night or during inclement weather they can also act as shelters when not generating any power.

The generation of solar power obviously depends on local weather conditions which can often be unpredictable. However, unlike wind power, solar power is more predictable in the sense that it can definitely be known when the sun is not available, i.e. at night. This would make storage easier to handle in cases for off-grid use. Third world countries can benefit greatly from solar power and associated energy storage facilities, as many locations are off-grid and are in mostly tropical, sub-tropical and desert areas where plenty of sunlight is available, so represent a potentially big market. Given suitable infrastructure, power generated in desert areas can be exported to regions with high power demands, an obvious case being countries in North Africa supplying power to Europe.
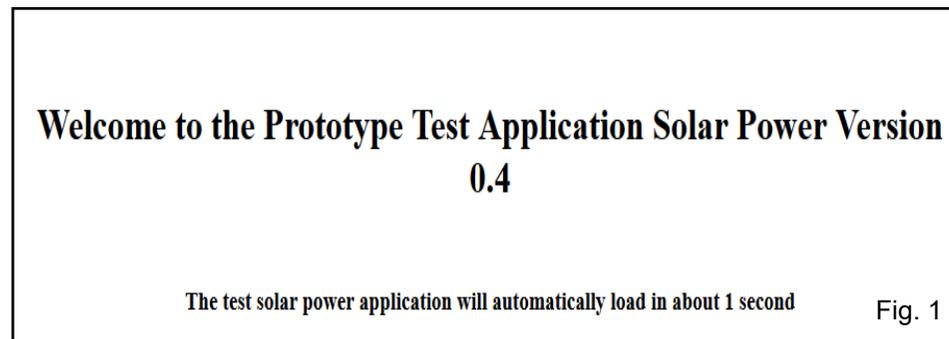
Technical details about how electrical power is generated from solar panels, inverted to the voltage and frequency of the country's grid and sold to it, or alternatively stored for use at night and other times for locations not on the grid are beyond the scope of this document, which only considers calculations involving the geographical and astronomical information.

This documents is a preliminary report of an application written in Java Server Faces 2.2, where all the astronomical, geographical and trigonometric calculations are performed on the server, and client-side code written is used to display output suitable for

the user and to determine the user's location, date and time zone. Account is taken of the variation of the distance of the earth from the sun, the average extinction of sunlight in yellow light at a wavelength of 8540 Ångström, and even the curvature of the earth, where the latter two can become significant at low solar altitudes.

The results are displayed in graphic form in a browser where the power is normalized such that a theoretical panel orientated horizontally will generate 1000 watts of electricity at sea level when the sun is at the zenith (unit air mass) and the earth is at its mean distance from the sun (1 Astronomical unit = 149.6 million km). This corresponds to a few degrees south of the equator. The normalized value of a 1000 was chosen for convenience because the solar constant is 1361 watts per square meter[1]. To calculate the power of a real solar panel depends on many factors outside the control of this application, in particular its area and efficiency. More technical details are given in the last section. Note that this is a preliminary report of an application that has not yet been fully tested and debugged.

Using the Solar Power Application: On entering "somedomain.com/solarpower"[2] in the browser the following page is displayed during initialization[3] in figure 1.

Welcome to the Prototype Test Application Solar Power Version 0.4

The test solar power application will automatically load in about 1 second

Fig. 1

This will be shown for typically about 1 second, but could be a few seconds depending on the connection.

The display then switches to the main page as is displayed in figure 2, except that all the input fields are initially blank. This is the start page for all operations of the application, and is the page to return to when specifying a new setup.

1 The solar constant is defined as the total power per square meter received from the sun above the earth's atmosphere when the earth is at its mean distance from the sun at 1 astronomical unit or 149.6 million km.

2 At the moment a domain name has not been allocated, once the application has been uploaded to a server hosting a suitable domain this will be changed.

3 All pages displayed in the bowser apart from popups show a provisional title at the top with the prototype version number. The titles on these pages will be changed after the code is put online and further developed.

For any location, you have the option of either entering the latitude and longitude in degrees, minutes and seconds in the input fields on upper the left, or in degrees and decimals of a degree in the input fields on the upper right. When entering degrees minutes and seconds, exact non-negative values are required. The radio buttons are used to select north or south for latitude, or east or west for longitude.

For the time zone the hours must be

Fig. 2

Solar Power Prototype Main Input Version 0.4

Enter Latitude: 32 ° 13 ' 19 "   ◉ N ○ S   Or as a decimal: 32.2218603 °

Enter Longitude: 110 ° 58 ' 1 "   ○ E ◉ W   Or as a decimal: -110.9669333 °

Enter Time Zone: -7 h 0 m   + east / − west   Or click for: [Time Zone & Location]

Enter elevation: 768   In meters   Or click to: [Clear Decimal Input]

[Submit]   [Reset]   [Form Info]   [Technical Info]

Click to enable/disable tooltips: ☐

entered as negative for west with minutes entered as a non-negative whole value. The elevation is entered in meters above sea level, as this is less critical, if it is not known an approximate values can be used, or at worst enter zero. The input must be non-negative and a whole number. For any elevations below sea level, zero must be used.

Alternatively, if you wish to use your own location rather than entering the above values manually, click the "Time Zone & Location" button on the right. The application will first read your computer's clock to display the time zone, followed by a popup window asking permission to get your location, and the message in green below the elevation field: "Searching for location..." is displayed. If permission is granted, after a short delay the application will attempt to use a location API to obtain your latitude, longitude and elevation. The latitude and longitude are automatically entered as signed decimal values in the input fields on the right, and converted to the rounded values in degrees, minutes and seconds and their associated radio button. If the latitude and longitude could not be obtained, an error message in red is displayed above the "Submit" button, and you will have to enter the values manually, as above. If the elevation could not be obtained, this is a non-fatal error with zero displayed, and depending on the browser, a warning message in blue may be displayed. In that case enter the elevation manually, if known, or use the default value of zero. Even if the latitude and longitude are obtained, their accuracy depends on your Internet connection. As the time zone is obtained from your computer's clock, make sure it is set for the correct time zone.

Once all the data are entered, you continue to the next page of inputs by clicking the "Submit" button. If an input field has an invalid value, either by being out of range or containing non-numeric characters, this page is redisplayed with one or more errors shown in red, and you will be unable to continue until all the errors have been corrected. Below the "Time Zone & Location" but-

ton on is the "Clear Decimal Input" button, which clears only the decimal values in the latitude and longitude input fields above, with the rest of the form being unaffected. The use of this is described below, and the "Reset" button clears all inputs and resets the radio button to their defaults for "N" and "E".

By clicking the "Form Info" button a scrollable popup window is displayed giving explanations of the function of the input fields and buttons on the page, as shown here in figure 3. By clicking the "Technical Info" button to its right, a scrollable popup window is displayed, as shown here in figure 4.
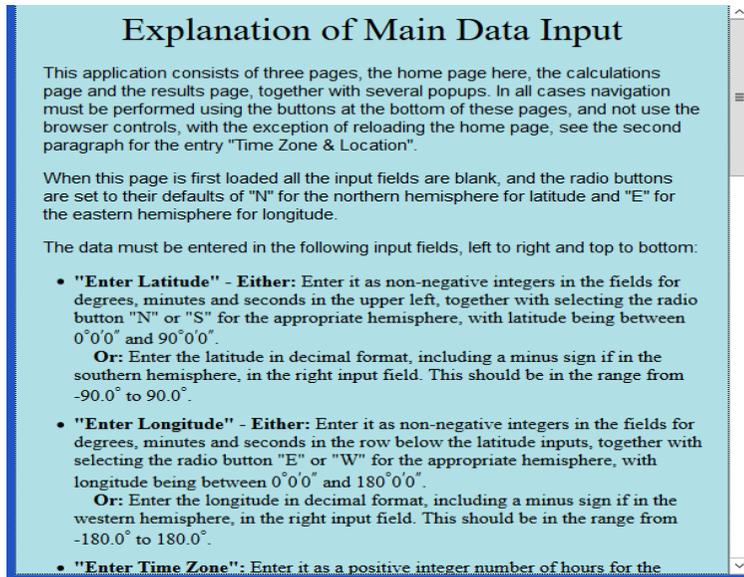

Explanation of Main Data Input

This application consists of three pages, the home page here, the calculations page and the results page, together with several popups. In all cases navigation must be performed using the buttons at the bottom of these pages, and not use the browser controls, with the exception of reloading the home page, see the second paragraph for the entry "Time Zone & Location".

When this page is first loaded all the input fields are blank, and the radio buttons are set to their defaults of "N" for the northern hemisphere for latitude and "E" for the eastern hemisphere for longitude.

The data must be entered in the following input fields, left to right and top to bottom:

- **"Enter Latitude"** - Either: Enter it as non-negative integers in the fields for degrees, minutes and seconds in the upper left, together with selecting the radio button "N" or "S" for the appropriate hemisphere, with latitude being between $0°0'0"$ and $90°0'0"$.
  Or: Enter the latitude in decimal format, including a minus sign if in the southern hemisphere, in the right input field. This should be in the range from $-90.0°$ to $90.0°$.

- **"Enter Longitude"** - Either: Enter it as non-negative integers in the fields for degrees, minutes and seconds in the row below the latitude inputs, together with selecting the radio button "E" or "W" for the appropriate hemisphere, with longitude being between $0°0'0"$ and $180°0'0"$.
  Or: Enter the longitude in decimal format, including a minus sign if in the western hemisphere, in the right input field. This should be in the range from $-180.0°$ to $180.0°$.

- **"Enter Time Zone"**: Enter it as a positive integer number of hours for the

Fig. 3

As stated above, the "Clear Decimal Input" button clears only the decimal inputs above it. This is because on clicking "Submit", the values in these fields take priority over the corresponding values in the degrees, minutes and seconds fields to the left with the radio buttons, and are stored on the server for later use, with the corresponding entries on the left not being used. This is even the case if a zero latitude or longitude are in the decimal fields. When these are cleared to a blank input, on clicking "Submit" the values on the left are converted to decimal values and copied to the decimal fields before being sent to the server. When data are entered manually, this feature enables you to use either input formats for latitude and longitude.
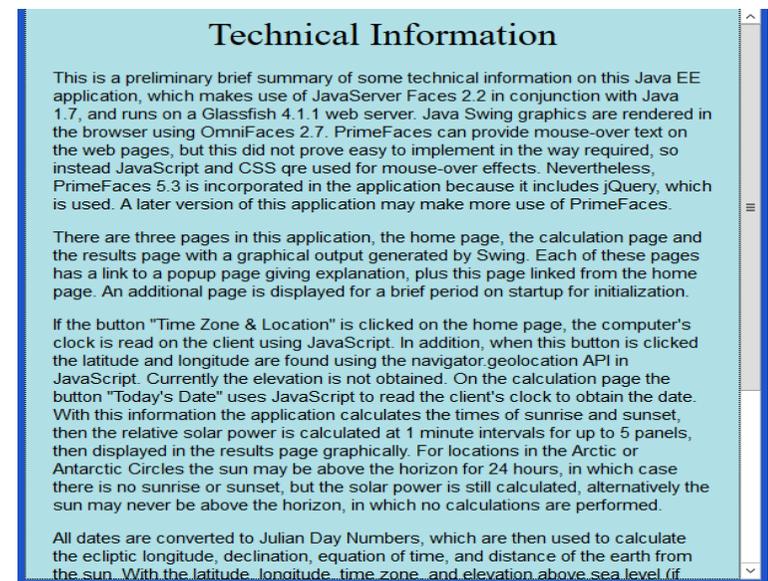
As mentioned earlier, when using the automatic option to get your location, you grant permission in the popup window. If you do not grant permission, a red error message is displayed indicating that this has been denied. In such a case either you have to enter the values manually, or reload the application from scratch so that figure 1 is displayed. The "Reset" button will not clear this.

Finally on this page, when the "Click to enable/disable tooltips" checkbox is checked, mouse-over tool-tips are displayed as the mouse is moved over input fields and buttons.

Technical Information

This is a preliminary brief summary of some technical information on this Java EE application, which makes use of JavaServer Faces 2.2 in conjunction with Java 1.7, and runs on a Glassfish 4.1.1 web server. Java Swing graphics are rendered in the browser using OmniFaces 2.7. PrimeFaces can provide mouse-over text on the web pages, but this did not prove easy to implement in the way required, so instead JavaScript and CSS qre used for mouse-over effects. Nevertheless, PrimeFaces 5.3 is incorporated in the application because it includes jQuery, which is used. A later version of this application may make more use of PrimeFaces.

There are three pages in this application, the home page, the calculation page and the results page with a graphical output generated by Swing. Each of these pages has a link to a popup page giving explanation, plus this page linked from the home page. An additional page is displayed for a brief period on startup for initialization.

If the button "Time Zone & Location" is clicked on the home page, the computer's clock is read on the client using JavaScript. In addition, when this button is clicked the latitude and longitude are found using the navigator.geolocation API in JavaScript. Currently the elevation is not obtained. On the calculation page the button "Today's Date" uses JavaScript to read the client's clock to obtain the date. With this information the application calculates the times of sunrise and sunset, then the relative solar power is calculated at 1 minute intervals for up to 5 panels, then displayed in the results page graphically. For locations in the Arctic or Antarctic Circles the sun may be above the horizon for 24 hours, in which case there is no sunrise or sunset, but the solar power is still calculated, alternatively the sun may never be above the horizon, in which no calculations are performed.

All dates are converted to Julian Day Numbers, which are then used to calculate the ecliptic longitude, declination, equation of time, and distance of the earth from the sun. With the latitude, longitude, time zone, and elevation above sea level (if

Fig. 4

After clicking "Submit" the application takes you to the page shown here in figure 5 if there are no errors. The latitude, longitude, time zone and elevation are displayed at the top, as entered in the previous page. The date defaults to 1 January 2000, and

below you can specify up to 5 of panels with different orientations in 3 columns. Initially the panels have zero tilts (horizontal), and azimuths of 180°, i.e. facing due south in the northern hemisphere, or 0°, facing due north in the south-ern hemisphere. Obviously when a panel is horizontal the azimuth has no meaning. The right most column is the contribution of each panel, which is initially zero.

Solar Power Prototype Calculation Input Version 0.4

Latitude: +32:13:19   Longitude: -110:58:01   Time zone: -07:00:00   Elevation in meters: 768

Enter date (yyyy-mm-dd): [2019] - [2] - [15]   Or click for: [Today's Date]

Panel Name	Panel tilt	Panel azimuth	Panel contribution
Panel A:	35	90	10
Panel B:	20	180	20
Panel C:	35	270	10
Panel D:	0	180	0
Panel E:	0	180	0

[Submit]   [Rescale]   [Home Page]   [Reset]   [Form Info]

Click to enable/disable tooltips: ☐

Fig. 5

Any valid date can entered in the input fields as shown as yyyy-mm-dd in the range 1 January 1900 to 31 December 9999. If an invalid date is entered, such as 2019-02.30, an error message is displayed in red above the "Submit" button when an attempt is made to submit the form. The application checks that the date is valid before it is used. Alternatively, on clicking the button "Today's Date", the current date in obtained from your computer's calendar and clock, assuming your computer's calendar is correctly set.

For specifying up to 5 panels named A, B, C, D and E with different orientations, the tilt is specified to be between 0° (horizontal) and 90° (vertical), and the azimuth to be between 0° (due north) and 359° (1° west of due north). The entered values must be non-zero exact numbers in degrees in these ranges. As stated above, the default azimuths are 180° in the northern hemisphere and 0° in the southern hemisphere. In the right most column the panel contributions are entered as numbers between 0 and 100. This is the relative contribution each panel makes to the total power generated, and can have a decimal input. When the form is submitted, these are converted to percentages for the calculations.

Figure 5 represents what might be a fairly typical configuration for 3 panels working in the northern hemisphere. Panel A has a tilt of 35° and an azimuth of 90° (due east), and contributes a relative amount of 10 units to the total power generated. Panel B has a tilt of 20° with an azimuth of 180° (due south by default) and makes a contribution of 20 units. Panel C has the same tilt and makes the same contribution as panel A, but has an azimuth of 270° (due west). Panels D and E make no contributions so are ignored. The input for the panels can be in any order. When the "Submit" button is clicked the values in the right most

column are converted to percentages, if they have not already been done so. The form can be submitted with no panels (all contributions are zero), one panel (one non-zero contribution which is converted to 100), and more than one contribution. The calculations for these cases are discussed for the output in figure 7 below.

To the right of the "Submit" button is the "Rescale" button. This will rescale the values in the right most column to percentages. Although these are converted anyway, this allows you to see the percentages. The "Home Page" button takes you back to the home page, as in figure 2, preserving your original values. The "Reset" button resets all the input values to their defaults. When the "Form Info" button is clicked a scrollable popup window is displayed as here in figure 6, giving information on this page, and as with the home page, when the "Click to enable/disable tooltips" checkbox is checked, mouse-over tooltips are displayed.

As before, any invalid inputs in the input fields will be displayed in red when "Submit" is clicked, and you will have to correct these before continuing to the next and last page that will show the output. If there are no errors, the text in green "A graph of solar power is being calculated..." will be displayed above the "Submit" button while the calculations on the server are being performed, then the output is displayed, like in figure 7.

Here figure 7 is an example of graphical output corresponding to the input data in figure 5. The horizontal axis is the local time over a period of 24 hours from midnight to midnight centered at 12:00 for the specified date, and the vertical axis is the relative power generated in the course of the day normalized to 1000 units. The blue, green and red curves are the powers as described below.

Explanation of Calculation Data Input

This page displays at the top the latitude, longitude, time zone and elevation from the home page. Latitudes north of the equator are positive, and those south of the equator are negative. Longitudes east of Greenwich are positive and west of Greenwich are negative. The date and up to 5 panel configurations can be specified for performing calculations based on the location specified in the home page.

The date input fields must be all integers as follows:

- The year must be between 1900 and 9999. By default it is 2000.
- The month must be between 1 and 12. By default it is 1 (January).
- The day of the month must be between 1 (default) and the last day of the month, where the number of days in a month is calculated from the Gregorian calendar taking leap years into account.

Up to 5 panels can be specified in the 3 columns with entries being integers except for the panel contribution, which can be decimals as follows:

- **Panel tilt:** This is in degrees from the horizontal with a range between 0° (horizontal) and 90° (vertical).
- **Panel azimuth:** This is in degrees with a range between 0° and 359°, where 0°, 90°, 180° and 270° correspond to facing north, east, south and west, respectively. This has no meaning when the tilt is horizontal. By default on page load in the northern hemisphere these fields are set to 180° (facing south) and in the southern hemisphere they are set to 0° (facing) north.
- **Panel contribution:** This is the relative contribution each panel makes to the total power generated based on the relative areas of the panels, and assuming each

Fig. 6

Under the graphical output are the times of sunrise, transit and sunset, together with the culmination in degrees. In the northern hemisphere north of the tropic of Cancer the culmination is above the southern horizon, as is the case here denoted by "S", in the southern hemisphere south of the tropic of Capricorn the culmination is above the northern horizon, and in the tropics it could be either depending on the latitude and the time of year. If the location is inside one of the polar circles, the sun may never rise on the date specified. In that case no plot is generated, and the culmination is negative.

Below this are the buttons and the tooltips checkbox, as described later. Depending on your browser's window, you may need to scroll down to see the bottom of the page. The size of the graphical part of the page can be changed by adjusting the width
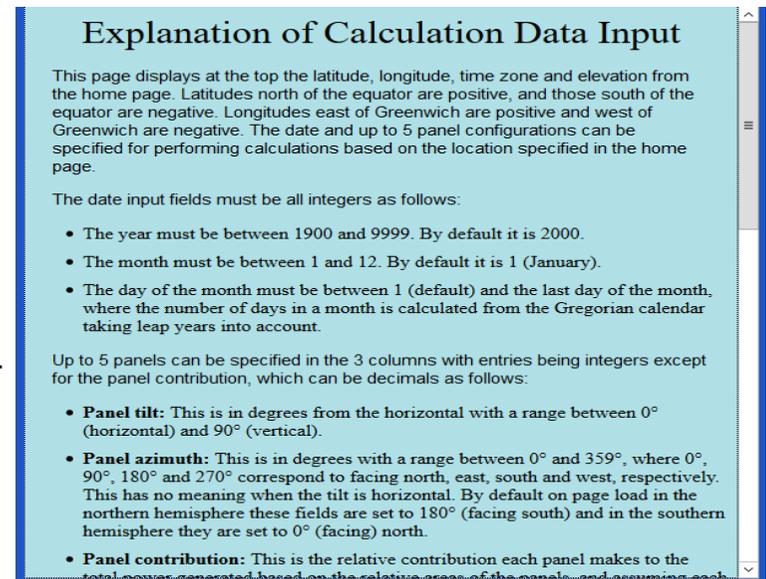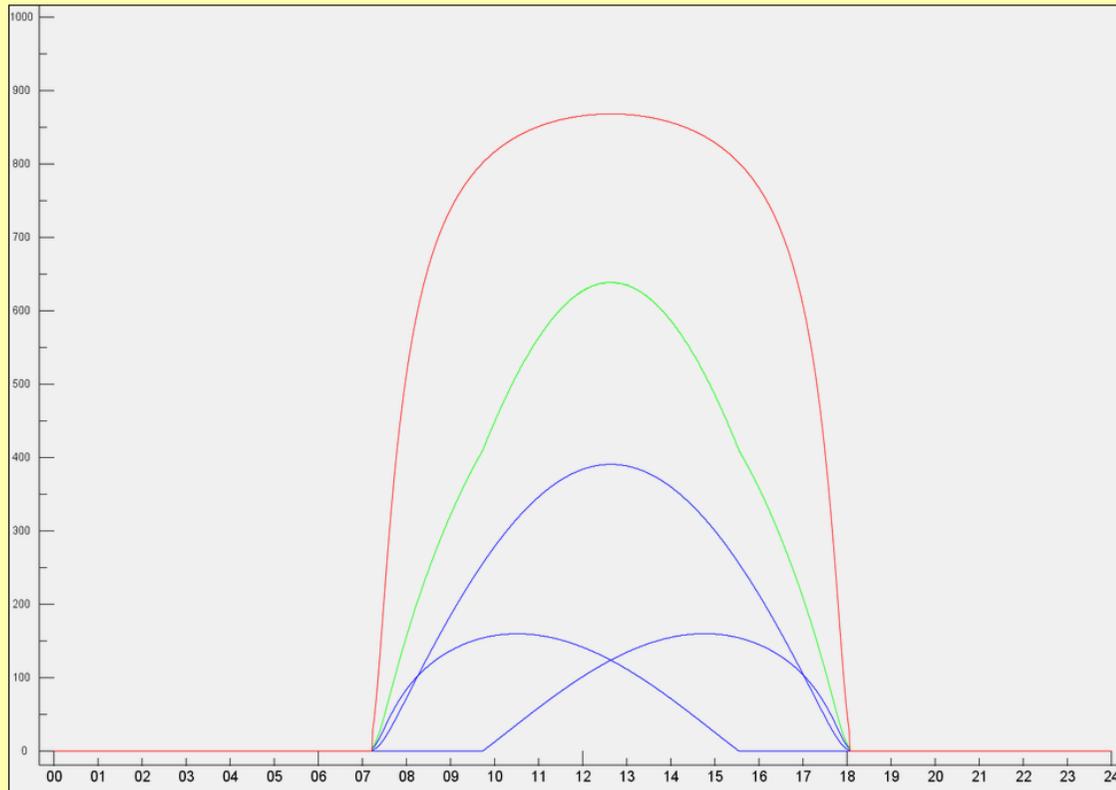
Fig. 7

The figure contains:

Solar Power Prototype Results Page Version 0.4

Sunrise: 07:05
Transit: 12:38
Sunset: 18:12

Culmination: 44:05 S

Calculation Page | Home Page | Graphics Info

Click to enable/disable tooltips: ☐

of the browser's window, with the aspect ratio of the graphics maintained.

The three blue curves show the relative contributions of the three panels mentioned above during the period between sunrise and sunset, taking into account the angle the sun illuminates each of the panels and their relative contributions, i.e. their relative areas, assuming equal efficiencies and no panels are in shadow. The variation of the absorption caused by the earth's atmosphere due to the sun's changing altitude in the course of the day affects all the panels equally.

The single green curve is the sum of the output from the individual panels, and the single red curve is the output produced by a panel of the same area as the individual panels combined that exactly track the sun, i.e. the sun is normal to the panel. The shape of this curve is due to the variation of the absorption of sunlight as the sun's altitude changes. Note that none of the blues curves can cross the green curve, although a blue curve can be tangent to the green curve, and the green curve can never cross the red curve, although they can be tangent.

As up to 5 panels can be specified, up to 5 blue curves can be displayed. However, the number of blue curves can be less than the number of panels, and even zero, if a panel is orientated in such a way that the sun never shines on it, such as facing in the

wrong direction so a not to receive the winter sun in the hemisphere in question. Note that if two or more panels have exactly the same orientations, it would be better to replace them by one panel with the sum of the relative contributions. If only one panel is specified, no green curve is shown. You can even specify no panels, which is the default with all the relative contributions set to zero. In that case only a red curve is drawn corresponding to a theoretical panel that exactly tracks the sun.

While the sun is below the horizon between midnight and sunrise, then again after sunset and the following midnight, only the red curve is shown with a zero value. Inside one of the polar circles on a date when the sun is 24 hours above the horizon the red curve is always non-zero, but the panel contributions may or may not always be non-zero, depending on their orientations.

Two situations can arise when local midnight does not take place between sunset and sunrise of the following day, i.e. midnight takes place before sunset or after sunrise. This can happen when the wrong time zone is specified, in particular if the wrong sign is provided. A warning is shown, no plot is displayed and you should return to the home page and correct the error. The other situation is a marginal effect that can happen at high latitudes close to or inside one of the polar circles when on some dates the sun will be above the horizon for almost 24 hours, but will briefly dip below the horizon, which may not correspond to the local midnight. At the moment this cannot be distinguished from an incorrect time zone.

At the bottom of the page is the button "Calculation Page". On clicking on it you are returned to the previous page in figure 5 where you can specify a different panel setup for a different date but at the same location. On clicking on the "Home Page" button you are returned to the home page as in figure 2, where you can start a new set of calculations from scratch for a different location. On clicking the "Graphics Info" button a popup is displayed giving information on the graphics display, as described above, and is shown here in figure 8. Finally, as previously, the "Click to enable/disable tooltips" checkbox when checked displays toolips as the mouse is moved over the screen.

Technical Overview: This is a brief description of some of the technical details for this application, which makes use of Java ServerFaces 2.2 (henceforth referred to as JSF) in conjunction with the Glassfish 4.1.1 web server. By clicking on the "Technical Info" button on the home page the popup shown earlier in figure 4 is displayed.

Nearly all the astronomical, geographical and trigonometric calculations

Graphics Display

This displays the relative solar power generated by one or more sets of panels at different orientations in the course of a day. The horizontal axis is the time of day from midnight through to the following midnight local time, and the vertical axis is the relative power generated in arbitrary units in the course of the day between sunrise and sunset. Up to three types of curves can be displayed as follows in **list A:**

1. BLUE: This displays the relative contributions for each of the panels with different orientations. If no panels are specified, this is not shown.
2. GREEN: If more than one panel is specified, this displays the sum of the contributions from the different panels.
3. RED: This displays the maximum relative power that can be generated from a panel that tracks the sun exactly in the course of the day, and depends on the average atmospheric extinction and the distance of the earth from the sun. It corresponds to the sum of the areas of the individual panels based on the percentages of their contributions. The blue and green curves, if present, can never cross this curve, although they may be tangent to it. If no panels are specified, only the red curve is shown.

Depending on the time of year, latitude, longitude and the time zone selected, five situations are possible as follows in **list B:**

1. Outside the arctic and antarctic circles the sun always rises in the morning and sets in the evening. Outside this period the power generated is zero.
2. Inside the arctic and antarctic circles the sun could be above the horizon for 24 hours, depending on the time of the year, in which case the red curve (A3) is non-zero for the full 24 hours, but the contributions from the panels depend on their
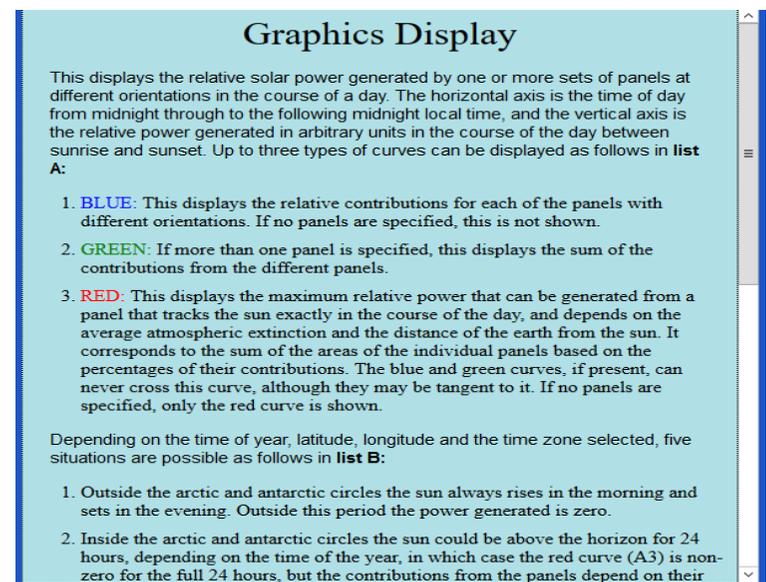
Fig. 8

are performed on the server using Java, with JavaScript in the browser used to control the display, obtain the user's location, time zone, etc. CSS3 Grid is used for much of the layout in the pages, including any possible error messages. It is assumed that the client's computer uses a modern browser with HTML5, and the computer's clock, calendar and time zone are all set correctly.

When the home page is first loaded and displayed, as shown earlier in figure 2, the input fields are initially blank with the radio buttons set to their defaults values of "N" and "E". The JavaScript session.Storage object is used to check if this is the first time the page has been loaded in the current browser's session. If it is, then the page is initialized to the default values, otherwise the previous values are displayed. Rather than entering the data manually, if the user clicks the "Time Zone & Location" button, the time zone is first obtained from the client's clock and written to its input field. A popup asking for permission to obtain the location is then displayed, and if permission is granted, then the navigator.geolocation.getCurrentPosition() method is invoked with a timeout of 10 seconds. If this is successful, a method is invoked that obtains the user's latitude, longitude and altitude, and writes the first two to the input fields on the upper right, and the altitude to its input field in the lower left. JavaScript is also used to convert the latitude and longitude in decimal format to degrees, minutes and seconds, and write these to the corresponding input fields on the left, with the radio buttons set accordingly. If after timeout the location could not be obtained, an error handler is invoked to display that the position could not be obtained, or permission is denied if the user had denied permission when asked to grant it. In all cases any previous inputs and error messages are first cleared.

After the data have been entered, either manually or by clicking the "Time Zone & Location" button, then when the "Submit" button is clicked, some JSF tags are used to check that data are valid and within range, such as for e.g. latitude lies in the range between -90° and +90°. If all the input are valid, they are sent to the server for later processing. If any errors are found, these are reported on the home page and the user will be unable to continue until they have been corrected. The decimal values of latitude and longitude in the two input fields in the upper right are sent directly to the server, and take priority over any corresponding values in the input fields on the left. If one of the decimal input fields is blank, JavaScript first converts the corresponding values in the left inputs fields to a decimal value, then copies it to the decimal field which is sent to the server. The "Clear Decimal Input" button is used to clear both input decimal fields instead of clearing them manually. As a zero in one of the decimal input fields is a valid input, this will be used instead of any data in the corresponding left input fields unless it is cleared to a blank. When the "Reset" button is clicked, the form is cleared with JavaScript in the browser and the data are also cleared on the server.

The buttons that open the popups use the JavaScript window.open() method to read the name of the file holding the text to be displayed, then opens the popup required. Although tooltips can be displayed with CSS3, as well as by using PrimeFaces, in this application it proved to be more satisfactory to use code making use of jQuery in conjunction with CSS3 and defining a new

HTML attribute from the link http://www.jquerybyexample.net/2012/09/tutorial-for-creating-simple-stylized-tooltip-using-jquery.html. This has been used elsewhere, such as at https://cs-cubed.com/physics/diatomic.html. However, as PrimeFaces incorporates jQuery, the 5.3 version of the jar file is included in the library. It is planned that later version of this application will make more extensive use of PrimeFaces. This feature is activated when the "Click to enable/disable tooltips" checkbox is checked. As the pages used to set up the calculations and showing the results also use popups and checkboxes, this information covers these pages.

The calculation page is displayed after the data have been successfully submitted from the home page, with the latitude, longitude, time zone and elevation entered previously being formatted and displayed at the top. Data entered here and from the home page are used to perform the calculations that will be displayed in the results page. As with the home page, CSS3 grid is used to layout the page and any error messages, and JSF tags are used to check that data entered in the input fields are valid before being sent to the sever when the "Submit" button is clicked, otherwise error messages are displayed and the user will have to correct them.. However, in the case of manually entering the date in their input fields, although the JSF tags are used to check that, say, the day of the month cannot be greater than 31, the date has to be fully validated on the server making use of the Gregorian calendar taking account of leap years. If the "Today's Date" button is clicked, the JavaScript Date object is used to read the date from the client's computer and enter it in the date input fields.

When the "Submit" button is clicked the entered data are sent to the server, if there are no errors a text message in green is displayed indicating to the user that calculations are being performed before the results are displayed. However, before these calculations, if any of the input fields for the relative contributions in the right column are non-zero, these are first converted to percentages on the server. The "Rescale" button invokes directly this method to do the rescaling without any further actions. This is simply to enable the user to see the rescaled values before continuing to the results. The "Home Page" button just returns the view to the home page from the server without any further actions, and the "Reset" button clears the data entered in the browser and on the server.

A separate Java class on the server handles most of the utilities, and is used to perform all the astronomical, geographical and trigonometric calculations after the required data have been passed to it. First the Julian Day Number (JDN) is obtained for 12:00:00 local time, i.e. noon, taking account of the time zone. Initial approximations are made for the JDNs of sunrise and sunset by subtracting and adding 0.25 of a day to it, respectively. This can be improved in a later version of the application. The mean anomaly is calculated for these three instants, from which the true anomaly, ecliptic longitude, declination of the sun and the equation of time are calculated. These are used to obtain more accurate times of sunrise and sunset, as well as the time and altitude (culmination) of the sun at transit, and are displayed immediately below the graphical output in the results page, but are not used in the detailed calculations discussed below. If the sun is above the horizon for 24 hours, the text "Sun never

sets" is displayed in place of the sunrise and sunset times, and similarly if the sun is below the horizon for 24 hours the text "Sun never rises" is displayed in place of the sunrise and sunset times. In the latter case no further calculations are performed and no graphical output is displayed, but the time of transit is still shown together with the culmination, which is negative. An approximation is to assume that the declination of the sun and the equation of time do not change much in the course of about 3 hours for these initial calculations.

The main calculations are now performed for each minute of time from midnight to the following midnight local time, of which there are 1441 points in time. For each time point the JDN is first obtained with the time zone accounted for, then from the JDN the mean anomaly, true anomaly, ecliptic longitude, declination of the sun (the right ascension is also obtained but not used), equation of time, hour angle and the sun's altitude. If the altitude is not negative, the air mass as a function of the elevation above sea level and sun's altitude are calculated, from which the extinction is obtained at 584 nm in yellow light. Account of the curvature of the earth is taken, which can be important at low solar altitudes and elevations well above sea level.. The distance of the earth from the sun is calculated using a simple Taylor's series approximation of Kepler's equation, then this is combined with the extinction to obtain the relative solar power for each time point. As stated earlier, the relative power is normalized to 1000 for unit air mass and the sun is at a distance of 1 Astronomical unit.

With the solar intensity, the relative powers of each of the up to 5 solar panels are calculated by taking the cosine of the incident angle to the normal of the direction of the sun multiplied by the relative contribution of each of the panels. Obviously if the incident sunlight makes an angle of more than 90° to the normal of a panel, that panel produces no power. The output from each panel is plotted as a blue curve in the output graphics, of which up to 5 may be shown. If two or more panels are considered, their sum is also obtained and plotted as the green curve in the output. In all cases the red curve in the output represents the relative power described in the previous paragraph, and corresponds to a panel with a combined area of the individual panels that tracks exactly the sun. The blue curves can at points be tangent to the green curve, but never cross it, and the green curve can be tangent at a point with the red curve, but never cross it.

If no panels are specified only the red curve is drawn and corresponds to a theoretical panel that exactly tracks the sun with the relative power normalized as above. As stated earlier, the solar power is only calculated if the altitude is not negative. If it is negative, no power is calculated and the red curve only is drawn with a zero value from midnight until sunrise, then again from sunset to midnight. If the sun is above the horizon for the full 24 hours the red curve is non-zero, and if the sun is below the horizon for the full 24 hours, no graphical output is generated.

Java Swing is used to generate the graphics. Unlike a standalone application which draws the output on a local screen, the graphics is written as a buffered png image, then a read only bean method is used to render the image in the browser making

use of the OmniFaces 2.7 jar file in the application's library. Within limits, the image is scaled from the browser's window using JavaScript. The scaling and the positioning of the axes and output powers in the graphics window are specified in a properties file, so these are more easily changed if required. In fact drawing and scaling the axes were one of the more challenging parts of working on the graphics.

Future Improvements: This is the preliminary 0.4 version being developed on a Windows 10 platform using the Eclipse Kepler IDE with the Glassfish 4.1.1 server hosting Java ServerFaces 2.2, Java 1.7, OmniFaces 2.7 and PrimeFaces 5.3 (currently used only for jQuery). Several improvements should be considered, as listed here:

1) The Glassfish web server times out after a period of inactivity, so that on clicking a button to submit or navigate to another page the HTTP error code 500 is returned (Internal Server Error).

2) Some issue with JavaScript when processing the input forms should be fixed.

3) In addition to the axes with their tick marks, they should be labelled.

4) Calculating the times of sunrise, sunset and transit can be improved.

5) Currently only direct sunlight is considered. Some of the light falling on a panel is diffuse light and should be included.

6) Average meteorological conditions for a particular location could be included. Obviously it is impossible to predict in advance if the sun is obscured at any particular moment, but some statistics can be considered.

7) Particularly at low solar altitudes panels may be in shadow. Some provision where a user can specify local topography and nearby objects such as building and trees could be allowed for.

8) More extensive use of PrimeFaces can be made to improve the user interfaces.

9) Java 1.7 is currently used and works perfectly well. A later version of Java and other resources may be used in the future if needed.

As some of the changes are made and improvements are considered, the list above will be amended as appropriate.
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