Explanation of Sundial Program in Excel

1. Summary

This Excel program calculates and draws sundials. The calculations are based on the prescriptions given in: "Een Uniforme Methode om Vlakke Zonnewijzers te berekenen" by Fer J. de Vries, 2002, and has all possibilities as his widely used program ZW2000 for flat sundials, sundials with a mirror and bifilar sundials, which can also be under water. As an extra, the Excel program gives the user easy access to the underlying data. Because Excel exists for various operator systems (OS), one is not bound to a specific OS.
The program consists of the following five worksheets.

Input
On the sheet *"Input"* the basic data for the calculation are entered and the calculation is started.

Plot+Param
On this worksheet the sundials are drawn. Adjustments can then be made, such as the selection of lines to be shown and their color, thickness and type as well as the dimensions of the graph. The graph can then be re-plotted without recalculating the underlying data. The result can be saved. A new worksheet is then created with only the drawing. This can be edited with Excel functions if desired.

Spec. Pnts.
The sheet *"Spec. Pnts."* contains a number of tools to calculate specific points on the sundial. This can help the user to realize the sundial in practice on e.g. a wall. One tool provides the ability to calculate a point on a line for a specific value on both of its dimensions (day and hour for hour and date lines, but other quantities for other types of lines). The others calculate intersections of a calculated line with a horizontal line on the sundial (x-direction) or a line perpendicular to it (y-direction). With the latter, a grid can be placed over the plane of the sundial and the intersections with calculated lines can be marked on it. In addition, there is a tool for Date to (Solar) Declination conversion, one for calculating Polar Style data from Input data, primarily intended to determine Input data for bifilar sundials for which the angle between hour lines is always 15° and one for the conversion from clock time to local (solar) time.

Hour lines and Other lines
The sheets *"Hour lines"* and *"Other lines"* contain the calculated values which were used to compose the drawing/graph. With these the user can "look under the hood".

Sun Hours
In additional there is an option to determine the number of sun hours on a sundial (also available in ZW2000). This produces a graph with curves for sunrise and sunset times for a rotated planar sundial and for the corresponding horizontal sundial.

2. General

All worksheets are protected against unwanted editing. The user can only change the required input data and perform operations via buttons. However, you can copy calculated results to your own application. And the produced graph can be saved on an unprotected sheet and is therefore accessible for the usual Excel functions. The VBA code (macros) is also protected and therefore not accessible.

The general procedure has already been described in the "Summary". An explanation of the data items to be entered is given in the *"Glossary"* (section 10), with where applicable the format and the values that the item can assume, as well as an abbreviation that is used in the graph and the data worksheets. But also look at the comments that are given for many cells (marked by a red triangle in the upper right corner of the cell), in which the necessary explanation is also given.

3. Input

Language: First of all, on this (first) sheet you can choose the language in which you want to work: Dutch, English, French or German. All worksheets, comments, (error) messages are then converted to the relevant language.
Parameter Set: Then there is an option to select the parameter set for the *"Input"* and *"Plot+Param"* sheets. The corresponding button opens a separate screen with various options for managing these sets; see the *"Manage Parameter Sets"* section for further explanation.
The *"Input"* sheet also contains the basic data for the calculation:

- Sundial data: first of all, the type can be chosen: flat with pole style, flat with mirror on the point of the pole style or gnomon, or flat with 2 wires instead of a gnomon (bifilar) and either of these can also be submerged. The other data determine the size and position of the sundial and the mirror (for the second type) and the height and rotation of the wires of a bifilar sundial.
- Time and Place data: the year for date calculations and geographical coordinates of the place where the sundial will be located (Time zone to calculate the standard meridian).
- Types of lines to be calculated:
  - Date lines for different dates. A number of special dates are highlighted: those for the solstices (June 21 and December 21) and the equinox (March 20). Furthermore, lines can be calculated for a list of specific dates (via the "List" button).
  - Hour lines in different kinds of timekeeping. For each type of line, it can be indicated for which hours (or fraction thereof) a line must be calculated (with start, end and increment parameters). And a special '*Shadow Line*' to mark the shadow of the pole style for a specific time and/or a *'Shadow Point*' for the shadow of the gnomon, reflection of the mirror, or crossing of the shadow of 2 wires, depending on the type of sundial.
  - Sun lines. Lines indicating the position of the sun in terms of Azimuth and Altitude, or Declination (see Glossary); for the latter a list of specific values can be specified (via a "List" button).
  - Since for each date the sun is at a specific declination, date and declination lines differ only in the nature of the parameter used. On the "Spec. Pnts." worksheet you will find a tool to determine the declination for a given date, so that you can also use the declination list for additional date lines.
  - For the Zodiac, both date and declination lines can be used; the solstices correspond to the tropics of Cancer and Capricorn, the equinox to Aries and Libra; for the other signs 4 declinations can be created on the declination list with an additional button.

The calculations are started by pressing the *"Calculate"* button.

4. Hour lines

The results of the calculations are stored in the worksheets *"Hour lines"* and *"Other lines"*. These primarily form the basis on which the graphs are drawn, but can also be used to construct a drawing by yourself.

The worksheet *"Hour lines"* provides the results for the hour lines for the different types of timekeeping. For each hour (or fraction) a number of lines are given with Date, x and y values of a point on the line, with an indication of the type of line in the headings above the x and y coordinates and the hour fraction respectively; the type of line is also used as the name of the line in the plot. For a number of other line types, notably Astrological Houses, Islamic Prayer Lines and Solar Azimuth Lines, the results are also given here, but with different dimensions.

Some hour lines are straight lines, for which two points are sufficient to plot the entire line. For local and standard time, the x and y values of the penetration point are given as an extra (with date = 0). This is the point where the stile goes through the dial plate. There is an option to extend these hour lines to the penetration point. This only applies to the flat sundial above water. For curved lines, a number of points are given, which number depends on the degree of curvature.

With the two (x, y) points for straight lines, you can easily calculate additional points yourself with the interpolation formulas:

$$y = y_1 + \frac{(y_2 - y_1)}{(x_2 - x_1)} * (x - x_1) \qquad \text{of} \qquad x = x_1 + \frac{(x_2 - x_1)}{(y_2 - y_1)} * (y - y_1).$$

5. Other Lines

This sheet shows the results for all other lines, in the form of (x, y) coordinates of points for drawing the line. These are first of all a number of basic elements of the sundial: 2 to 4 points for the *Shadow Line* (incl. penetration point and/or shadow point) or just 1 point for a *Shadow Point*, *Gnomon*: 5 points, which together form a rectangle around the point (0,0), that is the projection of the gnomon on the plane of the sundial, *Penetration point*: 2x2 points for two lines to draw a + on this point, *Substyle*: 2 points to connect point (0,0) and penetration point, for the bifilar sundial two lines for the x-,y-Threads. Also 2 points for the *Horizon*, as seen from the gnomon; this is a line parallel to the x-axis, but only for the plane sundial; for the mirror sundial there are 2 horizon lines. Then lines and tick marks for the *Scale* indicator: either a Frame, which can be drawn around the graph, or a bar in the x and y directions to indicate scale. All of these lines are in the first two columns, but the order may vary. If the sundial is submerged, the points for the (then curved) horizon, including the second one for the mirror, are given after the date lines, etc., of the next paragraph.

From the 4th column onwards the results are given for Date Lines, Sun Declination Lines and Sun Altitude Lines. For each of these lines 2 columns with x and y values per Hour point (10 points per hour, so 1 per 6 minutes) or Azimuth value (1 point per degree) for Altitude Lines. The headers of the x and y columns show respectively the abbreviated name of the line and the date (dd-mm), declination or altitude, from which the name of the line in the plot is also composed.

6. Plot+Param.

This sheet shows the calculated graph and provides various options to modify the plot:

- Plot Parameters: this indicates the range of the plot in terms of minimum and maximum values of the x and y coordinates for which the lines must be drawn. A scale factor can also be given to make the graph fit within the screen.

- ▼ Do not make the plot much larger than will fit within the Excel window at zoom 100%, otherwise inaccuracies in the plot may occur. Guideline: scale factor * gnomon length <= 5. Use the Excel zoom function to zoom in on details.

- Range of Hour Lines: Selection list with 3 options: lines are only drawn within both solstice date lines, or can be extended to the perforation point of the style. The latter part is not realistic, in the sense that the shadow point of the gnomon does not reach there. And this option only applies to hour lines for local or standard time. The 3rd option holds only for extending the Shadow line. If the plane of the sundial is parallel to the Earth's axis there is no penetration point; then the shadow line is drawn as a line through (0,0) across the entire plane; and the other hour lines are not extended.
- Line properties: for each line separately, the color can be specified, as well as the thickness and type (different shapes such as: solid, striped, speckled, etc., see the comment of the cell in question). This can be done for any type of line, as well as for the basic elements of the sundial.

For each type of line, a check mark in the corresponding box can be used to indicate whether or not it should be drawn. This has an effect only on lines that were calculated, the names of line types that were not calculated are displayed in gray.

Once all choices have been made, the adjusted graph can be drawn using the *"Replot"* button.

There is also a *"Save"* button that copies the graph to a new separate worksheet that is not protected, so that various actions can be performed on it, such as:

- All Excel operations on the graph are possible here
- Print to a printer or PDF file; click on the graph to give it focus, then only the graph is placed on a whole page.
- Copy to another application, such as a graphic editor, to edit it further and/or save it in a standard format such as jpg.
- An interesting possibility is to make the chart transparent (using the Options Chart Area, Fill, No Fill). Then you can place it in Powerpoint over a photo of a sundial to compare this with a calculation.

But a few points deserve attention:

- You can stretch or shrink the graph in all directions with the mouse on the points of contact, but then you lose the aspect ratio of x and y directions. If you want to make the graph larger or smaller, use the size options on the Formatting tab in the menu bar; the aspect ratio is then kept fixed.
- Also remember that the copy of the graph uses the data in *"Hour lines"*. If you make new calculations via *"Input"* then these results are also shown in the copy. So first save a graph that you want to keep in a print or another application.

7. Spec. Pnts.

This worksheet is intended to be able to calculate specific points (see section 1 for the idea behind it). It consists of the following options:

A. Calculate a point on a specific line. This calculates the x and y values of a point after entering the following data:
   - Select the type of line from the first drop-down list. This will automatically adjust the names of the variables of the line (2 dimensions).
   - Enter values for both variables (grey input fields).

- Press the button (with a lozenge) to perform the calculation.

B. Calculate a point on a line for which calculations have already been performed:
   - Select the type of line from the second drop-down list. This only shows line types for which calculations exist.
   - A drop-down list with the available lines of that type will then be automatically filled and the name of the variable in question will be adjusted. Select a specific line from this drop-down list.
   - Enter an x or y value (in a grey input field) to calculate an intersection of the line with a vertical or horizontal line on the dial, respectively.
   - Press the button (with a lozenge) on the relevant line to perform the calculation.
C. Calculate the declination of the sun on a given date on that day.
   - This option has been included to make it possible to expand the number of date lines, by also using the list of declinations.
   - As an extra, an option has therefore been provided to determine the declinations for each 1st of the month in the given year in one go.

616 / 5.000

D. Polar style Data from Input Data.
   - The input data can be copied from "*Input*" (button with a lozenge) or entered manually in the first set of blue rows.
   - To calculate the Result, press the second button with a lozenge.
   - The result provides characteristics of the style in relation to the sundial plane, intended to mount the style with the correct length in the correct position. The last two items can be used as input for bifilar sundials, for which the angle between hour lines is always 15° (Height x-Thread and Rotation = Angle Substyle-Y-axis).
E. Converting clock time to local time.
   - Uses the same data entry options as in the previous tool; to calculate the result, you also need to enter the date and time (and daylight saving time indication) of the desired clock time.
   - The result gives the corresponding local solar time. This can be entered, along with the date, as parameters for a *Shadow Line* in the "*Input*" worksheet.

The calculation of option B. is done on the basis of an interpolation of the results for the line in question in the worksheet "*Hour Lines*" or "Other Lines", with a linear interpolation for straight lines (see the formulas given in the description of the sheet "*Hour lines*") or with a ('cubic spline') interpolation for curved lines.

N.b.: The grey fields are input fields and the results are in the white ones. Press the buttons (with a lozenge) to perform the calculation in question.

All calculations (except those of options D and E) are stored in a list of *Results*, with for each calculation: Type of line, variables of the 2 dimensions (usually Day, and Hour, but for some Types different; see the comment at "Var.1") and x, y coordinate. You must maintain this list yourself. You can copy results to a file of your own, delete redundant results and move results within the list. The results of each new calculation are placed in the first free place in the list, where no Type has been entered.

The *Results* of the Date->Declination conversions are stored in a similar list.

8. Manage Parameter Sets

This screen is activated by clicking a button on *"Input"* and provides the following options for managing parameter sets (input data for the sheets *"Input"* and *"Plot+Param"*):

A. *"Save"* a set, the name of which must be entered in the input field of the combobox. This box also provides a list with an overview of previously saved sets, which can be overwritten if necessary (except for the "Initial" set). **Note**: Double-clicking the input field refreshes the list box.
B. *"Load"* a previously saved set; select a set from the list.
C. *"Delete"* a previously saved set; only the "Initial" set cannot be deleted.
D. *"Export"*: The parameter sets are saved in a (hidden) worksheet *"Param.Sets."* Exporting provides an unprotected copy of that worksheet for external use.
E. *"Import"*: It is possible to reload an exported worksheet. Then include that worksheet in the ZwExcel workbook and enter its name in the Import function. This is primarily intended to transfer the parameter sets to the new version in the event of a ZwExcel update, but it can also be used to reload historical settings. However, ***WARNING***: no validation is performed during import, so be cautious about modifying an exported worksheet.

9. Sun Hours

This worksheet shows a graph with curves for the sunrise and sunset times of a rotated planar sundial and the corresponding horizontal sundial, as a function of solar declination (or the corresponding dates). The data for the year and the location and orientation of the sundial can be modified. The red curves indicate the times during which the rotated sundial can receive solar rays. These are constrained by the time during which the sun actually shines at that location, as shown by the blue curves for the horizontal sundial. The black horizontal lines indicate sunset.

Note the interpretation of the "From" and "To" columns for the rotated sundial. The data there form the basis for the red curves. One curve always falls entirely between 0 and 24 hours, and the corresponding data are in a continuously ascending or descending series in one of the columns. However, the other curve can be split in two, with a data series that transcends a day boundary (24:00). Whether the sun rises or sets between the two curves is indicated by a sign in a separate column.

Finally, there is a calculation tool to calculate the sunrise and sunset times for both the rotated and horizontal sundial on a specific date. For the rotated sundial, these are the hours during which the sun actually shines on it, and these can be two periods, in that case, at the beginning and end of the day.

10. Glossary

For an explanation of the terminology relating to sundials, you can also visit the site of the Zonnewijzerkring, https://www.dezonnewijzerkring.nl/53-woordenlijst.php. This section contains a brief explanation of the terms used in this program. Where applicable, the following is also indicated: the format in which the data must be entered, the possible values that the item can assume and for lines an abbreviation with which the item is indicated on data worksheets and in the graph.

Sundial data

Type of Sundial: A flat sundial consists of a flat plate with a pole style. A mirror sundial has a mirror on the tip of the gnomon, which casts a beam of light onto a flat plate (or wall), instead of a shadow. A bifilar sundial has two threads parallel to the plane instead of a style, which intersect the gnomon line (perpendicular to the plane through (0,0)) at different heights. Initially, the threads run parallel to the y- and x-axes, hence the names y-Thread and x-Thread, but they can be rotated together through a certain angle about the y-axis. The time can be read from the intersection of the shadows of both threads.

Underwater: All three sundial types can also be calculated if the entire sundial, including the gnomon, mirror, or wires, is immersed in water or another transparent medium. In that case, the *Refractive Index* of the medium must be specified. It is assumed that the surface of the medium is horizontal.

Length Gnomon: The gnomon is the end point of the shadowing pole style. The gnomon length is the (perpendicular) distance from this point to the plane of the sundial. The corresponding line segment is also referred to as the gnomon. The length is given in cm. For the bifilar sundial this data item is used as the value for the Height y-Thread.

Inclination of the plane (or the mirror): angle that the normal on the plane makes with the zenith (perpendicular to the earth's surface). In degrees: 0° <= i < 180° (horizontal i = 0 vertical i = 90).

Declination of the plane (or the mirror): (azimuth) angle through which the plane is rotated around the perpendicular to the earth's surface. In degrees: -180° <= d <= 180, south = 0°, west positive, east negative.

Penetration point: The point at which the pole style intersects the plane of the sundial.

Substyle: Perpendicular projection of the pole style onto the plane of the sundial; connects the penetration point with the point (0,0) of the sundial. The (0,0) point is the perpendicular projection of the gnomon onto the plane. If the plane of the sundial is parallel to the Earth's axis, the substyle is drawn as a line through (0,0) across the entire plane.

Style elevation: Angle that the style makes with the sundial plane.

Scale Indication: The scale of the plot can be indicated by a *Frame* with scale division or a *Scale Indicator* consisting of a bar of given length in the x and y directions.

Time and Place data:

Year: used in date calculations (and conversion to day number 1-366), but is otherwise not very relevant. Format: yyyy, value: 1900-2200.

Place latitude (phi): -90° <= phi <= 90°, north latitude positive, south latitude negative.

Time zone (tz): according to UTC: -12 <= tz <= 12; this is used to calculate the standard meridian.

Standard meridian (SM): longitude in the middle of a time zone; SM = tz*15°.

Local meridian (LM): the local longitude; this is used together with the time zone to determine a longitude correction LC=SM-LM for calculating standard time: -180° <= LM <= 180°.

Sun Lines:

Solar declination (DSline): the latitude where the sun is directly overhead. This varies from -23.5° to 23.5° (between both solstices). However, the program can specify values from -90° to 90° to study hypothetical positions.

Azimuth lines (Azline): the direction of the sun, measured along the horizon; from -180° to +180°; calculated from the south; negative to the east, positive to the west.

Altitude lines (Alline): the angle between the direction of the sun and the horizontal plane, expressed in degrees. The horizon is at 0°, the zenith at 90°.

Types of Hour Lines:

Hour Lines General: Line (or curve) for a specific time (usually a whole hour or fraction of an hour) in a particular time system, along which the shadow point of the gnomon runs from day to day. An abbreviation is given between ().

Local time or true solar time (Ltime): the time indicated by a sundial, based on the position of the sun in the sky.

Shadow line of Pole style (Shline): Hourline Local time for one specific time, intended to match a photo of a sundial, with its own line properties. Applicable only to a flat sundial (not underwater), this corresponds to the shadow of the Polar Style and is drawn in its entirety.

Shadow Point: Depending on the sundial type, the shadow of the gnomon, the point of the reflected sunbeam on the sundial face, or the intersection of the shadow lines of the wires, at a specific date and time. This is intended to match a photo of a sundial.

Standard time (Stime): local clock time; = UTC plus local time zone.

Analemna: time adjustment loop: correction to local or standard time for the elliptical shape of the earth's orbit around the sun and the position of the earth's axis relative to the plane of the earth's orbit.

1st and 2nd half: Some of the following line types are split into a 1st and 2nd half, corresponding to the lengthening days (21 Dec to 21 Jun) and shortening days (21 Jun to 21 Dec). In those cases the two halves differ, while in other cases they are identical.

Local time + Analemna (Lt+A1 and Lt+A2): local time with time adjustment = mean local time.

Standard time + Analemna (St+A1 and St+A2): local time with longitude correction and time adjustment.

Babylonian time (Btime): counts 24 equal hours per day starting at sunrise and ending at sunset.

Italian time (Itime): counts 24 equal hours per day starting at sunset and ending at the next sunset.

Antique time (Atime): counts 12 equal hours per day starting at sunrise and ending at sunset.

Sidereal time (SiTime1 and SiTime2): The hour angle of the vernal point, measured along the celestial equator from the south over the west. The vernal point is one of the intersections of the

ecliptic and the celestial equator. At hour 0, the vernal point coincides with the local highest point of the equator.

Planetary hours (PlHr1 and PlHr2): the time required for the rising of a half sign of the zodiac (according to Joseph Drecker, 1925). In astrology, a certain planet always dominates the time between 2 hour lines. The following rules apply:

- On each day of the week, one planet is the ruler: Sun: Sun, Mon: Moon, Tue: Mars, Wed: Mercury, Thu: Jupiter, Fri: Venus, Sat: Saturn.
- Also, each period between two hour lines is dominated by one planet in a repeating sequence of the seven planets: Sun, Venus, Mercury, Moon, Saturn, Jupiter, Mars, starting at the first hour with the ruler of the day of the week.

Ascendants (Asc1 and Asc2): The ascendants indicate the time when a sign of the zodiac rises. Astronomically speaking, the ascendant is the intersection of the ecliptic with the horizon. The hour of a line determines a point in the zodiac (h*30° along the ecliptic). A person can determine his ascendant by doing the calculation for the latitude of his birthplace and looking between which ascendant lines the time of his birth falls on the date line of his birth. The lowest hour number determines the ascendant: 0: Aries, 1: Taurus, 2: Gemini, 3: Cancer, 4: Leo, 5: Virgo, 6: Libra, 7: Scorpio, 8: Sagittarius, 9: Capricorn, 10: Aquarius, 11: Pisces. A person's zodiac sign is determined by the sign at sunrise on his date of birth.

Astrological Houses (AstrH): form a division of the day into 12 ‘houses’, by dividing the day into 4 quadrants with 3 houses each: from 1: ASCendant – sunrise, to 4: IC Imum Coeli (or nadir) – lowest point, 7: DESCendant – sunset, 10: MC Medium Coeli (or zenith) – Highest point in the afternoon.

Islamic Prayer Lines (IsGlijn): indicate the times at which certain Islamic prayers must be performed. Z: Zuhr, AA: Asr-Awwal, AT: Asr-Tâni.

Zodiac: The zodiac is a division of the ecliptic into 12 signs (of equal arc lengths of 30°), corresponding to the constellations that are located (or rather once were) in that segment. The sign in which the sun rises on a person’s date of birth determines his zodiac sign. The declination of the sun at the moment it first rises in a particular sign of the zodiac is an accurate marker of the beginning of that sign. The date at which this occurs is less accurate, but also quite useful. By drawing declination or date lines for these declinations on a sundial, one can read off one's zodiac sign.

Date lines:

Date lines General: Line (curve) for a specific date, for which the course of the shadow point during a day is calculated. The abbreviation between () is supplemented with the date in the format dd-mm.

Solstices (Ss1 and Ss2): June 21 and December 21. Days on which the sun, as seen from the earth, reaches its northernmost or southernmost position. The sun is then directly above one of the two tropics (Tropic of Cancer or Tropic of Capricorn). The solstices determine the boundaries of the hour lines.

Equinox (Eqn): March 20. Falls exactly between both solstices and is the date on which day and night are of equal length.

Specific dates (Dline1 – Dline10): A list of 1 to 10 dates to be determined by yourself for which a date line must be drawn.