Solar Hot Water Fundamentals

Siting, Design, and Installation

Peter Skinner, P.E., with Todd Paternoster,
Will Skinner, Betsy Ferris Wyman, and Alan Paul

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GREEN MECHANICAL COUNCIL

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We are very grateful to Michael Fredericks of Ghent, NY for his professional photographs for our cover and of components featured in the textbook. He captured the cover photo of a home in Ghent, NY in the summer of 2012 which features not only a large photovoltaic array but also a two panel drainback domestic hot water array and 11 panel pool heating array. These systems were installed by SunDog Solar and E2G Solar, design and installation firms located in upstate New York.

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Second Edition, July 2012

We dedicate this book to the guys and gals sweltering or freezing on the roof, crawling through the attic and still sloshing in the basement at 6 pm. All the theory and practice guidance that we have put into this book should help you better understand why the system is working, how of fix it when it doesn't and how to stay safe. It will also help you avoid mistakes and make your systems more reliable and efficient. Slow down, ask questions, choose the right equipment and use the best tools skillfully. In the end, your experience and knowledge will create great installs and satisfied customers, save energy and cool our climate and even put a little money in your pocket. Thanks for all you do!

E2G Solar LLC — A Solar Thermal Collaborative

E2G Solar is a center for professionals passionate about solar thermal system design, installation and learning Innovation. Led by veteran professional engineer, Peter Skinner, E2G Solar is a true collaborative of scientists and engineers who team up to conquer any thermal system or education project opportunity. Much more information is available on its website, www.e2gsolar.com.

Author Pete Skinner

E2G Solar staff has designed, simulated performance, built and comprehensively monitored dozens of state of the art solar thermal systems for residential and commercial clients systems across the nation from Maine to Alaska. Our unique expertise allows us to explore integration of solar thermal systems with all kinds of heat creation, transfer and storage equipment in the HVACR world from the newest devices to traditional wood fired heaters.

In addition to its design and installation work, E2G Solar offers a complete solar thermal education program consisting of long and short courses for students and trainers, hands-on mobile teaching devices, curriculum packages, system animations and learning manipulative tools. We continually upgrade our programs to keep pace with developments in the solar, building technology, HVACR and education technology fields.

For more information about what E2G Solar can do to enhance your project and help make it happen, please contact the company through email at e2g@verizon.net.

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INTRODUCTION

Since I was a small kid growing up alongside the Mettawee River in Vermont, I loved moving water. I built low dams in the stream and diverted water in pipes that I scrounged from the barn. After graduating from Lehigh, the engineer at my first job interview pronounced that at Penn State, he'd learned that the five laws of engineering were "Drainage, drainage, drainage, drainage and drainage!" I didn't work for him but applied those laws often in my 33 years of work in the NY Attorney General's Environmental Bureau — and now, in the solar thermal arena as well!

Fast forward to "retirement" and the chance to get my hands dirty with solar thermal systems where drainage is really important. From work in the energy efficiency field, a solar thermal job came my way. With Tom Lane's sage advice and collaboration with Alan Paul of Apex Thermal Services, I built (the hard way, for sure) my first 7 panel drainback — which still works just fine. Designing and installing only custom systems introduced me to all the things that can go wrong — and right. Research and teaching in this field have required me go back to engineering basics that serve as the foundation for what works in this field.

This textbook has grown out of frustration the authors felt with the lack of a SHW book that was organized and simple enough to serve as the basis for a short course on this subject. We pooled our resources and wrote and researched steadily for months to create this book that we hope will serve as the basis for courses all over America, eventually the world.

Since the book's first publication back in early 2011, experts from across America have weighed in and suggested improvements. We reviewed their modifications and integrated as as many changes as the book's current layout allowed. This July 2012 edition reflects these changes.

As solar thermal installers, we are faced with economic challenges from other fuels like natural gas and low cost PV systems. Savvy customers still clamor for systems that are not only reliable and efficient, but "green" as well and many are looking for relief from the stubbornly high heating oil prices. While federal and state incentives make solar systems attractive to customers, these policies may evaporate in the years ahead. We must innovate to stay relevant and in business.

I believe that the greatest opportunity lies in connecting solar thermal systems to other established and emerging technologies effectively. Solar thermal systems can do more than heat domestic hot water; their output can power space heating and cooling and business processes too, especially consistent heat demands for dairies, laundromats, and industrial sites.

Possibly the most exciting is the quiet revolution taking place with heat pump efficiency. We can now combine our solar thermal system outputs with heat pumps to leverage the yields — turning 1 solar BTU into 2, 3, or even 4 useable BTUS! Similarly, advances in web based performance monitoring and PLCs will help us optimize and demonstrate the utility of our systems

C'mon guys and gals — these advances (and many others) in energy collection, transfer and storage offer the solar and HVACR professional an amazing palette of options with which to integrate solar thermal system outputs, especially when excess production during the summer days occurs. All in all, there is a bright future ahead for innovators in this field.

Three decades ago, Darryl Thayer was creating solar thermal hybrids in the Middle West, long before heat pumps offered COPs of 3 and 4 and the web offered real time operating information remotely. We need to grasp embrace his pioneering ingenuity and build excitement for and utility of our systems. This textbook is just the beginning — there's much more to come! Education and curiosity powers innovation!

Pete Skinner, PE

West Sand Lake, NY, July, 2012

ACKNOWLEDGEMENTS

As the spark plug for this book, I want to recognize the hard work and knowledge of my collaborators who have made this book happen. A particular nod goes to William Skinner who took a break from other career opportunities and adventures to pull all the pieces together, keep the original authors on track, get the text and illustrations to match and even do some of the esoteric solar and hydronics math. Also, without the artistry and skills of our publication designer Ron Toelke and technical illustrator Terrel Broiles, this book would be only words on paper rather than an attractive and compelling presentation. We also owe a debt of gratitude to Adam Farrell of SunMaxx Solar and Jody Rael of SunDog Solar for giving Todd Paternoster and Betsy Wyman the time they needed to prepare their sections of the original version. Without the research and writing of Mark Graham and Alan Paul, this book would have big holes in the roofing and electrical areas. Thanks also to Jack Kennedy, the business manager at E2G, and to Luke Forster for his help revising this book. We owe special thanks to our publishers at ESCO, especially Renee Tomlinson.

After the initial publication of this textbook, we exposed it to a wide array of solar thermal installers and experts in the field. We also dug deeper into some of the topics which have been the subject of debate and became familiar with new equipment and operating procedures and innovative ways to integrate solar thermal systems for residential and commercial applications. We want to thank all these professionals for their contributions and look forward to issuance of a new edition that will give a more complete treatment of the topics that they explored.

I want to also thank the following contributors and reviewers: David Block, Dr. Barry Butler, Robert Cooley, Mark Graham, Steve Harrison, Todd Hoitsma, Greg MacLeod, Chuck Marken, Jeremy Mills, Fortunat Mueller, Morgan Pileggi, Robert Rohr, John Siegenthaler, Darryl Thayer, Vaughan Woodruff.

This dish symbolizes one of many bold directions solar thermal systems are going today. As our industry matures, technology pioneers will create the shape of an exciting future for solar. Installing solar thermal systems to preheat domestic hot water alone is just the start; the greatest opportunity for solar thermal lies in combining it with emerging technologies. To stay ahead and remain relevant, clever installers must consider innovative ways to integrate their solar thermal systems with all kinds of different heating, cooling and energy storage systems. Innovative integration will be the foundation of a sustainable future for both our earth and our business. Education and ingenuity are the keys to unlock the full possibilities of solar thermal systems. Our textbook is just the beginning.

Solar dish: Client Paul Adler (left) and *Solar Hot Water Fundamentals* principal author and installer, Peter Skinner, pose next to the Solarbeam 2-axis tracking parabolic solar thermal collector they installed at Martha's Vineyard in 2012. The heat collected by this dish is stored in three 120 gallon tanks sequenced to heat Paul's hot water and swimming pool. In colder months, the system helps out with the nearby home's space heat demands as well. (See page 90 for an example of the efficiency curve for tracking parabolic dishes). We hope that our textbook will serve as a foundation for 1000s of innovations like this dish.

The future belongs to innovators.

Pete Skinner

1 Solar Site Assessments

There has never been a better time to become a solar hot water installer. Oil prices are volatile, but inevitably rising. People across the country are getting excited about "going green," through techniques such as energy efficiency, sustainability, and renewable energy sources like wind and solar. And federal and state agencies have programs which can help jump-start the renewable energy market. These factors make solar systems more attractive and affordable than ever for consumers, and business is booming! There's money to be made by installers! This should be music to the ears of anyone trying to make ends meet in the current economy. In addition to creating business opportunities, solar thermal systems can save clients money as well. It's a win-win!

America's love affair with oil and coal has blinded us to the huge waste of free energy from the sun. As we fly around the western hemisphere teaching about solar thermal systems, we rarely see roof tops with solar panels — even in the sunny southwest. We call it "The Great American Solar Spill." Every single day, there is more energy being reflected (spilled) away from buildings than has been spilled in the Gulf of Mexico during all the oil spills ever. This wasted energy causes us to buy and burn far more dirty fossil fuels than we need. To save money and the environment, Americans need to work together to plug our solar spill and move toward energy independence.

Figure 1-1: The power of the sun.

Solar thermal is a powerful and simple technology that can help residential and commercial clients save money on their heating bills and reduce their carbon footprint. As we begin to learn about solar thermal systems, it's important to understand exactly what they can and cannot do.

Solar Thermal systems produce hot water — *not electricity*. This hot water can be used for many things, including:

- **Domestic hot water (DHW).** This is the hot water that is used for sinks, showers, laundry, dishwashing, etc.
- **Pool heating.** Many people like to keep their pools warm and they want to extend the swimming season — earlier in the spring and later into the fall. Meeting these objectives requires a large amount of energy. Solar panels are especially efficient at heating pools, and a relatively cheap pool-heating system can save clients thousands of dollars in heating costs each year.
- **Space heating.** Solar thermal systems are not as cost-effective for space heating as they are for pool heating, but they can supplement heat supplied by boilers and furnaces to provide space heating or radiant floor heating.
- **Commercial purposes.** Solar thermal systems can be used to provide hot water for loads such as cleaning milking equipment, laundromat loads, or car wash water. This solar-created hot water reduces the amount of oil, gas, or electricity otherwise used for these purposes.

A solar thermal system can not produce 100% of the hot water needs of a home all year round. Remember, solar production depends on the sun conditions. During the sunny summer months, the system may produce more hot water than the client needs. However, if the weather turns cold and cloudy for several days straight, the solar panels will probably not be able to produce all the heat needed (see Figure 1-3). As a result, **solar thermal systems need to be mated with some kind of backup heater.** Often, you can leave the client's existing hot water heater in place, link it into the solar system, and simply use it less often, because the solar system is producing enough heat. A solar system will also not replace the client's boiler, used for heating the home. However, the solar energy can supplement the boiler's output and help it use less energy!

Figure 1-2: Bathtub filled with solar-heated hot water.

Solar thermal heat production is more efficient than producing electricity from sunlight because photovoltaic panels are less efficient than thermal panels. However, unless the thermal panels are connected to a very large heat storage system or used at a site with a large continuous load, some of the heat that could be collected may be wasted.

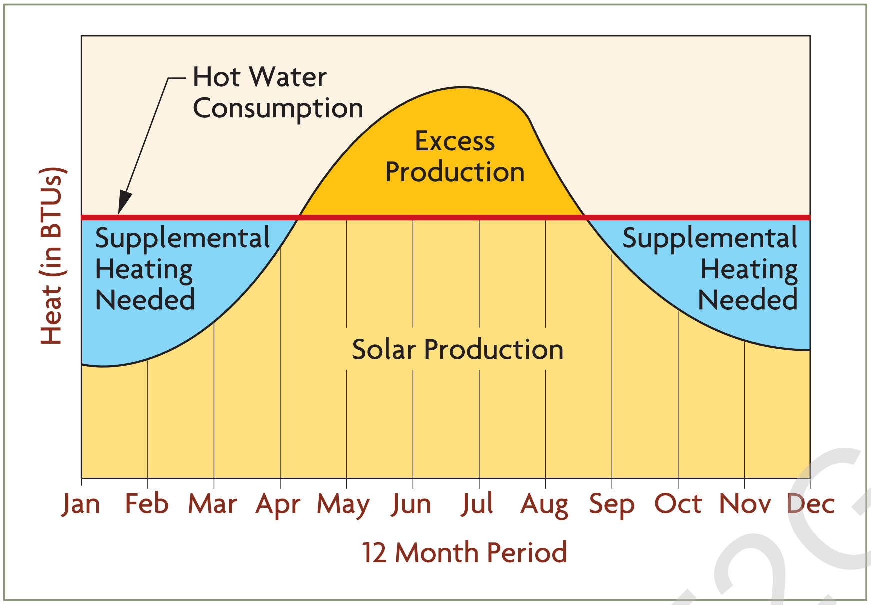

Figure 1-3: Seasonal system production and DHW loads.

WHERE DOES SOLAR THERMAL WORK?

Solar thermal can be used effectively all across the country, even in areas with long, frozen winters. Of course, the amount of heat produced by a solar system is directly related to the amount and intensity of sun that a site receives. The amount of sunlight hitting the surface of the earth is known as **insolation.** Insolation is measured in units of **BTUs/ft²/day** (in the metric system, its units are in kWh/m²/day.) A **BTU** is a measure of heat, and stands for **British Thermal Unit.** It is a very important measurement, and will come up again and again in this book and in real life. **A BTU is defined as the amount of energy necessary to heat one pound of water one degree Fahrenheit.** As you would imagine, different parts of the country receive very different amounts of sun (see Figure 1-4 on next page).

In Seattle, WA, which has one of the lowest average yearly insolation rates in the lower 48 states, a solar panel tilted at the latitude angle (more on this later) receives an average of 1230 BTUs/ft²/day, while a tilted collector in southern Arizona receives an average insolation of 1840 BTUs/ft²/day[1]. As you would imagine, the amount of insolation for both of these locations is greater in the summer, and smaller in the winter. But what causes these differences in average insolation?

The most important factor is cloudiness. Notice how, in Figure 1-4, Seattle, which is notoriously cloudy, gets far less insolation than Idaho and Montana just to the east, which are at the same latitude, but less cloudy.

The sun's path also plays a big role in determining insolation. You don't need to be an astronomer to know that the sun's path over your project site changes every day. Likewise, it's no surprise that it rises on your site's east side and sets on the west side and is much lower in the sky in the winter throughout its traverse of the sky (see Figure 1-5). Because the sun is lower in the sky and strikes the earth's surface at a sharper angle in the winter, we receive less insolation, which results in colder weather overall.

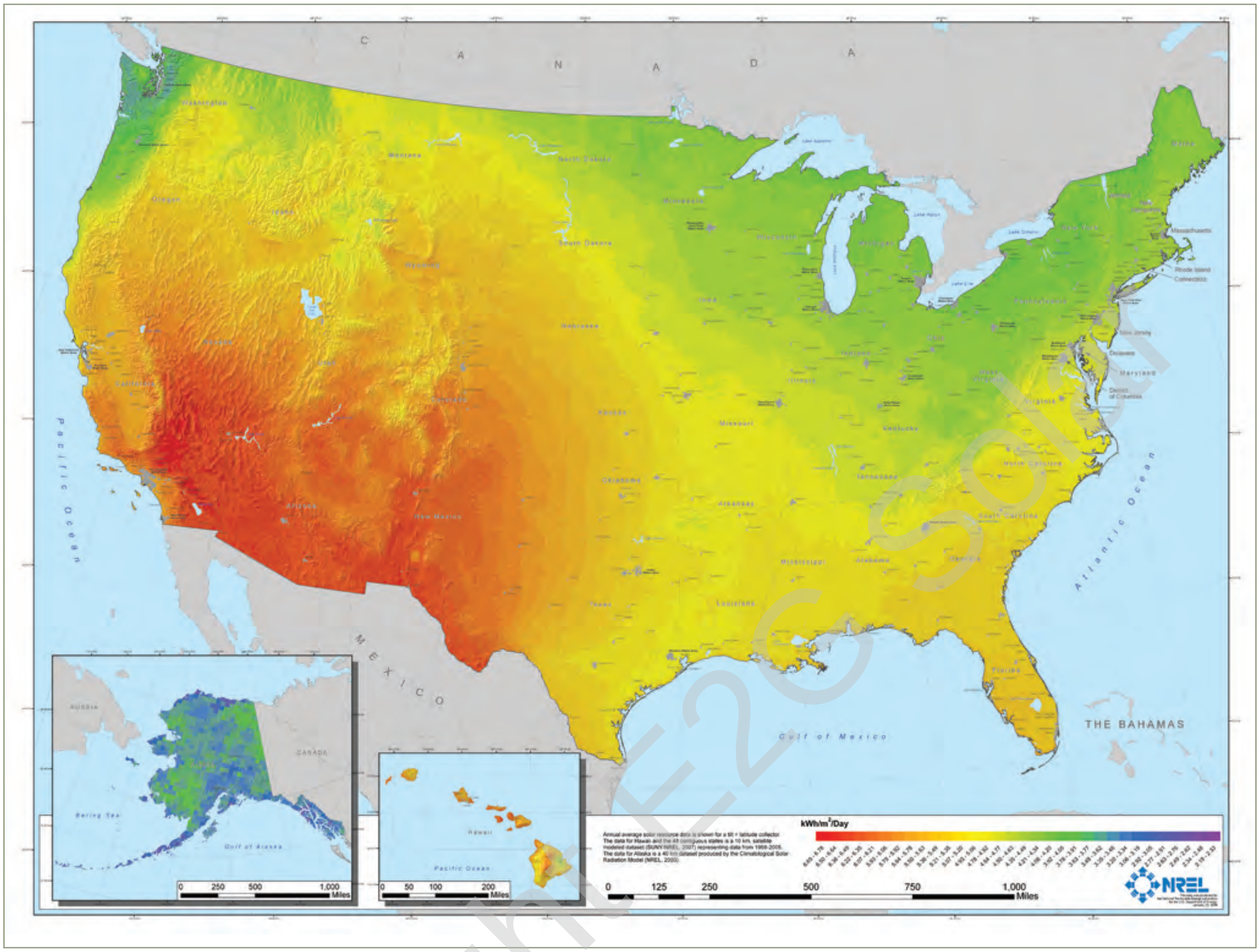

Figure 1-4: National annual insolation map. This map takes into account the effect of geography, latitude, and average cloud cover on the amount of sun striking a place. Courtesy National Renewable Energy Laboratory, U. S. Department of Energy.

In the temperate zone (areas north of the Tropic of Cancer, at 23°N latitude), **the sun is never directly overhead at noon — it is always shining from the South.** This is because the sun is directly overhead in the tropics (which explains their warm climate). **Since solar panels produce the most energy when they are pointed directly towards the sun, we always try to mount our panels facing southwards.** (If you are working in the southern hemisphere, the sun comes from the North and panels should face that direction.)

Few project sites, especially in the Northeast, offer perfect, south-facing

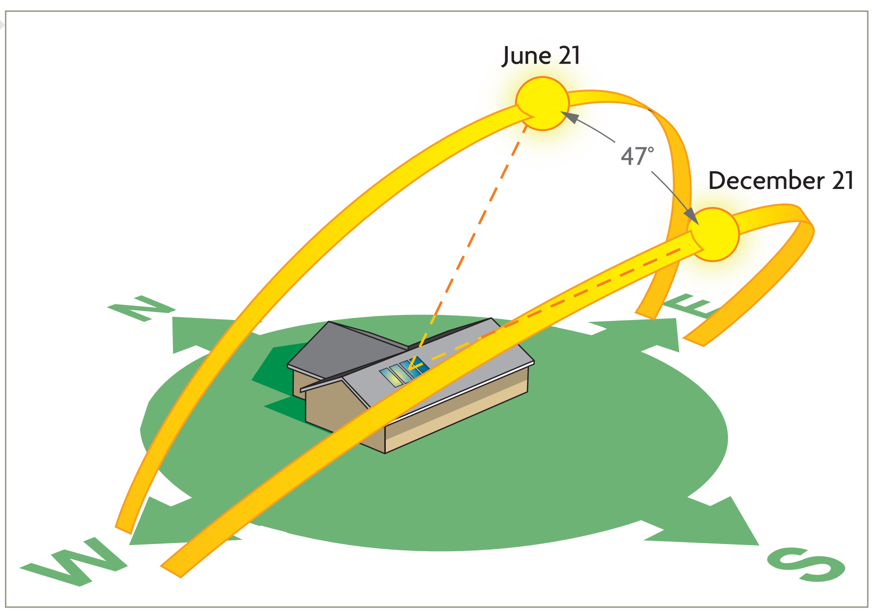

Figure 1-5: Seasonal sun path in the northern hemisphere.

solar exposure. Don't worry! Solar thermal panels are very forgiving. Consult Figure 1-6, and you will see that your array will pick up at least 90% of the available sun power as long as they are oriented between southeast and southwest (that gives a 90° range of options). If your project's panel orientation is outside these limits, adding an extra panel will easily make up the difference.

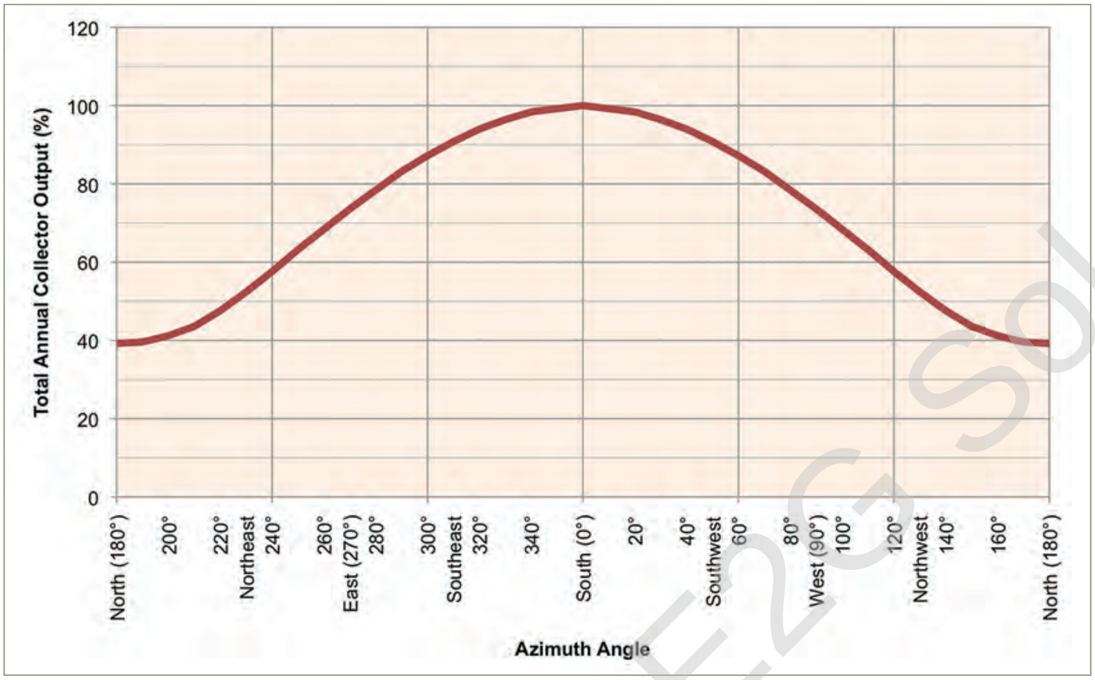

Figure 1-6: Graph of collector output vs. azimuth angle. These data are based upon a RETScreen simulation for latitude-tilted collectors in Albany, NY, with cloudiness ignored.

Tilt

In addition to facing south, panels should be tilted upwards to maximize their output. Panels will produce the most total energy in a year if they are tilted up at an angle equal to the latitude of the site (see Figure 1-7). Remember, **latitude** lines are the horizontal rings around the earth, parallel to the equator. New York City is located at about 40° North latitude, and Miami is at about 25°N. If you tilt the panels steeper than their latitude, it will increase their output in the late fall, winter, and early spring. If you mount them at a flatter angle than their latitude, they will produce more efficiently in the summer months (See Figure 1-8.) Steep tilts are harder to install, increase wind loads, and many clients will not like how they look.

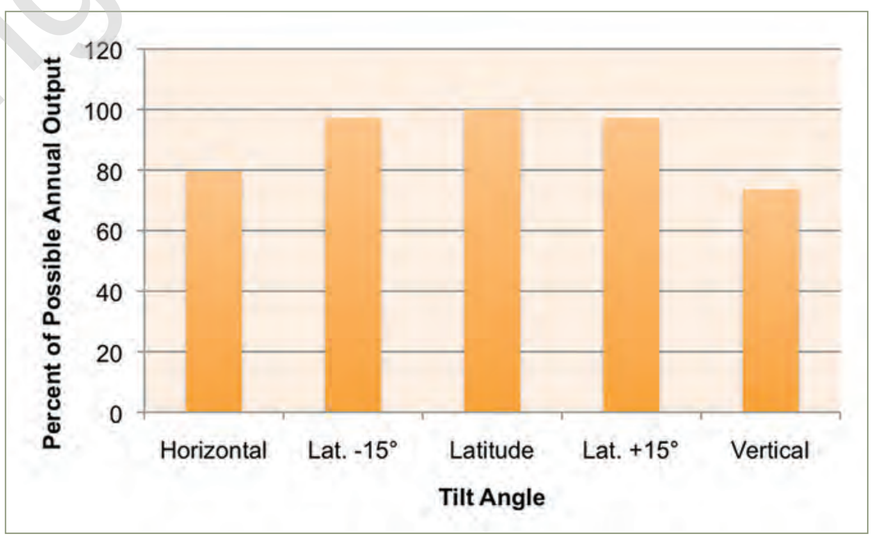

Figure 1-7: The effect of tilt on total collector outputs. Collectors tilted upwards at the same angle as the location's latitude will have the greatest total output in a year. However, these data from a RETScreen simulation for Albany, NY, show that even if the tilt is 15° steeper or flatter than the latitude angle, the total output is almost the same.