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# Solar Thermal System

## The Art and

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# Design: the Science

**By Justin Weil and Patrick O'Boyle**

One of the happiest days at any solar thermal integration company is when the contract for a large commercial project is signed. The staff gets word that after months of hard work, the sales team has sealed the deal. Installers know they will be kept busy on a fresh project. Marketing begins thinking of ways to promote the system. Accounting prepares the schedule of values and other billing documents. Having fulfilled its role in the process, the sales team hands off the project to the design team, whose job now is to turn promises and projections into reality. In our last article (June/July 2011, *SolarPro*), we focused on system commissioning, the final step in the installation process. In this article, we turn our attention to an initial stage of the process: going from signed contract to final system design.

When the signed contract hits the designer's desk, the clock starts ticking. It is time to dig in, examine the initial concepts for the system and produce a robust, polished design that will ultimately underpin a successful installation. Good designs lead to happy clients and stable systems that function and perform as promised. Bad designs lead to poorly functioning systems that cast doubt on the efficacy of solar thermal technology. More than any other part of the solar construction process, design is critical to the success of not only the solar thermal company, but also of the solar thermal industry itself.

## Design Process Overview

There is no single correct or best way to conduct the design process. How a design unfolds depends on what the objectives are, such as aesthetics versus production or achieving a certain percentage of total usage with solar. Whom the designer is designing for—an experienced in-house installation crew or perhaps a plumbing contractor unfamiliar with solar thermal technology—is another factor that influences the process. This article is based on our experience in designing commercial solar thermal systems. Other solar integrators, engineering and architecture firms, HVAC companies and solar equipment manufacturers have their own design processes that can be just as effective.

The designer's goal is to design a system that will last, that meets the client's business needs and that generates profit for the solar thermal company. Clients expect a safe, reliable system that will last decades and help, rather than hinder, their business. A good design is the foundation of a solid system that is accepted by those who use it and that allows the system owner or stakeholders to shine as the individual or individuals who made the wise decision to invest in solar thermal. Designers must at all costs prevent the perception among clients and the general public that investing in solar thermal is not a sound decision.

Solar thermal system design is a complex calculus that factors in many variables, including:

- Facility hot water load
- Integration with existing water-heating or mechanical equipment
- Collector type, size, angle, racking and mounting
- Heat exchange
- Flow rates, temperatures and pressures
- Storage capacity
- Pipe and pump sizes
- Fluid and pipe expansion
- Solar radiation
- Equipment layout
- System location and altitude
- Aesthetics

These factors must be balanced with what can be done for what cost. Design is the "special sauce," the alchemy that underpins all successful implementations of solar thermal technology. There are many installers and subcontractors who can build systems; unfortunately, there are currently far too few designers who can generate high-quality designs. Ideally, significantly more mechanical engineers will become competent solar thermal designers. Increasing the number of professionals who have mastered the art and science of solar thermal design is vital to achieving mass implementation of the technology and avoiding any black eyes to the industry, such as those suffered during the 1980s in the US.

## Coordination with Sales

Experienced design and sales teams stay connected from the early stages when sales teams interact with the client and conduct an initial analysis of the facility. There should be an ongoing dialogue between design and sales teams regarding best practices and best materials to use for different types of systems. Continually reviewing what works well and what does not will help the company and its employees progress. As the sales process moves forward, the designer should collect information about the potential project by reviewing the sales team's notes and site photos, and reviewing the work that the sales team has done in regards to calculating projected load, equipment selection and layout, and determining how the solar thermal system will tie into existing equipment. The sales team should also keep the designer in the loop regarding client expectations. By the time the project is sold, the design team should have a well-informed idea of the project's scope. However, a formal handoff meeting is required to ensure that everyone is on the same page. You will need to double-check with the sales team that the cost of system design is included in the project bid. The designer should create a standard form featuring specific questions about the project that the sales representative fills out and brings to the meeting.

Once the sales team has handed off the project, the designer takes over and can begin to verify the site-specific information that the sales team collected. The designer's initial questions include the following:

- How will the collectors be mounted to the building structure?
- What is the facility's true hot water load, and what effect will it have on the production of the solar field?
- Where exactly in the building will the solar equipment, particularly the water storage tank(s), be installed?

It is now time for the designer to closely examine initial assumptions and create the actual design. For many designers, this pursuit of clarity is one of the most enjoyable aspects of their work.

Solar thermal design differs greatly from PV system design because solar thermal systems typically integrate with complex existing mechanical systems within the facility. How and where the solar thermal system connects to existing water heating or mechanical equipment is an important question solar thermal designers must answer early on. Tying into another system or process requires the designer to be somewhat of a "jack-of-all-heating-systems." The designer must become familiar with a variety of different systems and heating processes, and their related equipment. When designing a system for a yogurt factory, for example, the designer needs to understand the basics of pasteurization. For wineries, familiarity with the winemaking process is important. For a client in the hotel industry, the designer should know all the different ways these facilities use hot water, such as laundry, food service, guest bathrooms and pool heating. There are so many ways to heat water and air that CONTINUED ON PAGE 76

> "Design for me is an art and a science. When the contract is signed, that's when the project becomes real, and that's when I get excited about putting the technology to work. The creative juices kick in, and I know that this is when I can dive in and start figuring out how to make the best design within the given budget, and do it better than originally thought." — Justin Weil, SunWater Solar

system design constitutes an endless education. If you do not enjoy learning about new mechanical systems, gaining proficiency in solar thermal design is next to impossible.

Mastering this diversity of applications, systems and technologies is one of the joys of being a solar thermal designer and why many system designers enjoy working in the solar thermal field. Clients are often happy to educate designers on how site-specific systems function. Ideally, the solar thermal designer becomes a member of the team responsible for the facility's heating system, learning new things each day about how various business types utilize heat.

## Reach Out to the Client

The designer should contact the clients soon after the contract is signed and discuss their understanding of the project. The designer can answer any questions the clients have, learn what their expectations are and get any concerns out into the open before heading too far down the design path. Next, the designer sets up a site visit to access different parts of the facility, especially the roof and mechanical area, and meet with any stakeholders who have an influence on the design. Designers need to artfully communicate to the stakeholders any potential pitfalls, such as possible structural issues, so that if problems occur, all parties are forewarned. Your company will gain the client's respect if you are up-front about any potential risks.

### SITE VISIT

The designer should already have ample background on the site, garnered through discussions with the sales team, but the designer must still get on-site and view everything holistically. The designer needs to take time to explore the facility and consider the possibilities, looking for things that the sales team may have missed or that the client did not reveal, such as the need to replace existing equipment. Other tips for making the most of the site visit include the following:

- Get a feel for the site and for the client.
- Ask lots of questions about the heating process that your system will feed:
  - How often does it run? How many days per week?
  - What are the temperature tolerances?
  - Who maintains the equipment?
  - How often is the equipment maintained?
  - Is there a weak point in the existing system?
  - Does the existing system run at full capacity?
  - Can the boiler accept preheated water?
- Ask for contact information for the company or individual who maintains the existing heating system.
- Confirm roof and mechanical room measurements.
- Confirm the condition and type of roof, and of existing equipment that the solar thermal system will tie into, (water heaters, pumps, chillers and so on).
- Confirm existing pipe sizes and types.
- Check the electrical supply and determine how the system will connect to power.
- Take photographs and make notes.
- Identify potential code concerns (clearances, venting requirements and so on).

"Hide the tank meetings" are common during this early stage of the design process, especially with new construction projects where the architect or engineer may not have allocated space for a large storage tank. These clients often want to know, "Where are we going to put this massive solar storage tank?" Clients rarely want the tank to be visible, but oftentimes there are few choices for where to place it. You and the designer will want to make clear in these meetings that tank location can have an effect on system performance and price. Offer an honest assessment of the client's options regarding tank location, but stress that, one way or another, at the end of the day, they do in fact need the tank.

Courtesy SunWater Solar

**Existing equipment** Determining how and where to tie into existing mechanical equipment, such as this domestic water heating system, is one of the most difficult phases of designing a commercial solar thermal system.

**Retrofit sites.** The trickiest aspects of retrofit projects are laying out the solar thermal equipment and integrating it with existing equipment. During the site walk, designers must identify the tie-in points to existing equipment. In addition, they should note the temperatures that the equipment is currently set at, verify that electricity is available to power the solar pumps and create a mechanical room layout dimensioned with equipment.

The designer should keep an open mind and look for ways to make the project more successful. You obviously want to avoid cutting corners, but always consider CONTINUED ON PAGE 78

Shawn Schreiner

**Racking considerations**
Proprietary collector array racking systems provided by manufacturers are typically easy to install, and in some instances are even combined with preexisting racking infrastructure.

ways to reduce installation costs. Is there an easier way to run the solar trunk lines from the roof to the mechanical room? Are there low-cost options for mounting, racking or other materials? The design is not yet set in stone, and now is the time to lay plans for a successful implementation.

**New construction sites.** For new construction projects, designers should carefully review all project drawings, then contact the general contractor and project plumber. Find out where solar thermal fits into the schedule. In new construction, the solar thermal team is often brought onboard late in the game, so there is a good chance the designer will already be behind the eight ball. Solar thermal is often an afterthought in new construction due to funding issues, the general contractor or design team avoiding solar until the last minute, or the mistaken belief at the start of the project that the project plumber can handle the solar thermal design and installation.

It has become common recently for the general contractor or project architect to provide solar thermal designers with a "placeholder design" that includes collector layout or even a system schematic. Frequently—but not always—placeholder designs have been created by individuals whose expertise is not in the area of solar thermal technology. The original designers (often an engineering or architecture firm, or other solar contractor) will have given it their best shot, but until solar thermal systems become more commonplace, professional solar thermal designers must assist in the design process and try to pass on best practices. The designer should review the original design, get a feel for what parts of it are required and identify any areas that may be incorrect. Justify any recommended changes because the other parties may assume that the placeholder design reflects what you will build, even if the design is incorrect.

## Hot Water Load and System Sizing

Hot water load and system sizing are critical elements of solar thermal design. Sales and design teams should begin discussing these topics as soon as the client provides initial load data. By collaborating, design and sales can often determine early on what size system is ideal for the client's facility. Hot water load is a major determiner of solar thermal system production and efficiency. If a client is promised a certain amount of energy based on an assumed load, and the actual load turns out to be different, then the system's energy output will change. This is quite different from what occurs in the PV world. For example, 150 PV panels will produce close to the same 150 units of energy regardless of the building's electrical load. However, if 150 solar thermal collectors are installed, but the building only needs 100 collectors to heat its water, the collectors will overheat, running less efficiently and creating less energy. If the building needs 200 solar thermal collectors to heat its water but only 50 are installed, those 50 collectors could end up creating twice as much energy as assumed since they will be running at a lower temperature.

Unlike PV, where system sizing is relatively precise, solar thermal system sizing often involves an educated guess because precise data on hot water load is often not available. With PV, if the sizing is slightly off, the technical consequences, such as system breakdowns and increased maintenance costs, are typically insubstantial. Furthermore, if the PV system is oversized and generates more energy than CONTINUED ON PAGE 80

the facility can utilize, the excess power is simply pushed onto the grid. This situation may have financial implications, but it does not impact overall system efficiency or put additional stress on system components. The situation is quite different with solar thermal: If too much heat is generated, the consequences can be dire. System oversizing can lead to unusually high maintenance costs or even complete system failure. Correct sizing of the system during the design phase is absolutely critical.

## HOT WATER LOAD ANALYSIS

Hot water load has a major effect on system sizing, performance and long-term value. Occasionally in the commercial/industrial market, thorough load data exists for the system that will be assisted by solar thermal. In our experience, however, clients rarely have a 100% accurate picture of how much hot water each piece of equipment uses. For buildings where the load is not known, the designer can almost always establish an approximate figure for load by collecting information from the client and applying various rules of thumb based on the building and system type. As early as possible, review any existing load information and assess whether metering of the equipment is necessary.

Further load information can often be obtained from employees and maintenance staff. For example, you might have a hotel or restaurant manager count the number of laundry or dishwasher loads done on a given day. These numbers provide only part of the complete picture, but they can help in system sizing. Be sure to run new performance simulations as new information is collected. For most projects, the performance does not change much more than 10% either way, but this is not always the case. If you are making assumptions, it is good to refer to ASHRAE charts to see whether your projections fall into the typical usage pattern for that type of heating system or facility.

If assumptions regarding load are made during the design phase, it is important to make clear to the client that you are assuming *x* load and that *x* is an educated guess. System size, energy production and monetary savings are based on this specified load. If the clients are not comfortable with that, they may be willing to pay to have monitoring equipment installed.

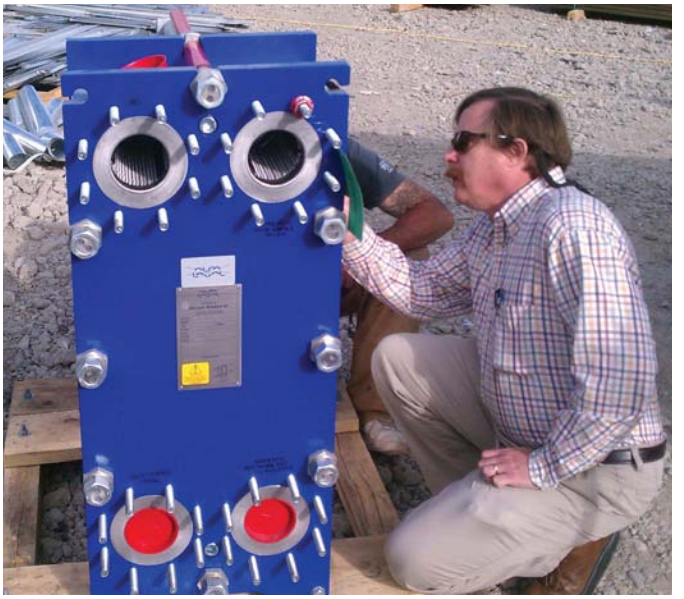
## METERING HOT WATER USAGE

Using rules of thumb and data provided by clients to determine an approximate hot water load can be effective and is a commonly accepted practice in the solar thermal industry, since individual water heating and mechanical systems are rarely metered. Metering, however, is the only way to truly pinpoint the exact load.

If it is decided to meter the load as an initial step in the design process, a variety of tools are available: water meters, natural gas meters, BTU meters, ultrasonic flow meters and dataloggers, for example. Often in older commercial buildings or facilities where the load is completely unknown or impossible to determine, solar thermal designers CONTINUED ON PAGE 82

**Roof penetrations** Designers typically predetermine what type of mounts installers will use. However, for retrofit systems, installers often do not know until they cut into the roof exactly how far down the mounts will sit.

**Preferred equipment** Over time, solar thermal system designers develop lists of preferred equipment. This heat exchanger, manufactured by Alpha Laval, was installed as part of a 70-collector system that SunWater Solar designed for a multifamily building in Union City, California.



Courtesy SunWater Solar (2)

may choose to determine load using these tools. Incentive programs such as the California Solar Initiative-Thermal (CSI-T) program may also require metering for some installations, such as very large systems or those that fall outside established gallons per day parameters. In most large commercial buildings built within the last 5 years, systems and pieces of equipment that generate or consume energy are frequently metered. In the past, solar thermal systems did not receive much attention, but today many clients want their systems metered after installation in order to quantify system value.

If it is determined that metering is necessary after the contract is signed, the designer has several options:

- Have the client pay for a permanent water or natural gas meter.
- Have the client pay for a permanent BTU meter. These are very expensive, but provide the most accurate readings.
- Loan the client an ultrasonic meter. These units can cost thousands of dollars.
- Loan the client a BTU meter with an ultrasonic flow meter. These are also very expensive.

Many times, meters must be left in unsecured locations, so proceed with caution. The problem with having one high-quality, expensive meter to loan is that the designer typically needs around one month of metering data and may need to meter several facilities at once.

Courtesy SunWater Solar

**Hide the tank** Early in the design phase, decisions such as where to locate the system storage tank must be made. This decision impacts other design variables, such as piping runs, materials, flow rates and temperature differentials.

### WORKING UP THE DESIGN

After analyzing the site and verifying load, the designer can make real headway on the design itself. Handling design in-house gets easier over time because your completed projects can serve as templates for future designs. The more systems your firm designs, the larger and more diverse your collection of roof penetration details, mounting details and mechanical room schematics becomes, for example. For solar thermal installation companies lacking in-house design capability, handing off design to a mechanical engineering firm can be a viable option. Cost and lead time vary greatly between a firm that is already familiar with solar thermal and one that is not. Because many engineering firms do not have solar thermal experience, it is wise to pass their designs along to the collector manufacturer for review.

While the design is in process, the designer needs to coordinate with the staff whose equipment the solar thermal system will tie into. They need to understand exactly what will happen and when, well before your installers arrive on-site and start turning bolts. If the client is expecting a rebate or tax incentive, confirm that the system you are designing qualifies. You also need to acquire existing building plans for the facility that are relevant to the solar thermal system. Designers should also consider aesthetics, such as matching the solar thermal equipment's appearance to that of existing HVAC or mechanical room equipment. Solar thermal arrays are typically racked at a much higher angle than PV and tend to stick out more. Therefore, the designer needs to give serious thought to the appearance of the collector, collector racking and related piping.

When the design is complete, run it by the client and your sales team. Is the design what they thought it would be? When everyone is satisfied, you are ready to submit your system design package to the building department for review.

## Design Submittal and Approval Process

Solar thermal designers should contact the building department early in the design process to get details on local regulations. Many cities now even offer checklists for solar designers. Although most of these checklists have been created for the PV industry, they can still provide useful information relevant to solar thermal installations. Inform the building department if there are requirements on the list that do not work for solar thermal or that are impossible to meet. Find out whether the building department will work with you on this or force you to conform to PV rules, such as electrically grounding the collectors on the roof.

Before submitting your design to a building department, double-check your design and conduct a peer review to confirm that the system will meet all *Code* requirements. This helps prevent delays in design approval and avoids nasty surprises during final inspections. Building CONTINUED ON PAGE 84


Courtesy SunWater Solar

**Pump station**
For each system, the designer must decide whether to install a prefabricated pumping station, such as this Heliodyne Commercial Station, or have installers build the pumping station on-site.

department personnel carefully review all submitted designs, but generally speaking, they cannot be held liable for failing to identify aspects of the design that are not up to *Code*. If elements of the system fail to pass inspection, the solar thermal company—not the building department or the client—is left holding the bag.

Despite the fact that solar thermal has been in use for many years, building department officials are not always familiar with the technology. Some departments are tougher than others when it comes to enforcing the letter of the law. Solar cooling systems can be even more confusing to building departments than solar water heating systems. For any system type, invest the time to make sure your design is up to *Code* and consult with building department officials when necessary. A written narrative explaining the system can help the design review go more smoothly. Explain the purpose of the system, the sequence of operations, what the solar fraction is and so on. This is especially important when you are seeking approval for a complex system or one that is feeding a unique existing system or load.

Throughout the design review and permitting process, communicate clearly with the client regarding review times and any *Code* concerns related to the project. In some cases, clients can help by interfacing directly with the building department.

## Handoff to Project Manager

After the building department has approved the design, it becomes a living project and moves on to its next phase: production. Production runs more smoothly if the designer reviews the project in detail with the project manager before crews head out to the jobsite. Provide an accurate, up-to-date equipment schedule with the approved design and pass on relevant information about the client, the building and the project schedule. Warn the project manager of any potential difficulties you foresee. You should also discuss whether your installers or a subcontractor will perform different portions of the installation. Finally, after the system is built and commissioned, be sure to walk the site, examine the system during operation and note specific design elements that will be useful in future projects.

## Solar Thermal Design: Both Art and Science

Solar thermal system design is a craft requiring technical ability, artistic talent and communication skills. A vital part of the solar construction process, the designer's work is the bedrock on which installers build systems. Design must therefore be done correctly, and creating an internal process is key to ensuring success.

When a solar thermal designer takes on a large or experimental project, or has the opportunity to work with a high-profile client looking to do something new with the technology, there will be some intense moments when the challenge of completing the project on time and on budget may seem overwhelming. But overcoming such difficulties is the thrill that many designers thrive on: the excitement of creating something never seen before, of turning an idea into a technical, functional system.

Knowledge of solar thermal design needs to increase greatly for the industry to advance. When you are working with an engineering firm that is new to the technology, take the time to explain what you do. These are not cookie-cutter designs, and it will take a long time for the engineering firm to learn what you know. The lack of qualified solar thermal designers is an impediment to industry growth. One part of the solution would be to have a solar thermal industry group that could create a strong design guide and train engineers in the craft. Manufacturers are currently inundated with design inquiries; demand for the technology is growing; and solar thermal design is not straightforward. Training more designers is a tide that would lift all boats, and solar thermal designers should do all they can to educate others on the art and science of solar thermal system design.

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