

LESSON PLAN - Optimum Orientation of Solar Panels Using Soltrex Data

Title of Lesson: Optimum Orientation of Solar Panels Using Soltrex Data

Description of class: High School physics, astronomy, or environmental systems, possibly Middle School science.

Length of Lesson: 90 minutes

Purpose: In this lesson, students are asked to investigate how the orientation and tilt of solar panels affects their energy production at time scales from days to years.

Objectives:

- Understand that the angle of incidence of light on a solar panel is a control on its output. Know that the output varies with the sine of the angle between the sun and the surface.
- Be able to relate solar energy production changes to the seasons and to different climates.
- Know that there are other factors like temperature, clouds, shadows, and absorption by the atmosphere that influence solar energy production.
- Understand that fixed solar panel orientations are a compromise to get the most energy for a year.
- Analyze data in graphs and draw conclusions
- Use the Internet to gather and analyze data

Student background: Students should be familiar with the changing position of the sun with the changing seasons. Basic trigonometry is mentioned in one question.

TEKS addressed

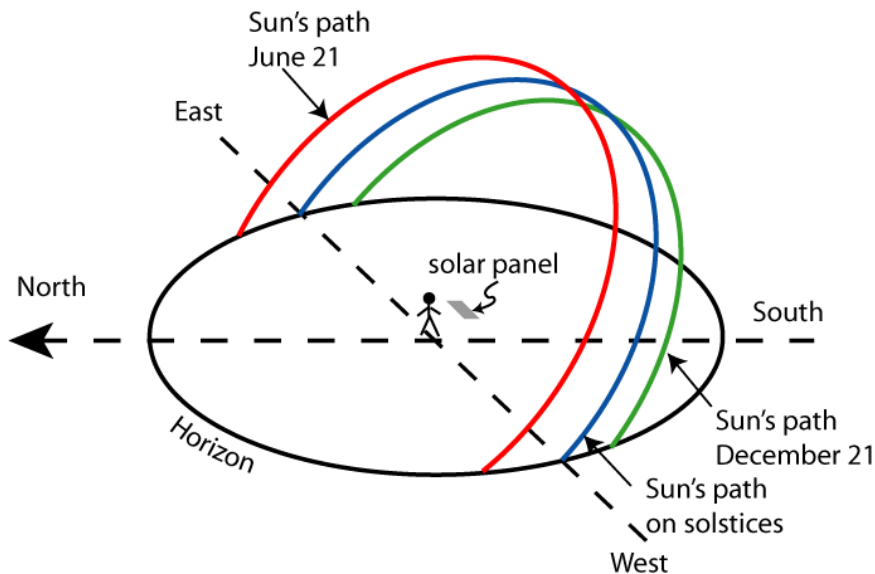
§112.33. Astronomy, Beginning with School Year 2010-2011

(c) (8) (C) recognize that the angle of incidence of sunlight determines the concentration of solar energy received on the Earth at a particular location

§112.37. Environmental Systems, Beginning with School Year 2010-2011

(c) (6) (B) describe and compare renewable and non-renewable energy derived from natural and alternative sources

Equipment and Supplies: A computer or computers with Internet access.



We know that the sun changes its route through the sky with the seasons. The diagram above shows this from the viewpoint of a person in the mid-latitudes of the northern hemisphere. We want to answer one question: How do we orient a solar panel to collect the most solar energy? That is, which direction do we point them and how much should the panels be tilted? To get the most energy from solar panels, they must be pointed in the direction that captures the most sun. There are a number of variables in figuring out the best orientation.

Let's look at the energy output of some existing solar panels. If you have access to the Internet go to <http://infinitepower.soltrex.com/> and register (OR HAVE YOUR TEACHER REGISTER) at <http://infinitepower.soltrex.com/mysoltrex/account.cfm?myaction=register> to access solar energy collection data from a large number of Texas schools and other facilities supported by the Texas State Energy conservation Office (SECO). When you are logged in, click on the link "Explore systems" <http://infinitepower.soltrex.com/systems.cfm> or the "Create customized graphs and charts" link. Use the graphs at the end of this lesson if you do not have Internet access.

In the *Graph Controls* on the right select **Kendall Elementary School** for the *System*. Set the *Beginning* date to a year **earlier than today's date** (reduce the year by one). Set the *Interval* to **Day** and the *Data Set* to **Energy Production (kWh)**. Then click the *Refresh Graph* button. You should get a day-by-day record of energy production for the year. Why are there big differences in output day to day? To help answer this question you may want to compare the Kendall School graph to the graph of the same period for the Gene Roddenberry Planetarium (El Paso, TX) by changing the *System* selection in the *Graph Controls*. What is the climate like in El Paso? The local climate is an important control on potential solar energy use. See <http://www.nrel.gov/rredc/pvwatts/version2.html>

If you have time, check out other systems from across the state and see how they vary. Where is the nearest array to your school?

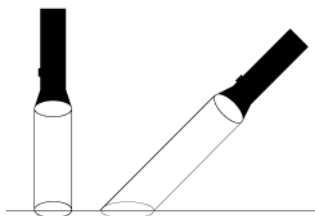
Go back to the Kendall School data and click on the *Systems details* link. Note the direction the array is pointing, the Array Azimuth (180°, due south) and the Array Tilt (35°) and then go back to the graph.

If you mentally connect the tops of the highest points on the graph (the sunny days) you get a curve that has two high points and two low points.

- 1) Why does this "sunny day" value change during the year? Note the dates of the solstices and equinoxes on the graph. Where are they located compared with the seasonal the highs and lows in the top line? Look at the diagram of the path of the sun at different times of the year (top of the page) and consider what you know about the seasons.
- 2) At what time of the year does the sun spend the most time above the horizon —yielding the longest days?
- 3) At what time of the year is the sun highest in the sky?
- 4) Is this the time of the highest output of the solar panel? Why not?

The "why not" is not a simple question. Several things affect how much energy reaches a solar panel.

- 5) What direction is the Array pointed? Check the Array Azimuth on the on the Systems details link. The Kendal Elementary School's array is pointed due south, 180°. Is this the best direction? Sometime a convenient mounting surface dictates the Array Azimuth. For example, check the system details for Bryker Woods Elementary School (Austin, TX).
- 6) The length of the day should affect the amount of solar energy. Does the graph show evidence of more solar energy reaching the panel when days are longer in the summer?
- 7) Look at the diagram of the sun's yearly path. In the summer, where does the sun rise and set compared the plane of the solar panel? (Behind it!)
- 8) Is it important for energy generation that the Sun's rays hit the panel at a high angle? Consider the diagram



to the left. If you had a flashlight that put out a certain amount of light (energy) it would put its light into a smaller area if it is pointed at a high angle to the surface than if it is at a low angle. Using trigonometry, calculate the difference in energy per area between a beam perpendicular to the surface and one that is inclined 45°. [The energy (light) per area decreases as the sine of the angle. So with the sun at 45° from the surface of the solar panel you get 0.7071 times the energy as you would with it beating down at a right angle (the sine of 45° is 0.7071)].

- 9) What is the Array tilt for Kendall School? This angle was chosen, for the most part, to maximize the amount of solar energy collection over the whole year without changing the tilt. It is a compromise. Typically, fixed panels are inclined at an angle close to the site's latitude. What is Austin's latitude? Is this the same as the Array tilt at Kendall?

- 10) Looking at the diagram at the beginning of this exercise, what times of year represent the “average” path of the sun during the year? What dates on the *energy production versus date* graphs are highest (ignoring low values due to cloudy days)?
- 11) Do you think that this solar array might have obstructions (buildings, trees) blocking the sun in the morning or near sunset? How could you improve efficiency if it does? Consider your answers to question 9.
- 12) Does solar panel input get reduced when the sun is lower in the sky than when it is high in the sky due to absorption by a thicker layer of atmosphere?

So, how do you calculate the fixed angle between the sun and the surface of a solar panel so you can maximize the average angle between the sun and the panel surface? Look at the first figure in this exercise. The angle changes minute by minute during the day as the sun arcs from the east to noon to the west. It also changes each day as the sun rises in a new spot on the horizon, travels to a new noontime high position, and sets in a new spot. This long calculation has been worked out by the US Naval Observatory <http://aa.usno.navy.mil/data/docs/AltAz.php>

Links you may find useful.

<http://www.macslab.com/optosolar.html> Observations and calculations of the best array tilt by Charles R. Landau
http://www.nrel.gov/rredc/solar_resource.html The National Renewable Energy Laboratory has data on solar energy at different locations including a solar performance calculator.

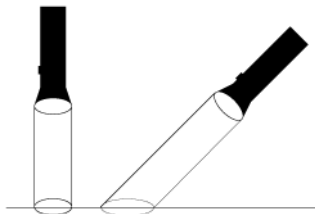
The US Naval Observatory <http://aa.usno.navy.mil/data/docs/AltAz.php>

Sample answers to questions

- 1) Why does this “sunny day” value change during the year? **Because the position of the sun changes with the seasons.** Note the dates of the solstices and equinoxes on the graph. Where are they located compared with the seasonal the highs and lows in the top line? **At the highs.** Look at the diagram of the path of the sun at different times of the year (top of the page) and consider what you know about the seasons.
- 2) At what time of the year does the sun spend the most time above the horizon —yielding the longest days? **Summer**
- 3) At what time of the year is the sun highest in the sky? **Summer**
- 4) Is this the time of the highest output of the solar panel? **No it’s higher Spring and Fall at the equinoxes!** Why not?

The “why not” is not a simple question. Several things affect how much energy reaches a solar panel.

- 5) What direction is the Array pointed? Check the Array Azimuth on the on the Systems details link. The Kendal Elementary School’s array is pointed **due south, 180°**. Is this the best direction? **Yes, unless there are trees or buildings that shade the array.** Sometime a convenient mounting surface dictates the Array Azimuth. For example, check the system details for Bryker Woods Elementary School (Austin, TX).
- 6) The length of the day should affect the amount of solar energy. Does the graph show evidence of more solar energy reaching the panel when days are longer in the summer? **Although more energy does reach the panel due to the length of day other factors hide this in the graph.**
- 7) Look at the diagram of the sun’s yearly path. In the summer, where does the sun rise and set compared the plane of the solar panel? **Slightly behind it, to the north of due east and west.**
- 8) Is it important for energy generation that the Sun's rays hit the panel at a high angle? Consider the diagram



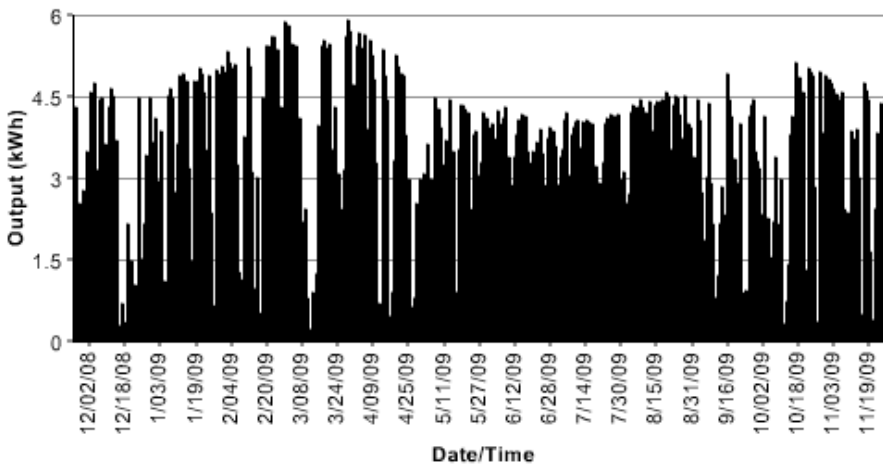
to the left. If you had a flashlight that put out a certain amount of light (energy) it would put its light into a smaller area if it is pointed at a high angle to the surface than if it is at a low angle. Using trigonometry, calculate the difference in energy per area between a beam perpendicular to the surface and one that is inclined 45°. [The energy (light) per area decreases as the sine of the angle. So with the sun at 45° from the surface of the solar panel you get 0.7071 times the energy as you would with it beating down at a right angle (the sine of 45° is 0.7071)].

- 9) What is the Array tilt for Kendall School? **(35°)** This angle was chosen, for the most part, to maximize the amount of solar energy collection over the whole year without changing the tilt. It is a compromise.

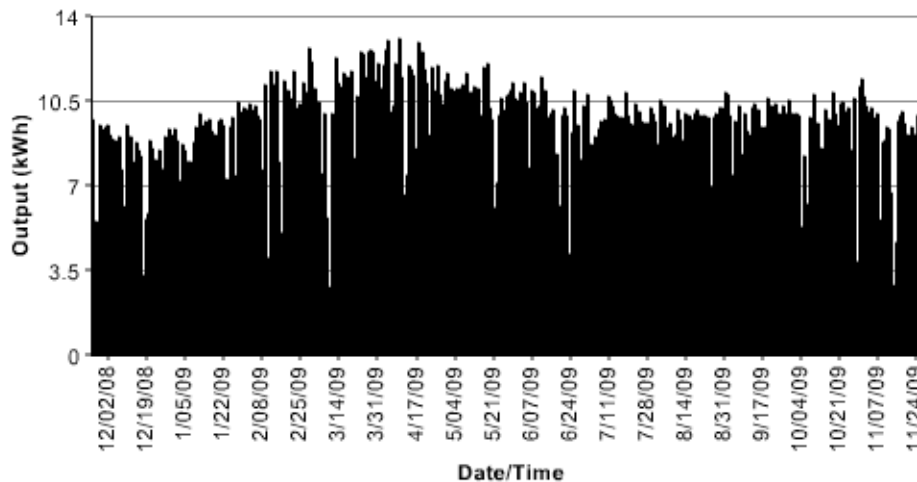
Typically, fixed panels are inclined at an angle close to the site’s latitude. What is Austin’s latitude? **30 degrees N** Is this the same as the Array tilt at Kendall?

- 10) Looking at the diagram at the beginning of this exercise, what times of year represent the “average” path of the sun during the year? **Equinoxes** What dates on the *energy production versus date* graphs are highest (ignoring low values due to cloudy days)? **Equinoxes**
- 11) Do you think that this solar array might have obstructions (buildings, trees) blocking the sun in the morning or near sunset? **Probably not** How could you improve efficiency if it does? Consider your answers to question 9.
- 12) Does solar panel input get reduced when the sun is lower in the sky than when it is high in the sky due to absorption by a thicker layer of atmosphere? **Yes**

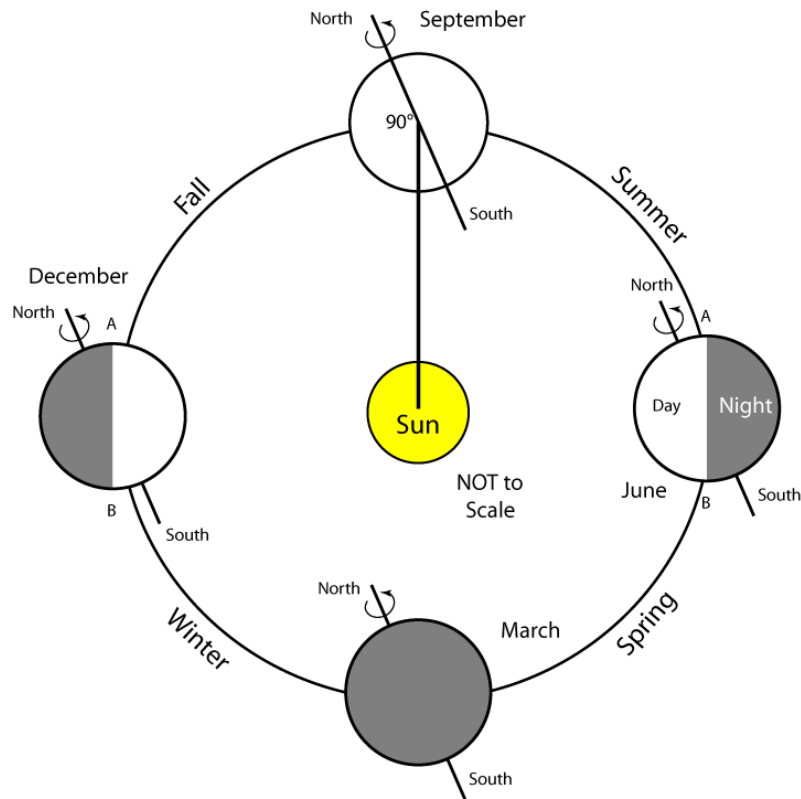
Kendall Elementary School (Boerne, TX) ▶ [System details](#)
 Power output in kilowatt-hours (kWh) Nov 24, 2008 - Nov 29, 2009



Gene Roddenberry Planetarium (El Paso, TX) ▶ [System details](#)
 Power output in kilowatt-hours (kWh) Nov 24, 2008 - Nov 29, 2009



A Review of the Seasons



The Earth's rotation axis makes an angle of about 23.5 degrees with the direction perpendicular to the plane of the ecliptic (the plane of Earth's orbit). The angle between the Earth's axis and the Earth-Sun line changes throughout the year. Twice a year, at the spring and fall equinox (around March 21 and September 22) the two lines are perpendicular (in the diagram the Earth's axis is tilted to the side, but it's still 90° to a line to the sun). At the summer solstice, around June 21, the North Pole is inclined towards the Sun (90° minus 23.5°). At the winter solstice, around December 21, it is inclined away from it 90° plus 23.5°. The seasons are NOT due to the sun being closer or farther from the sun at different times of the year. The sun is actually a little closer in the winter!

Summer and Winter

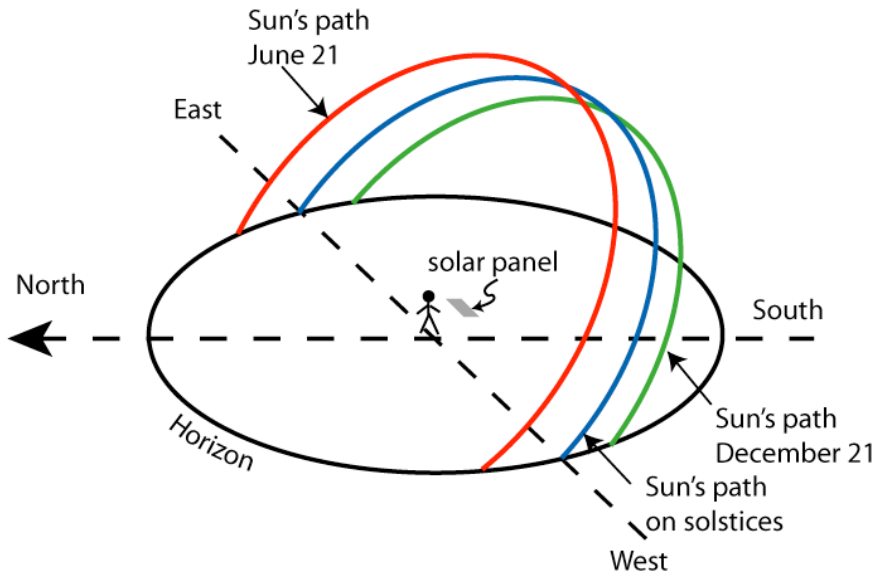
Look at the summer solstice first on the right side of the diagram. The boundary AB between sunlight and shadow--between day and night--is always perpendicular to the Earth-Sun line, but because of the tilted axis, as each point on Earth is carried on its daily trip on the rotating Earth, the part of the trip spent in daylight (unshaded part of the drawing) and in the night (shaded) are not equal.

- 1) In summer in the northern hemisphere which is longer day or night?
- 2) How long is the day at the North Pole on June 21?
- 3) How far north do you have to go to have a 24 hour day on June 21?
- 4) How high would the sun be at noon on that day?

North of the equator in summer, day is longer than night. On the summer solstice north of about 66.5° latitude, (the Arctic circle) there is no night at all. The Sun is just above the horizon and it makes a 360-degree circuit around it.

A mirror-image situation exists south of the equator. Nights are longer than days, and the further one gets from the equator, the larger is the imbalance--until one gets so close to the pole that the sun never rises. In that half of the Earth, it is wintertime. Half a year later, the Earth is on the other side of the Sun (left side of diagram). The Earth's axis however has not moved, it is still pointed to the area near the North Star, Polaris. Now the South Pole is bathed in constant sunshine and the north one is dark. Summer and winter have switched hemispheres.

WORKSHEET - Optimum Orientation of Solar Panels Using Soltrex Data



We know that the sun changes its route through the sky with the seasons. The diagram above shows this from the viewpoint of a person in the mid-latitudes of the northern hemisphere. We want to answer one question: How do we orient a solar panel to collect the most solar energy? That is, which direction do we point them and how much should the panels be tilted? To get the most energy from solar panels, they must be pointed in the direction that captures the most sun. There are a number of variables in figuring out the best orientation.

Let's look at the energy output of some existing solar panels. If you have access to the Internet go to <http://infinitepower.soltrex.com/> and register (OR HAVE YOUR TEACHER REGISTER) at <http://infinitepower.soltrex.com/mysoltrex/account.cfm?myaction=register> to access solar energy collection data from a large number of Texas schools and other facilities supported by the Texas State Energy conservation Office (SECO). When you are logged in, click on the link "Explore systems" <http://infinitepower.soltrex.com/systems.cfm> or the "Create customized graphs and charts" link. Use the graphs at the end of this lesson if you do not have Internet access.

In the Graph Controls on the right select Kendall Elementary School for the System. Set the Beginning date to a year earlier than today's date (reduce the year by one). Set the Interval to Day and the Data Set to Energy Production (kWh). Then click the Refresh Graph button. You should get a day-by-day record of energy production for the year. Why are there big differences in output day to day? To help answer this question you may want to compare the Kendall School graph to the graph of the same period for the Gene Roddenberry Planetarium (El Paso, TX) by changing the System selection in the Graph Controls. What is the climate like in El Paso? The local climate is an important control on potential solar energy use. See <http://www.nrel.gov/rredc/pvwatts/version2.html>

If you have time, check out other systems from across the state and see how they vary. Where is the nearest array to your school?

Go back to the Kendall School data and click on the Systems details link. Note the direction the array is pointing, the Array Azimuth (180° , due south) and the Array Tilt (35°) and then go back to the graph.

If you mentally connect the tops of the highest points on the graph (the sunny days) you get a curve that has two high points and two low points.

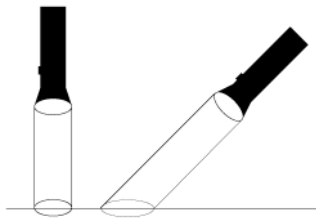
- 1) Why does this "sunny day" value change during the year? Note the dates of the solstices and equinoxes on the graph. Where are they located compared with the seasonal the highs and lows in the top line? Look at the diagram of the path of the sun at different times of the year (top of the page) and consider what you know about the seasons.
- 2) At what time of the year does the sun spend the most time above the horizon —yielding the

longest days?

- 3) At what time of the year is the sun highest in the sky?
- 4) Is this the time of the highest output of the solar panel? Why not?

The “why not” is not a simple question. Several things affect how much energy reaches a solar panel.

- 5) What direction is the Array pointed? Check the Array Azimuth on the on the Systems details link. The Kendal Elementary School’s array is pointed due south, 180°. Is this the best direction? Sometime a convenient mounting surface dictates the Array Azimuth. For example, check the system details for Bryker Woods Elementary School (Austin, TX).
- 6) The length of the day should affect the amount of solar energy. Does the graph show evidence of more solar energy reaching the panel when days are longer in the summer?
- 7) Look at the diagram of the sun’s yearly path. In the summer, where does the sun rise and set compared the plane of the solar panel? (Behind it!)
- 8) Is it important for energy generation that the Sun's rays hit the panel at a high angle? Consider the diagram to the left. If you had a flashlight that put out a certain amount of light (energy) it would put its light into a smaller area if it is pointed at a high angle to the surface than if it is at a low angle. Using trigonometry, calculate the difference in energy per area between a beam perpendicular to the surface and one that is inclined 45°. [The energy (light) per area decreases as the sine of the angle. So with the sun at 45° from the surface of the solar panel you get 0.7071 times the energy as you would with it



beating down at a right angle (the sine of 45° is 0.7071)].

- 9) What is the Array tilt for Kendall School? This angle was chosen, for the most part, to maximize the amount of solar energy collection over the whole year without changing the tilt. It is a compromise. Typically, fixed panels are inclined at an angle close to the site’s latitude. What is Austin’s latitude? Is this the same as the Array tilt at Kendall?
- 10) Looking at the diagram at the beginning of this exercise, what times of year represent the “average” path of the sun during the year? What dates on the *energy production versus date* graphs are highest (ignoring low values due to cloudy days)?
- 11) Do you think that this solar array might have obstructions (buildings, trees) blocking the sun in the morning or near sunset? How could you improve efficiency if it does? Consider your answers to question 9.
- 12) Does solar panel input get reduced when the sun is lower in the sky than when it is high in the sky due to absorption by a thicker layer of atmosphere?

So, how do you calculate the fixed angle between the sun and the surface of a solar panel so you can maximize the average angle between the sun and the panel surface? Look at the first figure in this exercise. The angle changes minute by minute during the day as the sun arcs from the east to noon to the west. It also changes each day as the sun rises in a new spot on the horizon, travels to a new noontime high position, and sets in a new spot. This long calculation has been worked out by the US Naval Observatory

<http://aa.usno.navy.mil/data/docs/AltAz.php>

Links you may find useful.

<http://www.macslab.com/optisolar.html> Observations and calculations of the best array tilt by Charles R. Landau

http://www.nrel.gov/rredc/solar_resource.html The National Renewable Energy Laboratory has data on solar energy at different locations including a solar performance calculator.

The US Naval Observatory <http://aa.usno.navy.mil/data/docs/AltAz.php>