Orientation and the Solmetric SunEye™

Understanding orientation issues in solar site analysis

1.0 Introduction

The Solmetric SunEye provides complete solar access and shade analysis in an integrated hand-held tool that can help optimize solar panel system design and installation. The SunEye is useful for solar energy systems such as photovoltaic (PV) systems and hot water systems, and it can be used to analyze both roof and ground mounted systems. The SunEye can also be used for other applications where solar access is important, such as passive solar house design and green architecture, and landscape design and architecture.

Solar energy production depends on the azimuth (direction) and tilt of the solar modules. Accurate azimuth and tilt measurements are important for accurate estimates of energy production. This note describes how to measure and account for orientation when using the SunEye.

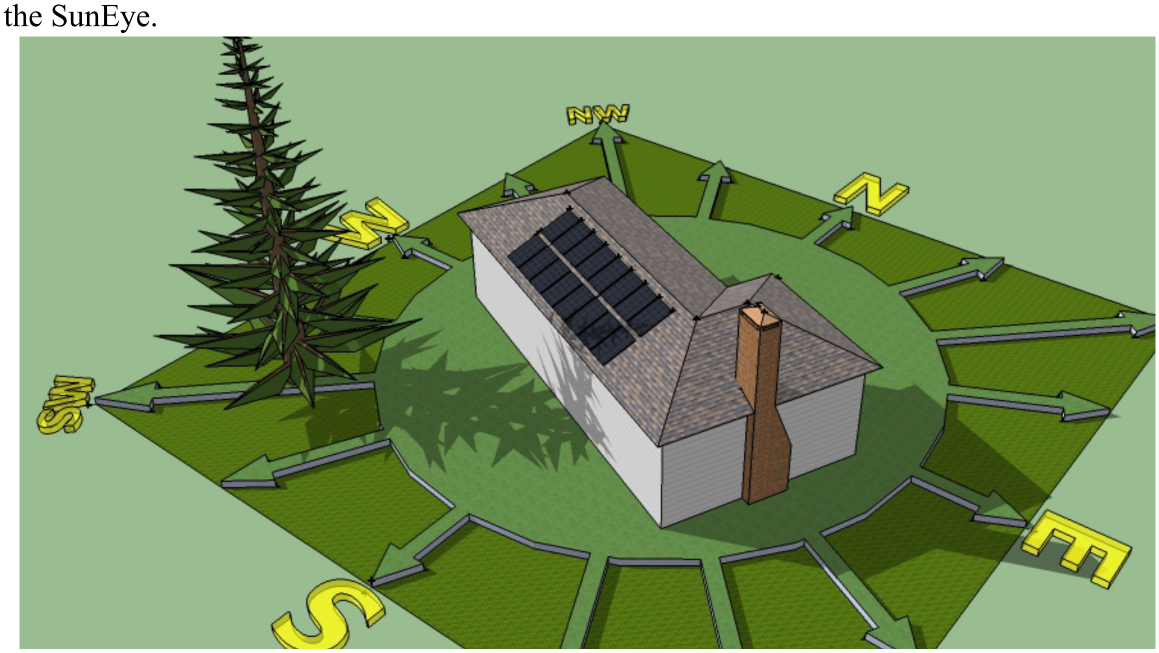

FIGURE 1. Orientation determines solar energy production and effects of shading from nearby obstructions.

2.0 Proper Orientation of the SunEye

The SunEye aids in the optimization of a solar energy system by analyzing shade on a "Skyline" image. The Annual Sunpath view of a Skyline image will display a 360 degree fisheye view of the sky above with the Sunpath for the specific location superimposed on top of the image. The SunEye assumes that the Skyline image was captured while in a specific orientation as a reference for displaying the image and for calculations of solar access and shade. An example Skyline image is shown in Figure 2. Proper orientation of the SunEye includes holding the device level, and pointing the device in the correct direction.

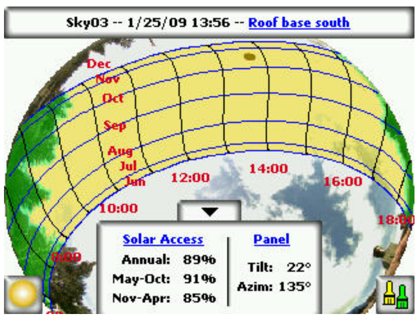

FIGURE 2. Annual Sunpath View of a Skyline Image

SunEye Tip
To hold the SunEye level, make sure that the protective cover is completely open, and then tilt the SunEye until the bubble is within the black circle in the center of the bubble level.

2.1 Pointing the SunEye

With the SunEye level, the user should turn to point the device toward magnetic south when making measurements in the Northern Hemisphere (north when making measurements in the Southern Hemisphere). Magnetic south is used vs. true south because it is easier to determine its azimuth using the built-in compass. The SunEye will automatically calculate the true azimuth for any Skyline image using the magnetic declination of that location. More information can be found in Section 3: "Azimuth", and in the Appendix: "Magnetic Declination".

In the northern hemisphere, the SunEye should be pointed south because the sun spends the majority of the day to the south, and because facing south is approximately the optimal orientation for a solar energy array. Also, because the user has to hold the SunEye while taking a Skyline image, pointing toward the south will insure that the image of the user does not appear as a shade-causing object in the Sunpath on the Skyline image[1].

In the southern hemisphere the user should be pointed north with their own image to the south. The sun paths will generally be to the north.

SunEye Tip
To point the SunEye south, turn the device so that the white side of the compass needle is aligned with the “S” label. The user should face the same direction as the device.

SunEye Tip
Once the SunEye is level and pointed in the correct direction, a Skyline image is ready to be taken by pressing the green “Snap” button or the center navigation button.

2.2 The Two SunEye Models

There are two Solmetric SunEye models. The 110N is intended for use in the northern hemisphere, and the 110S is identical to the 110N model, but features a different compass orientation so that the letters that indicate direction are facing the correct direction. Note that both the 110N and 110S can be used internationally, but using a model in the hemisphere other than it is intended requires special consideration. When using the 110N SunEye in the southern hemisphere, the user should still turn to face magnetic north when making measurements. When using the 110S SunEye in the northern hemisphere, the user should still face magnetic south when making measurements. In other words, the proper direction to face is dependent on the hemisphere, not on the device model. The on-screen instructions guide the user either model number.

SunEye Tip
To use a 110N model in the southern hemisphere, turn the device until the red side of the compass needle is aligned with the “S” on the label. The user should face the same direction as the device.

SunEye Tip
To use a 110S model in the northern hemisphere, turn the device until the white side of the compass needle is aligned with the “N” on the label. The user should face the same direction as the device.

1. If the user does obstruct the Sunpath on the Skyline image, the obstruction can be removed by editing the skyline image. For more information, read about the “Edit Tool” in the Solmetric SunEye User Guide.

The remainder of this note assumes measurement from the northern hemisphere. Concepts can be adapted for the southern hemisphere.

3.0 Azimuth

Azimuth, as it relates to the operation of the SunEye (and to navigation and mapping), is the horizontal angle measured clockwise from a line of longitude. Lines of longitude are imaginary arcs on Earth's surface that connect the north and south geographic poles. The north side of a line of longitude extends toward true north, is used as the reference plane, and is defined as having an azimuth of zero degrees. The horizon lines form a circle around an observation point and there are 360 degrees in a circle. Therefore, true south lies halfway around the circle at an azimuth of 180 degrees. The Azimuth of other directions can be found in Table 1.

Direction:	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Azimuth:	0º	45º	90º	135º	180º	225º	270º	315º

TABLE 1. The Azimuth of Various Directions

For example, consider solar azimuth, which is the angular position of the sun. In the northern hemisphere, on March 20th (Spring Equinox) the sun moves from east to west throughout the course of the day. This is equivalent to saying that the solar azimuth increases from 90 degrees to 270 degrees throughout the course of the day.

FIGURE 3. The Azimuth of Various Directions is shown on the SunEye compass.

3.1 Entering Azimuth into the SunEye

Before capturing the first Skyline in a new session, the user is prompted to set the panel azimuth and tilt for the session in the Panel Orientation dialog box (see Figure 4). The panel azimuth is simply the direction that the solar energy system will face.

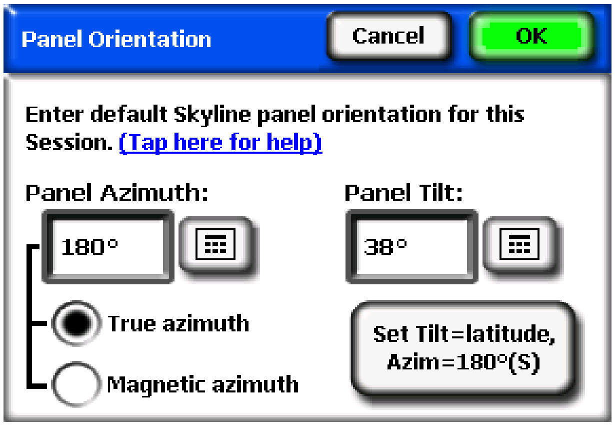

FIGURE 4. Panel Orientation Dialog Box

SunEye Tip
Azimuth and tilt can be changed after the Skyline is taken. However, it is normally convenient to enter in beforehand whenever possible.

3.2 Optimal Azimuth and Tilt

During the majority of the year, the Sunpath is to the south of locations in the northern hemisphere. Therefore the optimal panel azimuth for a solar energy system is 180 degrees (true south) in the northern hemisphere. However, other considerations need to be taken into account, such as local weather conditions and mounting systems. As an example, in the northern hemisphere it may be advantageous to use a southwestern azimuth in areas that frequently get fog in the morning. Also, it may be easier to install the mounting for a solar energy system parallel to the roof line, which will most likely have an azimuth other than 180 degrees (true south). For more information on efficiency, see section 3.3: “The Effect of Azimuth on Insolation and Energy Production”.

The default panel tilt in the Panel Orientation dialogue box (see Figure 4) is equal to the latitude of the session location. This is because the latitude is also the angle at which a panel will be normal (perpendicular) to the sun’s average peak elevation at the location, and therefore a panel will experience more insolation at this angle. For more information on insolation, see section 3.3: “The Effect of Azimuth on Insolation and Energy Production”. However, local weather conditions may need to be considered. For example, for locations with harsh winters, a steeper panel angle will allow the system to shed snow. For locations that are frequently cloudy, a shallower angle may be more efficient. Many panel mounting systems feature adjustable tilt. These allow the panels to use a steeper angle in winter when the sun is lower in the sky, and a shallower angle in summer. This adjustment can increase production by approximately 5%.

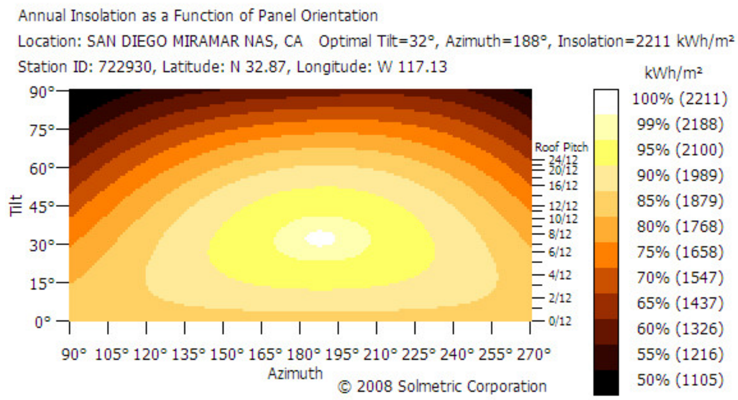

FIGURE 5. Annual Insolation chart showing optimum tilt and azimuth.

3.3 The Effect of Azimuth on Insolation and Energy Production

Irradiance is defined to be the solar radiation incident on a given surface and is expressed in watts per area. Insolation is the rate of delivery of irradiance multiplied by time, and is expressed in watt-hours per area. Solar energy systems experience more insolation, and therefore absorb more energy and produce more power, when they are positioned perpendicular to the sun's rays. In the northern hemisphere, the sun's position moves approximately from east to west, although the actual dawn and dusk azimuths depend on both the time of year and geographic location. Therefore it is best to orient solar panels so that their azimuth is 180 degrees (true south) because this will allow the panels to spend the maximum amount of time at a good angle (the closer to perpendicular the better) to the sun's rays.

The sun is at its highest when the solar azimuth is 180 degrees (true south) at around 12:00 noon. Therefore it is generally less likely that an object adjacent to the panels will cause shadowing. Ensuring that the panel azimuth is exactly 180 degrees is not critical, however. For example, a photovoltaic (PV) system with an azimuth 30 degrees from true south will only produce approximately 5% less power than one with an optimal 180 degree azimuth (true south). On the other hand, solar energy system costs are high enough that maximizing energy yield is advantageous. Accounting for shade causing objects and the ease of installation are other important considerations in determining the optimal azimuth for any solar energy system, as discussed in section 3.2: "Optimal Azimuth and Tilt".

3.4 Determining Panel Azimuth

The default panel azimuth in the Panel Orientation dialogue box (see Figure 4) is 180 degrees (true south) because it is usually close to the most favorable orientation for a solar energy system in the northern hemisphere. However, it may be advantageous to install a system at a different azimuth to align with a roof line, to avoid shade-causing obstructions, or for better visual appeal. The azimuth of a roof or similar surface can be done by using online tools, by using a compass, or by using a map or site plan.

3.4.1 Using Online Tools

The easiest and most accurate way to determine an azimuth is to use an online tool such as the Solmetric Roof Azimuth Measurement Tool, which can be accessed by visiting www.solmetric.com. For example, suppose we wish to determine the azimuth of a roof. First locate the roof by entering the address where the roof is located in the “Locate Roof” section. Then click the button in the “Measure Roof” section, and draw a line along the edge of the roof in the direction of the azimuth you wish to measure. The measured azimuth is immediately displayed in the “See Results” section.

SunEye Tip
When using the online tools, enter the value as a true azimuth in the Panel Orientation dialog box (see Figure 4) by selecting the “True Azimuth” radial button.

3.4.2 Using a Compass

The SunEye features a magnetic compass, although any magnetic compass can be used in this case. To obtain a magnetic azimuth reading, the compass must be held level. The compass needle should be aligned so that the red side points to the north (labeled “N”) and the white side points to the south (labeled “S”). In this orientation, imagine a straight line extending in the direction of the azimuth you wish to determine. Then, simply read the azimuth degree measurement nearest to that imaginary line on the outer edge of the compass.

A visual representation of this process can be seen in Figure 6. Here, the compass is placed on the roof. The green arrow indicates the direction of magnetic south (180 degrees), and extends in the direction of the white side of the compass needle. The blue arrow indicates the imaginary line extending in the direction of the roof azimuth. Note that it is parallel to the side roof edges. The blue arrow passes through the outer edge of the compass at a magnetic azimuth of 225 degrees.

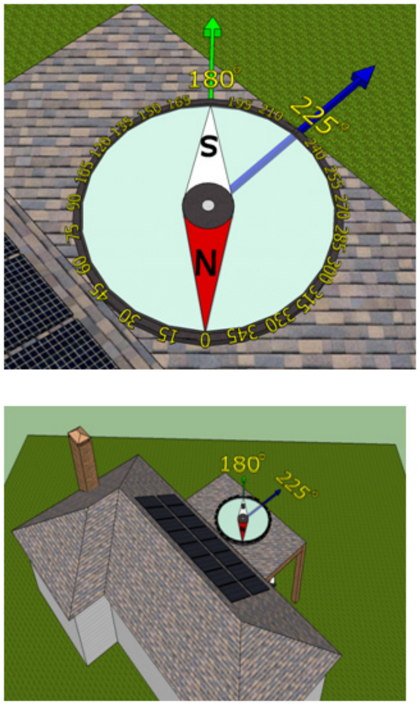

FIGURE 6. Using a Compass to Determine Magnetic Azimuth

It is important to note that this method measures magnetic azimuth, not the true azimuth. The Solmetric SunEye is programmed with the magnetic declination of the session location and will automatically make the correction to display true azimuth. When displaying the data results such as in the Annual Sunpath view or the Obstruction Elevation view, the SunEye displays true azimuth. The angular difference between magnetic and true azimuth is called magnetic declination and is discussed in the Appendix: "Magnetic Declination".

SunEye Tip
When using a compass, enter the value as magnetic azimuth in the Panel Orientation dialog box (see Figure 4) by selecting the "Magnetic Azimuth" radial button.

3.4.3 Using a Map or Site Plan

Measuring the azimuth of a surface using a map requires the use of a protractor. As an example, we will again determine the azimuth of a roof, but the same process can be used for another surface. Draw a straight line on the map that goes through the location of the roof that is parallel to the edge of the roof and extends in the direction that the roof faces. This may require the use of reference objects such as streets. Make sure that the line intersects one of the vertical grid lines on the map. These vertical grid lines run from true north to true south. Place the index of the protractor at the point where the drawn line intersects a vertical grid line, and measure the angle between the north side of the vertical line and your drawn line in a clockwise direction. This angle is the roof azimuth. Note that if the roof faces roughly southwest, the protractor may have to be repositioned to measure the part of the angle beyond 180 degrees.

A visual representation of using a map or site plan to measure the azimuth of a surface can be seen in Figure 7. Here we wish to determine the azimuth of the roof outlined in red. The vertical black line is a grid line of longitude (122.5 degrees West in this case) that runs from true north to true south. The yellow line is drawn on the map parallel to the edge of the roof, extends in the direction that the roof faces, and intersects the vertical grid line at the red dot. The protractor is placed at the intersection (the red dot), and the desired azimuth angle is measured from the north side of the grid line (black) to the drawn line (yellow) in a clockwise direction. The angle is shown by the green arc, and the azimuth in this example is approximately 160 degrees.

SunEye Tip
When using a map or site plan, enter the value as a true azimuth in the Panel Orientation dialog box (Figure 4) by selecting the “True Azimuth” radial button.

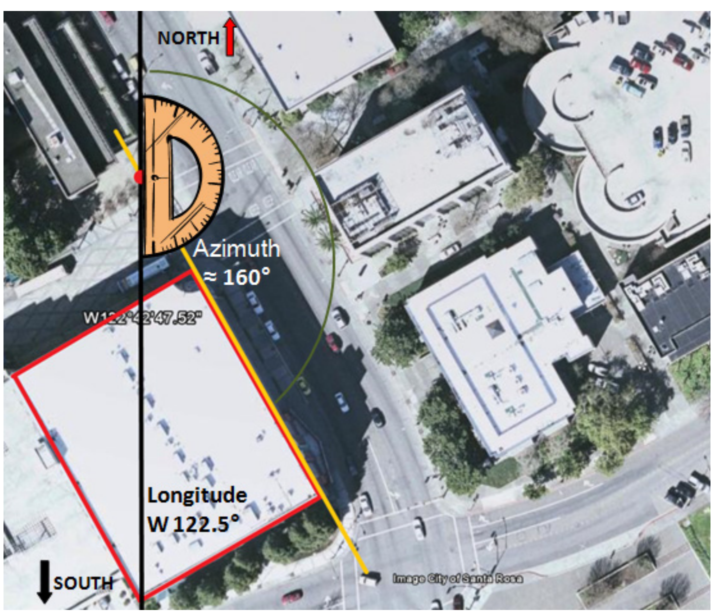

FIGURE 7. Using a Map to Determine an Approximate True Azimuth

3.4.4 Typical Azimuth Uncertainty

The accuracy of an azimuth measurement depends on the method used. Measuring the azimuth of a roof using a map or site plan may be difficult and may require greater care to obtain accurate results. Measuring the azimuth of a roof by using a magnetic compass is fairly simple, but the results are subject to human approximation error that can be as much as a couple of degrees. The preferred method is to use the Solmetric Roof Azimuth Measurement Tool, which is accurate to a couple tenths of a degree. However, while obtaining an accurate azimuth measurement may appear more professional, it has only a small impact on the accuracy of power and energy calculations for a solar energy system. For example, a few degrees of azimuth error will usually have a negligible effect on the accuracy of calculations of energy production.

4.0 Results and Calculations

After using the SunEye to capture a Skyline Image, the Annual Sunpath view will be displayed (see Figures 2 and 8). The Annual Sunpath view of a Skyline image will display a 360 degree fisheye image of the sky above with the Sunpath for the specific location superimposed on top of the image. The Sunpath will appear as though it is rotated on the image, the reason for which is discussed below in Section 4.1: “The Annual Sunpath View”. At the bottom of the image, a window displays the annual solar access. Solar access is the percent of the Sunpath that is exposed to open sky and is not subject to shading. The user has the option to display solar resource values, which are calculated values for Tilt and Orientation Factor (TOF) and Total Solar Resource Fraction (TSRF), which are discussed below in Section 4.2: “Solar Resource Values”.

SunEye Tip
To display solar resource values TOF and TSRF, tap on the solar access values. This will display the “Configure Current View” menu in which there is an option to output solar resource values TOF and TSRF.

4.1 The Annual Sunpath View

The Annual Sunpath view appears rotated because it is aligned so that the center of the image points towards magnetic south, just as the SunEye should be when a Skyline image is taken. The center of the Sunpath is aligned with true south. Therefore, the center of the Sunpath will be either to the right or the left of the center of the image depending on the magnetic declination of the specific location. If the location has an east magnetic declination, true south is east of magnetic south. Therefore the center of the Skyline (true south) will be to the east (left) of the center of the Annual Sunpath view. The image will appear as though the Sunpath has been rotated toward the east (counterclockwise) as in Figure 8. If the location has a west magnetic declination, the image will appear as though the Sunpath has been rotated toward the west (clockwise).

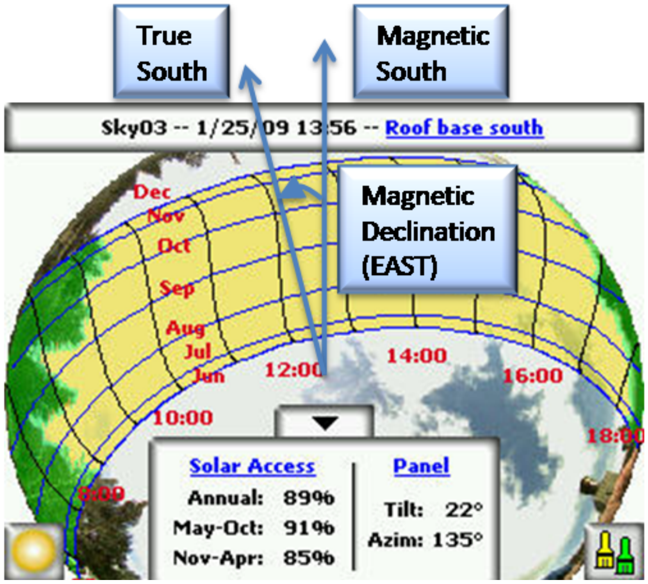

FIGURE 8. The Rotation of Annual Sunpath View

4.2 Solar Resources Values

The SunEye can view various numerical values for the computed results. Solar Resource view shows calculated values for Tilt and Orientation Factor (TOF) and Total Solar Resource Fraction (TSRF). It is important to note that the SunEye needs to be using the "NREL-TMY3" weather model in order to calculate TOF and TSRF. The United States National Renewable Energy Laboratory (NREL) published weather data for 1,020 locations in the United States calling "Typical Meteorological Year" (TMY3) data. TMY3 data includes the insolation of any NREL station in the United States during all hours of the day and all days of the year. When the "NREL-TMY3" weather model is selected, the SunEye, by default, selects the NREL station that is closest in geographical distance to the session location entered by the user. The SunEye then determines the optimal tilt and azimuth of a solar energy array for maximum annual insolation. This information, along with the actual tilt and azimuth, is used to calculate Tilt and Orientation Factor (TOF).

SunEye Tip
To use the NREL-TMY3 weather model (US only), select "Change Weather Model" in the Session menu, then select the "NREL-TMY3" radial button.

4.2.1 Tilt and Orientation Factor (TOF)

TOF is the solar insolation at the actual tilt and azimuth divided by the solar insolation at the optimal tilt and azimuth, expressed in percent. TOF is a useful quantity in analyzing the efficiency of a solar energy array, but does not account for shading. A better indication of the efficiency of a solar energy array is given by the Total Solar Resource Fraction (TSRF)

TOF (%)= Insolation at the actual tilt and azimuth/Insolation at optimal tilt and azimuth

4.2.2 Total Solar Resource Fraction (TSRF)

TSRF is the ratio of insolation available accounting for both shading and the specific azimuth and tilt of the array to the total insolation available assuming no shading and optimal azimuth and tilt. TSRF can also be thought of as solar access (the percent of the annual Sunpath that is not shaded) multiplied by TOF. Since shade is extremely detrimental to the output of a solar energy system, optimizing TSRF can be very advantageous.

TSRF (%)= (Solar Access) x (TOF)

5.0 Conclusion

When using the Solmetric SunEye, using the proper orientation and determining an azimuth can be confusing. However, using the correct orientation and panel azimuth during measurement is essential to the accuracy of the resulting Sunpath, Solar Access data, and solar resource values. Please be sure to use the proper techniques discussed in this document. When using solar energy calculators and when filling out state rebate forms, always enter true azimuth, not magnetic south.

References

Brian, Marshall. (April 1, 2000). “How Compasses Work.” Howstuffworks.com. Retrieved June 29, 2009, from http://adventure.howstuffworks.com/compass.htm

California Energy Commission. “The California Solar Initiative-CSI”. Gosolarcalifornia.ca.gov. Retrieved June 30, 2009, from http://www.gosolarcalifornia.ca.gov/csi/index.html

Davidson, Robert. (2008). “Chapter 6: Direction” Map-reading.com. Retrieved June 29, 2009, from http://www.map-reading.com/chap6.php

Del Vecchio, David. (April/May 2009). “Optimizing a PV Array with Orientation and Tilt.” Home Power Magazine. 130. 52-56.

International Union of Geodesy and Geophysics. “The International Geomagnetic Reference Field (IGRF).” iugg.org. Retrieved June 30, 2009, from http://www.iugg.org/IAGA/iaga_pages/pubs_prods/igrf.htm

National Geophysical Data Center (NGDC). “Geomagnetism Frequently Asked Questions.” Ngdc.noaa.gov. Retrieved June 30, 2009, from http://www.ngdc.noaa.gov/geomag/faqgeom.shtml

National Geophysical Data Center (NGDC). (May 29, 2009). “The World Magnetic Model.” Ngdc.noaa.gov. Retrieved June 29, 2009, from http://www.ngdc.noaa.gov/geomag/WMM/doDWMM.shtml

National Renewable Energy Laboratory (2009, March 10). Renewable Resource Data Center. Nrel.gov. Retrieved June 29, 2009, from http://nrel.gov/rredc/

National Renewable Energy Laboratory (2009, April 6). “PV Watts Version 1 Calculator.” Retrieved June 30, 2009, from http://pvwatts.org/

Sanchez, Justine. (June 2009). “The Circuit-Methods: Finding True South.” Homepower.com. Retrieved June 29, 2009, from http://www.homepower.com/article/?file=HP131_pg12_The%20Circuit_10

Solmetric Knowledge Base. Retrieved Junw 29, 2009, from http://www.solmetric.com.knowledgebase.html

Solmetric SunEye User’s Guide. Version 2.8. (January 2009). Retrieved June 30, 2009, from http://www.solmetric.com.support.html

Appendix: Magnetic Declination

The Solmetric SunEye has built-in data and correction for magnetic declination. This appendix provides details on the declination as background.

The Earth is surrounded by a magnetic field created by the rotational motion of molten iron and nickel in the outer core. A compass needle aligns itself with the horizontal component of this field to point toward magnetic north and south, which are not aligned with Earth’s axis of rotation. Therefore, there is a difference between magnetic north and true geographic north, which means that a compass can determine magnetic azimuth, but not true azimuth. However, magnetic azimuth can be corrected to true azimuth by adjusting it by an angle called magnetic declination.

A.1 Magnetic Declination Models

Earth’s magnetic field changes with time and is different depending on geographic location. Fortunately, it can be described by the mathematical models such as the International Geomagnetic Reference Field (IGRF) and the World Magnetic Model (WMM). IGRF is an international collaboration that has developed a mathematical description of the Earth’s magnetic field that has incorporated data from land, airborne, marine and satellite surveys. A new IGRF is adopted every five years. WMM is the product of the United States National Geospatial-Intelligence Agency (NGA) and is the standard model used by the U.S. Department of Defense and by NATO. WMM is also used in many civilian navigation systems. From these models, the magnetic declination of any geographic location can be very well approximated, as these models are accurate to less than one degree.

The IGRF is available for download at http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

The IGRF is available online at http://www.geomag.bgs.ac.uk/gifs/igrf_form.shtml

The WMM is available online as http://www.ngdc.noaa.gov/geomag/WMM.shtml

A.2 Correcting Magnetic Azimuth to True Azimuth

The Solmetric SunEye is programmed with an accurate value of magnetic declination for any geographical location, and corrects magnetic azimuth to true azimuth automatically. Recall that magnetic declination is an angle that allows magnetic azimuth to be corrected to true azimuth. The angle can be either an east declination or a west declination.

A.2.1 East Declination

East declination indicates that Earth's magnetic field is pulling the north (red) end of the compass needle to the east of true north and the south (white) end of the needle to the west of true south. In other words, true north is the magnetic declination angle west of magnetic north and true south is the magnetic declination angle east of magnetic south.

Another way to think of east declination is that it indicates that the compass needle is rotated clockwise from true north and south. Therefore, the azimuth of true north and south can be found by rotating counterclockwise by the magnetic declination angle from the position of the needle.

Example 1: Suppose the magnetic declination of a location is 10 degrees east. True north is 10 degrees west of magnetic north and true south is 10 degrees east of magnetic south. Therefore, the compass needle is really aligned with north pointing towards a true azimuth of 10 degrees (0 degrees + 10 degrees) and south pointing towards a true azimuth of 190 degrees (180 degrees + 10 degrees). A visual representation can be seen in Figure 9.

A.2.2 West Declination

West declination indicates that Earth's magnetic field is pulling the north (red) end of the compass needle to the west of true north and the south (white) end of the needle to the east of true south. In other words, true north is the magnetic declination angle east of magnetic north and true south is the magnetic declination angle west of magnetic south.

Another way to think of west declination is that it indicates that the compass needle is rotated counterclockwise from true north and south. Therefore, the azimuth of true north and south can be found by rotating clockwise by the magnetic declination angle from the position of the needle.

Example 2: Suppose the magnetic declination of a location is 20 degrees west. True north is 20 degrees east of magnetic north and true south is 20 degrees west of magnetic south.

Therefore, the compass needle is really aligned with north pointing towards a true azimuth of 340 degrees (360 degrees-20 degrees) and south pointing towards a true azimuth of 160 degrees (180 degrees -20 degrees). A visual representation of example 2 can be seen in Figure 9.

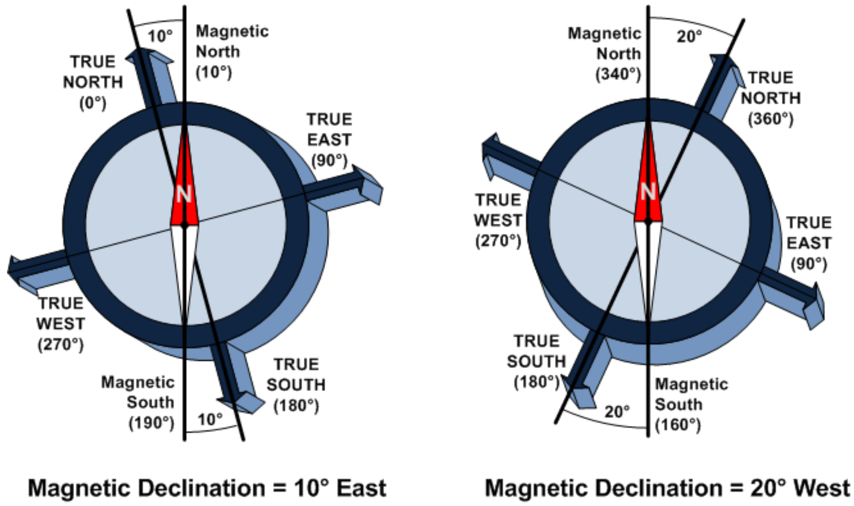

FIGURE 9. Relationship Between True and Magnetic Azimuth

The magnetic declination of any location can quickly be found online by visiting the National Geophysical Data Center's web site at www.ngdc.noaa.gov/geomagmodels/Declination.jsp.

A.3 Roof Azimuth Example

Suppose that the azimuth of a roof is determined to be 225 degrees (true southwest) and that the magnetic declination for that area is 15 degrees east. Also, suppose that this roof is in the northern hemisphere, which means that the SunEye should be held facing toward magnetic south. From visual approximation, using the compass on the SunEye, the roof azimuth appears to point 30 degrees west of magnetic south, or toward an azimuth of 210 degrees. More information on this operation can be found in section 3.4.2: "Using a Compass". The SunEye will automatically correct the magnetic azimuth to true azimuth, and will display the true azimuth in the results on the Annual Sunpath view, as well as on the Obstruction Elevation view.

SunEye Tip
For this example, correct operation of the SunEye is to manually enter the panel azimuth as 210 degrees (180 degrees + 30 degrees) in the Panel Orientation dialogue box (see Figure 4) and to make sure that the "Magnetic Azimuth" radial button is selected.

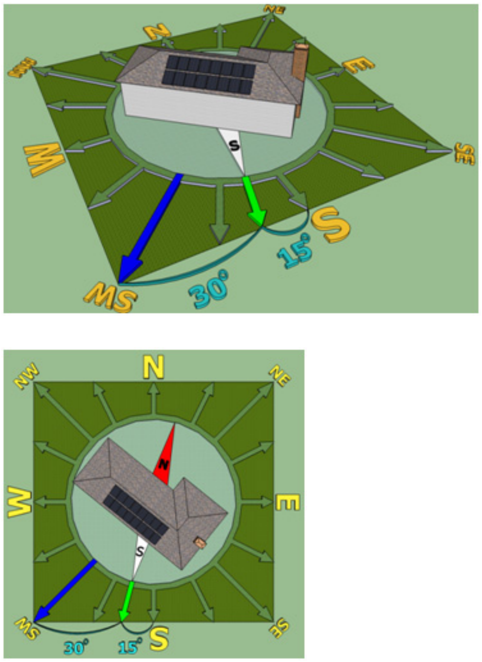

FIGURE 10. Roof Azimuth Example Visual Representation

Figure 10 shows a visual representation of this roof azimuth example. The yellow letters show true direction while the compass under the house shows magnetic direction. The green arrow points toward magnetic south and is different than the direction of true south by 15 degrees, which is the magnetic declination. The blue arrow points in the direction of the roof azimuth. Notice that the blue arrow is parallel to the side edges of the roof.

A few simple calculations can provide a quick verification of this example. Magnetic south (the green arrow in Figure 10) needs to be adjusted by a 15 degree east magnetic declination as in the Appendix: A.2: "Correcting Magnetic Azimuth to True Azimuth". The magnetic azimuth of the roof when read from the compass is 210 degrees. When corrected by the magnetic declination, the true azimuth of the roof is 225 degrees (210 degrees + 15 degrees).