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Tilt and Angle Orientation of Solar Panels

To get the most from position-fixed (or seasonally adjusted) photovoltaic or thermal solar panels, you need to point them in the direction that captures the most sun.

Solar panels should always face true south in the Northern Hemisphere, North in the Southern Hemisphere, tilted from the hoizontal at a degree equal to your latitude plus 15 degrees in winter, or minus 15 degrees in summer.

An additional 3 - 5%, though, can be gained by evaluating this more carefully.

Winter

The winter season has the least sun, so you want to make the most of it. The tilt should be designed so that the panel points directly at the sun at noon. To calculate, multiply your latitude by 0.9, and add 30 degrees.

For example: New York is at 40 degrees. 40 X .9 + 30 = 66 degrees tilt from horizontal.

See below for a list of cities and their latitudes.

Solar Seasons

Many systems allow for a manual adjustment. Adjustments should be made around March 1, April 19, August 23, and October 14th for the Northern hemisphere, half year later for the southern hemispehere.

Tilt angle: spring and autumn - latitude minus 2.5°.
Tilt angle for summer - 52.5° less than the winter angle.

These recommendations are based on sea level with an unobstructed view of the sky. At altitude, lowering the angle of tilt by a few degrees will capture more sunlight when the sun is lower in the sky. Thinner atmospehere will permit a better harvest of sunlight.

City	Latitude. n.		Longitude w.	
	°	'	°	'
Albany, N.Y.	42	40	73	45
Albuquerque, N.M.	35	05	106	39
Amarillo, Tex.	35	11	101	50
Anchorage, Alaska	61	13	149	54
Atlanta, Ga.	33	45	84	23
Austin, Tex.	30	16	97	44
Baker, Ore.	44	47	117	50
Baltimore, Md.	39	18	76	38
Bangor, Maine	44	48	68	47
Birmingham, Ala.	33	30	86	50
Bismarck, N.D.	46	48	100	47
Boise, Idaho	43	36	116	13
Boston, Mass.	42	21	71	5
Buffalo, N.Y.	42	55	78	50
Calgary, Alba., Can.	51	1	114	1
Carlsbad, N.M.	32	26	104	15
Charleston, S.C.	32	47	79	56
Charleston, W. Va.	38	21	81	38
Charlotte, N.C.	35	14	80	50
Cheyenne, Wyo.	41	9	104	52
Chicago, Ill.	41	50	87	37
Cincinnati, Ohio	39	8	84	30
Cleveland, Ohio	41	28	81	37
Columbia, S.C.	34	0	81	2
Columbus, Ohio	40	0	83	1
Dallas, Tex.	32	46	96	46
Denver, Colo.	39	45	105	0
Des Moines, Iowa	41	35	93	37
Detroit, Mich.	42	20	83	3
Dubuque, Iowa	42	31	90	40
Duluth, Minn.	46	49	92	5
Eastport, Maine	44	54	67	0
Edmonton, Alb., Can.	53	34	113	28
El Centro, Calif.	32	38	115	33
El Paso, Tex.	31	46	106	29
Eugene, Ore.	44	3	123	5
Fargo, N.D.	46	52	96	48
Flagstaff, Ariz.	35	13	111	41
Fort Worth, Tex.	32	43	97	19
Fresno, Calif.	36	44	119	48
Grand Junction, Colo.	39	5	108	33
Grand Rapids, Mich.	42	58	85	40
Havre, Mont.	48	33	109	43
Helena, Mont.	46	35	112	2
Honolulu, Hawaii	21	18	157	50
Hot Springs, Ark.	34	31	93	3
Houston, Tex.	29	45	95	21
Idaho Falls, Idaho	43	30	112	1
Indianapolis, Ind.	39	46	86	10
Jackson, Miss.	32	20	90	12
Jacksonville, Fla.	30	22	81	40

Juneau, Alaska	58	18	134	24
Kansas City, Mo.	39	6	94	35
Key West, Fla.	24	33	81	48
Kingston, Ont., Can.	44	15	76	30
Klamath Falls, Ore.	42	10	121	44
Knoxville, Tenn.	35	57	83	56
Las Vegas, Nev.	36	10	115	12
Lewiston, Idaho	46	24	117	2
Lincoln, Neb.	40	50	96	40
London, Ont., Can.	43	2	81	34
Long Beach, Calif.	33	46	118	11
Los Angeles, Calif.	34	3	118	15
Louisville, Ky.	38	15	85	46
Manchester, N.H.	43	0	71	30
Memphis, Tenn.	35	9	90	3
Miami, Fla.	25	46	80	12
Milwaukee, Wis.	43	2	87	55
Minneapolis, Minn.	44	59	93	14
Mobile, Ala.	30	42	88	3
Montgomery, Ala.	32	21	86	18
Montpelier, Vt.	44	15	72	32
Montreal, Que., Can.	45	30	73	35
Moose Jaw, Sask., Can.	50	37	105	31
Nashville, Tenn.	36	10	86	47
Nelson, B.C., Can.	49	30	117	17
Newark, N.J.	40	44	74	10
New Haven, Conn.	41	19	72	55
New Orleans, La.	29	57	90	4
New York, N.Y.	40	47	73	58
Nome, Alaska	64	25	165	30
Oakland, Calif.	37	48	122	16
Oklahoma City, Okla.	35	26	97	28
Omaha, Neb.	41	15	95	56
Ottawa, Ont., Can.	45	24	75	43
Philadelphia, Pa.	39	57	75	10
Phoenix, Ariz.	33	29	112	4
Pierre, S.D.	44	22	100	21
Pittsburgh, Pa.	40	27	79	57
Portland, Maine	43	40	70	15
Portland, Ore.	45	31	122	41
Providence, R.I.	41	50	71	24
Quebec, Que., Can.	46	49	71	11
Raleigh, N.C.	35	46	78	39
Reno, Nev.	39	30	119	49
Richfield, Utah	38	46	112	5
Richmond, Va.	37	33	77	29
Roanoke, Va.	37	17	79	57
Sacramento, Calif.	38	35	121	30
St. John, N.B., Can.	45	18	66	10
St. Louis, Mo.	38	35	90	12
Salt Lake City, Utah	40	46	111	54

San Antonio, Tex.	29	23	98	33
San Diego, Calif.	32	42	117	10
San Francisco, Calif.	37	47	122	26
San Jose, Calif.	37	20	121	53
San Juan, P.R.	18	30	66	10
Santa Fe, N.M.	35	41	105	57
Savannah, Ga.	32	5	81	5
Seattle, Wash.	47	37	122	20
Shreveport, La.	32	28	93	42
Sioux Falls, S.D.	43	33	96	44
Sitka, Alaska	57	10	135	15
Spokane, Wash.	47	40	117	26
Springfield, Ill.	39	48	89	38
Springfield, Mass.	42	6	72	34
Springfield, Mo.	37	13	93	17
Syracuse, N.Y.	43	2	76	8
Tampa, Fla.	27	57	82	27
Toledo, Ohio	41	39	83	33
Toronto, Ont., Can.	43	40	79	24
Tulsa, Okla.	36	09	95	59
Vancouver, B.C., Can.	49	13	123	06
Victoria, B.C., Can.	48	25	123	21
Virginia Beach, Va.	36	51	75	58
Washington, D.C.	38	53	77	02
Wichita, Kan.	37	43	97	17
Wilmington, N.C.	34	14	77	57
Winnipeg, Man., Can.				

MORE -Optimum Orientation of Solar Panels

To get the most from solar panels, you need to point them in the direction that captures the most sun. But there are a number of variables in figuring out the best direction. This page is designed to help you find the best placement for your solar panels in your situation.

This advice applies to any type of panel that gets energy from the sun; photovoltaic, solar hot water, etc. We assume that the panel is fixed, or has a tilt that can be adjusted seasonally. (Panels that track the movement of the sun throughout the day can receive 10% (in winter) to 40% (in summer) more energy than fixed panels. This page doesn't discuss tracking panels.)

Solar panels should always face true south. (If you are in the southern hemisphere, they should face north.) The question is, at what angle from horizontal should the panels be tilted? Books and articles on solar energy often give the advice that the tilt should be equal to your latitude, plus 15 degrees in winter, or minus 15 degrees in summer. It turns out that you can do better than this - about 4% better.

Optimum Tilt for Winter

The winter season has the least sun, so you want to make the most of it. To calculate the best angle of tilt in the winter, take your latitude, multiply by 0.9, and add 29 degrees. The result is the angle from the horizontal at which the panel should be tilted. This table gives the angle for some latitudes:

Latitude	Angle	% of optimum
25° (Key West, Taipei)	51.5°	85%
30° (Houston, Cairo)	56°	86%
35° (Albuquerque, Tokyo)	60.5°	88%
40° (Denver, Madrid)	65°	89%
45° (Minneapolis, Milano)	69.5°	91%
50° (Winnipeg, Prague)	74°	93%

These angles are about 10° steeper than what is commonly recommended. The reason is that in the winter, most of the solar energy comes at midday, so the panel should be pointed almost directly at the sun at noon.

The third column of the table shows how well this orientation will do compared with the best possible tracker that always keeps the panel pointed directly at the sun.

Other Seasons

If you are going to adjust the tilt of your panels four times a year, the best dates to do it are when the "solar season" changes. The table below gives the dates of each "solar season". (If you are in the southern hemisphere, you need to adjust these dates by half a year.)

Winter	October 13 to February 27
Spring	February 27 to April 20
Summer	April 20 to August 22
Autumn	August 22 to October 13

Fixed Tilt

If your need for energy is highest in the winter, or the same throughout the year, you probably want to just leave the tilt at the winter setting. Although you could get more energy during other seasons by adjusting the tilt, you will get enough energy without making any adjustment. The following tables assume that the tilt is set at the winter optimum all year long. They show the amount of insolation (in kWh/m^2) on the panel each day, averaged over the season.

Latitude 30°		
Season	Insolation on panel	% of winter insolation
Winter	5.3	100%
Spring, Autumn	5.6	106%
Summer	4.5	85%

Latitude 40°		
Season	Insolation on panel	% of winter insolation
Winter	4.3	100%
Spring, Autumn	5.3	123%
Summer	4.5	105%

Latitude 50°		
Season	Insolation on panel	% of winter insolation
Winter	2.9	100%
Spring, Autumn	4.9	169%
Summer	4.5	155%

Adjusting the Tilt for Other Seasons

Keeping the angle of tilt set for winter may not be best for you. For example, you may need more energy in the summer to pump irrigation water. Or maybe you have a cabin that is not used in the winter.

The optimum angle of tilt for the spring and autumn is the latitude minus 2.5°. The optimum angle for summer is 52.5° less than the winter angle. This table gives some examples:

Latitude	Spring/Autumn angle	Insolation on panel	% of optimum	Summer angle	Insolation on panel	% of optimum
25°	22.5	6.5	75%	-1.0	7.3	75%
30°	27.5	6.4	75%	3.5	7.3	74%
35°	32.5	6.2	76%	8	7.3	73%
40°	37.5	6.0	76%	12.5	7.3	72%
45°	42.5	5.8	76%	17.0	7.2	71%
50°	47.5	5.5	76%	21.5	7.1	70%

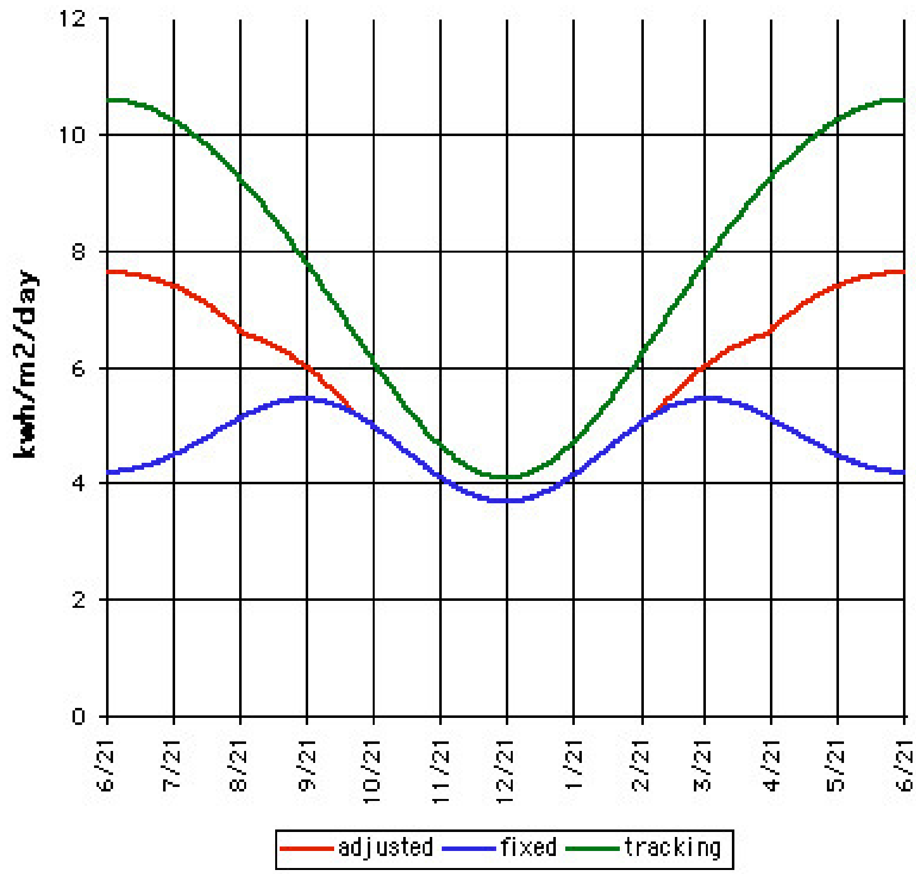
If you want to adjust the tilt of your panels four times a year, you can use these figures to keep capturing the most energy year-round.

Note that the summer angles are about 12 degrees flatter than is usually recommended. In fact, at 25° latitude in summer, the panel should actually be tilted slightly to the north.

It is interesting to note that all the temperate latitudes bask almost equally in the warmth of summer.

The efficiency of a fixed panel, compared to optimum tracking, is lower in the spring, summer, and autumn than it is in the winter, because in these seasons the sun covers a larger area of the sky, and a fixed panel can't capture as much of it. These are the seasons in which tracking systems give the most benefit.

The following graph shows the effect of adjusting the tilt. The blue line is the amount of solar energy you would get each day if the panel is fixed at the winter angle. The red line shows how much you would get by adjusting the tilt four times a year as described above. For comparison, the green line shows the energy you would get from two-axis tracking, which always points the panel directly at the sun. These figures are calculated for 40° latitude.



Time-of-Use Rates

In some grid-connected systems, energy is more valuable during peak periods. To see the effect of this on panel orientation, look at my time-of-use page .

Assumptions

These calculations are based on an idealized situation. They assume that you have an unobstructed view of the sky, with no trees, hills, clouds, or haze ever blocking the sun.

You may need to make adjustments for your situation. For example, if you have trees to the east but not the west, it may be better for you to aim your solar panels slightly to the west. Or if you often have clouds in the afternoon but not the morning, you might aim your panels slightly to the east.

The calculations also assume that you are near sea level. At high altitude, there is less atmosphere to absorb light, so it is more important to capture sunlight near sunrise and sunset. At high altitude it might be better to lower the angle of tilt a little.

How these numbers were calculated

For each configuration of latitude and season, over 12,000 data points were calculated for various times throughout the day and the year. For each data point, the equations of celestial mechanics were used to determine the height and azimuth of the sun. The intensity of the sun was corrected to account for the increased absorption by the atmosphere when the sun is lower in the sky, using the formula:

$$\text{intensity in } kw/m^2 = 1.35 * (1.00/1.35)^{\sec(\text{angle of sun from zenith})}$$

These factors, and the angle of the sun with respect to the panel, then determine the insolation on the panel. An iterative method then determined the angles that give the maximum total insolation during each season. Given those angles, the beginning and ending dates of the season were then adjusted to the optimum, then the angles recalculated, until the process converged. After the optimum dates and angles were calculated, it was determined that a linear formula approximates the optimum closely.

Other published articles on tilt angles have used less accurate calculations. For example, Richard Perez and Sam Coleman, in "PV Module Angles", Home Power n.34 p.14-16, 1993 , recommend an angle that puts the panel perpendicular to the sun's rays at noon. That is indeed the best angle at noon on that day, but it does not take into account the best angle for capturing solar energy at other times of the day. That article also leaves it to the reader to estimate the best angle over the period until the next time the tilt is adjusted.

Percentages may not be exact due to rounding.