Turning on the Heat

Solar Thermal System Commissioning

By Justin Weil and Patrick O'Boyle

Low natural gas prices and lack of public awareness of solar thermal technologies are the two most oft-cited barriers to significant expansion of the industry within the US. Unlike photovoltaics, which is relatively well known and certainly well publicized, solar thermal continues to be an esoteric segment of the solar technology spectrum.

While the activities of the solar thermal industry cannot impact the price of natural gas, the technology's public profile can be greatly improved with the deployment of high-performance solar heating systems that meet customers' expectations. Professional commissioning ensures long-lived, reliable and efficient installations. These systems, along with public outreach and education, are the keys to widespread solar thermal application awareness and acceptance.

THE IMPORTANCE OF COMMISSIONING

Picture the solar thermal installer in a mechanical room, deep in the bowels of a massive commercial building. After

months of hard work, a new solar heating system is nearly complete. The copper pipes have long since been roughed in, insulated and jacketed. Long banks of flat-plate collectors fill the roof, mounted on a properly engineered, secured and flashed racking system. In the mechanical room, the solar storage tanks are strapped in and full of water. The pumps, flow meters, sensors, and control and monitoring systems are wired up and plugged in. Commissioning, the official start-up of the new system, is the last major procedure to complete. Considering the overall scope of a project, commissioning does not take a significant amount of time, but doing it right is vital to the performance, longevity and value of the system.

As with solar thermal system design, project commissioning requires various levels of sophistication. For a residential application, it may be a simple procedure, while an industrial project may take several days. Residential domestic hot water systems, generally comprising four or fewer collectors, are the least complicated. Commercial and industrial systems that provide heat for applications such as process heating can include hundreds of collectors. Commissioning these systems

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System scale Commissioning procedures and documentation become more complex as project size increases. Commercial and industrial systems, such as this 40-collector installation (two arrays shown) by SunWater Solar, can take multiple days to commission and require customized, project-specific commissioning protocols and documentation.

is complex and time-consuming. Combi systems that provide heat for multiple loads and processes are typically the most difficult to commission. The wide variety of system types and elements means that a separate commissioning procedure must be developed for each application.

Some elements are common to commissioning each of these system types. In this article, we focus on the systems that we most often commission: commercial-scale active closed-loop glycol systems that provide domestic hot water to the facility. In the end, the goal is the same: to ensure that the solar thermal system remains in use for decades to come and performs optimally. After commissioning, the system is no longer a work in progress, but a work completed.

WORST-CASE COMMISSIONING SCENARIOS

Failure to commission solar thermal systems properly can have drastic consequences including property damage, injuries and delays in payment. Failed commissionings also damage the reputation of the installer, the technology and the industry as a whole. Over the course of many years in the solar thermal business, professionals have encountered all manner of commissionings gone wrong. Before we tackle specific procedures and approaches, here are some real-world examples where proper system commissioning would have saved installers time and money, and, in one case, would have prevented an injury.

Leaving a system manually on. One case involved a large commercial system with an unpressurized storage tank. At start-up, the system seemed to be functioning properly. The pumps were on and appeared to be operating normally during the sunny day that the commissioning took place. In reality, one of the sensors had failed and the system control was programmed incorrectly, bypassing the high temperature setpoint limit. The result was that the pumps were locked in the On position. After the installer left for the week, the unpressurized storage tank began to overheat. It got so hot that the mechanical room turned into a steam room. When a maintenance man grabbed the door handle to enter the room later that week, he suffered second-degree burns to his hand. The room's walls were destroyed and the entry door was warped from the heat.

Skipping a final pressure test. After pumping 100 gallons of a propylene glycol mix into an 80-collector commercial system, a commissioner climbed to the roof to check the collectors. He found that solder joints on several air vents had failed and that a drain valve had been left open. The roof was badly stained, and the propylene glycol was a total loss, having been discharged into the storm drain. The system had been pressure tested and precommissioned 4 months before that, but had been drained and left to stagnate while the building construction was finished. By the time the second and final commissioning took place, numerous weaknesses in the system became apparent.

Leaving a tank empty. While commissioning a commercial system, the commissioner failed to ensure that there was water in the solar storage tank. He therefore did not realize that a clog in the piping was preventing water from entering the tank. When the system was turned on, heat came from the solar collectors and the commissioner figured he was done. Unfortunately, the domestic-side pump was burned out by the next day.

Leaving water in collectors. One two-collector residential system installed in a high-altitude location was commissioned with water and left unused for several weeks until the project could be completed. An unexpected cold snap hit in late spring, and sure enough, the water froze. Not surprisingly, the system was nonfunctional. When installers responded to the service call, they discovered that the collectors and copper piping had cracked and broken.

Each of these scenarios could have been avoided if detailed, well-organized commissioning procedures and documentation requirements had been in place.

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Commissioning team The installation foreman typically commissions solar thermal systems. For commercial applications, it is common to have two individuals on site. The primary commissioner works in the mechanical room, and a second team member is stationed on the roof. Here, Sean Speagle, project manager from SunWater Solar, visually inspects pipe jacketing and roof flashing details.

WHO COMMISSIONS?

Solar thermal systems are mechanical in nature and can be very temperamental, especially just after installation. An

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experienced professional who knows what to expect should be in charge of a system's commissioning. Commissioners should be competent, unhurried and completely prepared on commissioning day. Taking the time to make sure that everything is perfect pays dividends in the reduction of service calls alone. Mistakes or overlooked items during commissioning can damage the system, incurring additional costs.

The installation team foreman usually commissions solar thermal systems, although engineering firms and consulting companies sometimes employ commissioning agents to handle the procedure. Ideally, the commissioner should already be familiar with the system, including both design and installation details. During the current solar thermal renaissance, however, this is not always the case. Most independent commissioning agents rely on the integrator to provide commissioning guidelines, checklists and confirmation of their findings.

One person is usually sufficient to commission a residential system, but for commercial and industrial systems, there should be at least two individuals on site. While the primary commissioner remains in the mechanical room, the second person is stationed on the roof, where he or she can check for leaks, open and close ball valves, balance flow through the arrays, vent air, listen for the sound of fluid moving through the collectors and make adjustments as needed. The commissioning team should remain in voice communication via radios or cell phones as the procedure is carried out.

It is always best to commission a solar thermal system on a sunny day. Heat exchange occurs best when the system is working at maximum capacity and liquids are moving freely through the system. Just as it is easier to diagnose a sick patient when the illness is most intense, powering up a solar thermal system on a sunny day allows the commissioner to put the system through its paces under strenuous conditions. However, collectors should be filled early in the day before they get too hot.

COMMISSIONING SCHEDULE

Solar thermal commissioning, particularly of a commercial or industrial system on an occupied building, should be timed according to when hot water is needed. Commissioning can occur soon after the system is installed. New construction projects, however, may require two commissionings: one to ensure that the system is operational and the second to enable the system to start heating water.

For new construction projects, the first commissioning occurs soon after installation is complete. Commissioners pump water into the system and run through the checklist of commissioning procedures to ensure that all system components are functioning properly. After this initial testing is complete, water should be drained from the system, air vents should be opened and collector temperature sensors should be removed. Draining and venting the system is critical. If occupants do not move into the new building for weeks or months, any fluid left to stagnate in the system can cause problems. Glycol, if left to cook in a stagnant system, may break down, greatly reducing the time before the fluid must be replaced. Sensors and air vents can also fail from overheating if left operational on a stagnant array.

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Existing systems For both new and retrofit commercial-scale applications, the integrity of the gas or electric water heating equipment should be verified by a mechanical/plumbing contractor before the solar thermal system is commissioned.

At the second commissioning of a system built for new construction, the fluids are refilled and everything is checked again. At this point, the system is fully operational. Commissioners can walk away knowing that the system has been double checked and is now providing occupants with solar-heated water.

TYING INTO EXISTING EQUIPMENT

Except for stand-alone applications, all solar thermal systems are supplementary in nature since they feed solar-heated water to existing equipment. That equipment may be as basic as a 40-gallon electric water heater in a homeowner's basement, or as complex as a series of industrial boilers heating tens of thousands CONTINUED ON PAGE 80

of gallons of water a day for a factory. Regardless of its size or complexity, the existing water-heating system must be functioning properly before commissioning a solar thermal system that is connected to that equipment.

Unlike PV systems that tie into the electrical grid, a solar thermal system ties into a complex mechanical system and its related equipment. It is much harder to troubleshoot problems on the solar thermal side if there are doubts about the integrity of the existing water-heating equipment.

If you are unsure about the equipment that the system is integrating with, get an expert to verify that it is functioning properly. At the very least, check the existing system for leaks, check the controls for faults, confirm the flow of existing pumps and test the system under a load before the solar thermal system is commissioned.

For new construction projects, it is best to have the gas or electric water-heating equipment commissioned and operational several days before the solar thermal system is brought on line. Allowing the mechanical and plumbing contractors to commission their systems enables them to sort out any kinks without the distraction of the solar heating system. It also minimizes finger pointing if their systems perform inadequately and the building is not getting sufficient hot water.

GLYCOL: THE POINT OF NO RETURN

Propylene glycol, or *solar fluid,* as it is often called, is the lifeblood of active closed-loop glycol systems. Due to the cost of glycol and the care that must be taken when handling it, charging a system with glycol is best done once and done correctly. Commissioning a closed-loop system needs to be carried out in the proper sequence (see page 86). Once glycol is pumped into the system, there is no going back without considerable difficulty and likely extra expense.

Glycol should not be added until system installation is complete, including wiring of electronic components. The domestic hot water side must be running and fully tested. The solar tanks must be full of water and all piping must be thoroughly flushed and disinfected if required. Most importantly, commissioners must be 100% confident that the system is free of leaks. Air or water should already have been used to pressure-test for leaks in the solder joints and other connections. Nothing spoils a commissioning like glycol leaks, which can be expensive, considering the $20–$40 gallon cost of the fluid. Finally, pools of leaked glycol cooking on a sun-baked roof leave behind stains and sticky puddles of congealed goo that are not fun to clean up.

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Point of no return Commissioning an active closed-loop glycol system needs to be methodically carried out in the proper sequence. Once glycol is added to the system, there is no going back without considerable difficulty and expense.

Before reaching this point of no return, commissioners should double check that they are using the manufacturer-recommended glycol type and that it is diluted properly. A 50/50 glycol-water mix is standard, although increasing the water content to 60% or even 70% is permissible in areas where freezing temperatures are extremely rare. Follow the manufacturers' temperature-to-ratio chart and make a mix that suits the climate. You will need a glycol tester in order to achieve the proper mixture ratios when combining glycol and water. Be sure to check the final mix by removing a small amount from the collector loop after charging is complete.

Open-loop or drainback systems do not require this point-of-no-return warning that closed-loop glycol systems do. The systems can be easily emptied and recharged if necessary. The water from an open-loop or drainback system, unlike glycol, can simply be directed down a floor drain and the system can be refilled if leaks or other problems are discovered during commissioning.

Equipment for Commissioning

Commissioning must be well planned, and part of that planning process is making sure that the commissioners are armed with all the necessary equipment. The following checklist is valid for residential, commercial and industrial systems, and includes specific items for commissioning active closed-loop glycol systems.

Charging station. The central tool in commissioning a propylene glycol system, the charging station allows you to pump a system full of a glycol mixture and purge unwanted air. Have extra hoses and buckets on hand in the mechanical room to direct water down drains or into jugs and catch leaking or spilled fluids.

Glycol. The food-grade propylene glycol that flows through active closed-loop solar thermal systems is typically diluted with water to reach a 50/50 solution.

Glycol tester. This tool is vital when diluting propylene glycol with water. The tester provides an accurate reading on the glycol-to-water ratio, a metric required on the commissioning checklist.

Camera. Take pictures of everything, especially equipment or installation details that present problems during the commissioning. Thorough documentation gives you a leg up if further troubleshooting is required.

Digital multimeter (DMM) with ac voltage and ohm functions. A DMM is required to test and verify pump and control voltage and sensor resistance values.

Voltage detector. Handy for quick checks, a voltage detector can determine if power is being supplied to various electrical components in the system.

Circuit setter/pressure differential read-out kit. This kit allows you to balance the flow on systems that have circuit setters.

Temperature meter with pipe sensor attachment. This tool makes it quick and easy to get a temperature reading on any pipe in the system.

Hand tools. At a minimum, you need wrenches to tighten hoses and screwdrivers for opening control panels.

Ladders. Stepladders are handy for getting above a wall-mounted pumping station or checking the solder joints on ceiling-mounted pipes. Extension ladders may be required for roof access.

Harness. Safety equipment is usually required for anyone working on the roof of a commercial building and is definitely needed when working on pitched roofs. ●

THE COMMISSIONING PROCEDURE

A solar thermal system generally lasts 25 years or longer, starting the day it is commissioned. Methodically completing and documenting each step of the commissioning process outlined here helps ensure that the system functions properly and meets your customers' expectations for years to come.

Various types of documentation must be on hand during commissioning. First, and most important, is the commissioning checklist, which serves as a step-by-step guide to starting up the system. Even the most seasoned solar thermal installer needs such a checklist. Companies that frequently commission systems usually keep separate checklists for residential, commercial and industrial systems, as there are procedural variations for each system type. Original and as-built design documents, and equipment specification and installation manuals should also be on-site during commissioning.

Perform a visual check. Begin the commissioning process by looking over the entire system, from the CONTINUED ON PAGE 84

System piping During commissioning, piping should be visually inspected and pressure-tested, and the results should be documented and included in the commissioning report. Items on the checklist include collector-to-collector connections, pipe support, jacketing and valve location, orientation and direction.

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roof to the mechanical room, to make sure that all work has been completed properly and according to the system design. It is useless to begin the commissioning process if something is clearly wrong and the system cannot be started up.

Review the system piping.

- ❏ Check that all piping, gauges and valves are per design.
- ❏ Check that the pipes are supported properly.
- ❏ Check the pipe insulation and jacketing.
- ❏ Check that pipes are labeled correctly.
- ❏ Check that the valves and gauges are installed in the proper location, orientation and direction.
- ❏ Check that pressure and temperature relief valves are installed in the proper locations to protect the components if conditions exceed maximum operating ranges.
- ❏ Check the collector connections.

Evaluate the roof work.

- ❏ Check that the collector mounting is complete and that all hardware is tightened.
- ❏ Check that mounting and piping is properly flashed and correct roofing practices were used for the building's specific roofing system.
- ❏ Confirm collector orientation and angle per design.

Verify the system's electrical wiring.

- ❏ Confirm that all system wiring is per design.
- ❏ Check that the system has overcurrent and surge protection.
- ❏ Check that wire sizes are correct.
- ❏ Confirm that a sufficient motor starter is installed for systems with 3-phase pumps.
- ❏ Check that all wiring is terminated correctly, including polarity.
- ❏ Check that the required conduit is used and properly supported.
- ❏ Check that the sensor wiring is secure and protected from UV.

Pressure-test the system. The installers should have pressure-tested the system with air or water prior to commissioning. The *2009 Uniform Plumbing Code* requires that piping be hydrostatically tested to 100 psi or twice its operating pressure, whichever is greater. It is wise CONTINUED ON PAGE 86

Glycol Charging Sequence

1. Fill the domestic-water side of the heat exchanger. For systems that use heat exchangers immersed in the tank, be sure the tank is full of water. For systems with external heat exchangers, be sure the water side of the heat exchanger is flooded.
2. Precharge the solar loop expansion-tank pressure per the design specifications.
3. Close all the drains and air vents on the roof.
4. Calculate the amount of glycol needed. Add the volume of fluid in the piping, in the collector field (consult manufacturer) and in the heat exchanger, or fill the system with water and measure the volume when drained. (The latter option should be used only if the system design allows it to be drained completely.)
5. Mix the required amount of glycol (if not using a premixed product). Use purified water if the tap water in the area is suspected to be of poor quality. If water quality is unknown, it should be analyzed by a qualified water-testing provider.
6. Connect the charging pump to charging ports on the collector loop so that the charging pump is flowing in the same direction as the collector-loop pump.
7. Close the charging-diversion valve, which is typically a ball valve between the two charging ports that forces the water through the loop.
8. Fill the charging pump reservoir or insert charging hoses into the bucket or barrel containing glycol.
9. Turn the charging pump on.
10. Turn the collector loop pump on.
11. Continue to fill the reservoir with glycol mix as needed.
12. If the system has multiple arrays, close all arrays but one and allow the glycol to flow for 2 minutes or until air is purged. Proceed similarly through all arrays. Once each array has been fully charged, open one array at a time until all arrays are open.
13. Allow the system to flow until all air is purged. Manually bleed off air periodically throughout the commissioning process.
14. Close the charging port that is returning to the reservoir.
15. Continue to inject glycol into the loop with the charging pump until the desired pressure is reached.
16. Close the final charging port.
17. *Immediately* turn off the charging pump. ●

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Control verification Temperature sensors should be tested and the reading should be compared to the reading at the control unit. All control functions and relay operation should be verified, and system control programming reviewed and documented.

to pressure-test again on commissioning day, especially if the system has been unused for a period of time.

Follow the correct glycol charging sequence. Detailed, step-by-step instructions for glycol charging are included in the above sequence. If you are charging the system on a warm day, be cautious not to close off an array full of liquid for any longer than is necessary. If the fluid in the array boils, the pressure can skyrocket and damage the system, perhaps blowing off pressure-release valves.

Verify system control.

- ❏ Test sensors by using a temperature meter to measure temperature at the sensor location. Confirm that it matches the sensor reading on the control. Using an ohmmeter at the solar control, test the resistance through the sensors. Look at a resistance-to-temperature chart and confirm that the measured resistance matches the actual temperature where the sensor is located.
- ❏ Verify that the control functions or relays are operating correctly. Is the system operating when the design differential is met? Change the high-temperature limit to below the current temperature of the storage tank and confirm that the CONTINUED ON PAGE 88

pumps turn off. You might need to artificially heat or cool sensors to confirm they are operating properly.

- ❏ Program the system control to achieve the desired sequence of operation per design.
- ❏ Record all settings.

Check and record flow rates.

- ❏ Check the collector pump-loop flow.
- ❏ Check the domestic pump-loop flow.
- ❏ Calibrate the arrays if they are fitted with circuit setters or flow meters. When balancing arrays, it is important to note that the fluid flow changes as each array is balanced. Restricting one array often adds more flow to another. Refer to the balancing valve manufacturer's instructions for directions. It may take several passes to correctly balance the arrays.

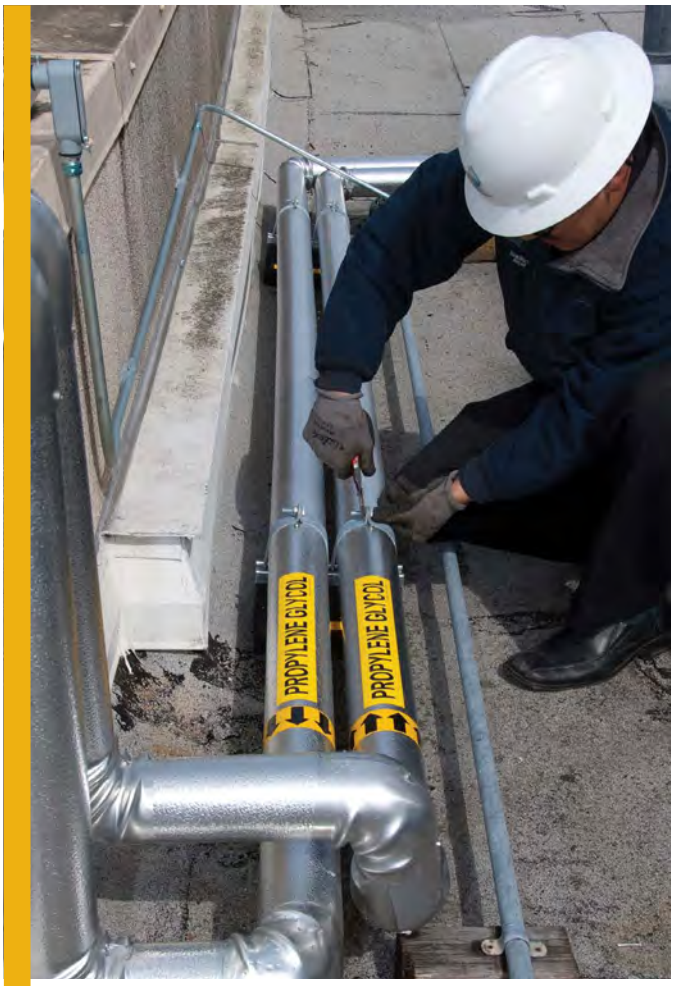
Calibrate valves and sensors.

- ❏ Calibrate the tempering valve and record the setting.
- ❏ Calibrate the temperature and pressure sensors as required.

Check labeling, postings and owner's manuals. One of the most common causes of a solar thermal system's premature death is the facility's service technicians' failure to understand how the solar thermal system integrates into the existing water heating system. In extreme cases, this can lead to the solar system being bypassed and rendered useless. Proper labeling, along with posting product information, solar contractor contact information and schematics, greatly reduces this risk. A system diagram must be posted near the solar equipment, along with a valve chart and shutdown procedures. All diagrams should be laminated. Pipes and each piece of equipment should be labeled per the schematic. Valves should be labeled per the valve chart. Owner's manuals should be posted and easily located.

For closed-loop systems, labels reading *Propylene Glycol* should be affixed to the solar loop. Many building departments also require labels on the heat exchanger that clearly state whether it is single or double walled.

Check the monitoring system. Monitoring systems allow installers and system owners to conveniently keep close tabs on system performance and production. Web-based monitoring provides maintenance staff and system installers with real-time system performance and production data to confirm system operation and productivity without a site visit. Some products feature alerts that allow installers to proactively address malfunctions, such as burned-out pumps or failed sensors. Monitoring systems typically require Internet connectivity, which can involve the installation of a router and Ethernet cable.



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Labeling In glycol-based systems, labels reading *Propylene Glycol* should be affixed to the solar loop. In addition, many building departments require labeling on the heat exchanger that indicates whether it is single or double walled.

FACILITY STAFF TRAINING

Training plays a vital role in commissioning. It provides an opportunity to raise the profile of solar thermal technology, educate potential solar thermal advocates and perhaps win more jobs with the client. Contracts often require solar thermal companies to educate maintenance staff and other on-site personnel on system operation, shutdown and troubleshooting. Take this occasion to get people excited about solar thermal and encourage system owners to publicize their adoption of the technology.

The training briefing usually takes place soon after the system is commissioned. Begin the CONTINUED ON PAGE 90

training session with an overview of how solar thermal and PV systems differ, as the two are often confused. During the training, point out where the system documentation is located (typically in the mechanical room). Thoroughly address system maintenance and at what intervals maintenance should be performed. Remember, facility maintenance staff often consider a solar thermal system to be just another thing that is going to break down and cause them trouble, and some maintenance personnel may opt not to be responsible for maintenance at all. Ask questions of the staff to get a feel for how much assistance they want with system maintenance. Record your findings and relay a summary to the service manager. Make sure to allocate sufficient time for the training session and stay on site until you have answered everyone's questions.

INTERNAL DOCUMENTATION AND THE COMMISSIONING REPORT

Internal documentation serves as a record of the entire commissioning process. The commissioner's handwritten notes can prove invaluable in troubleshooting any future malfunctions. The make, model and serial numbers of system components should be recorded. This information will be needed if components fail during their warranty period. This documentation also identifies who commissioned the system, the date of commissioning and any issues encountered during the process. Commercial building owners may demand a copy of items from this documentation along with the commissioning report before releasing final payment.

Original and as-built design documents are also important to the commissioning process. The commissioner must carefully compare every aspect of the as-built system to the original plans to determine design conformance. Record any discrepancies. The sizes of piping and tanks, the placement of valves and the collector layout are just a few of the features that must be double checked. All discrepancies or changes should be noted and documented.

In addition to the commissioning report, supplementary documentation should be provided. Requirements vary according to system owners' wishes, but generally include product manuals, as-built drawings, system shut-down procedures, valve charts and contact information for service companies. These materials are useful to any maintenance or repair personnel who need to service the system. One full set of documentation is left in the mechanical room, with items such as the valve chart and shut-down procedures laminated and posted in plain view. Additional sets of documentation should be handed off to the system owner. CONTINUED ON PAGE 92

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Follow-up Solar thermal system malfunctions can easily go unnoticed because backup heating systems will typically continue to supply hot water to the facility. Therefore, a commissioning follow-up should be scheduled 30 to 60 days after the initial commissioning to ensure that the system is operating as intended.

COMMISSIONING FOLLOW-UP

Commissioning is complete when the lead commissioner is satisfied that the system is up and running properly. That said, solar thermal professionals should always follow up 30 to 60 days after commissioning to ensure that the system is still operating smoothly. No news is good news, but do not assume that an absence of complaints from the client always indicates a flawlessly functioning system.

Malfunctions in the solar thermal system may go unnoticed. Because an electric or natural gas water-heating system nearly always backs up a solar thermal system, clients always have hot water. If a pump or control unit in the solar thermal system fails, for example, owners may not realize for weeks or months that something is amiss. Homeowners, as well as finance departments that pay the utility bills for commercial or industrial buildings, may not know how much energy savings to expect and therefore could not know that a newly installed solar thermal system is underperforming. Unlike PV systems, where production is clearly indicated on utility bills that show how much energy the system is producing, utility bills do not show solar thermal system production. In addition, solar thermal system production is hard to quantify by looking at gas bills alone since the gas portion of the bill is often accounting for numerous gas-powered appliances.

CONCLUSION

For installers, the two best days of a project are typically the first day on the job when the build plan is made and the day that the new system is fully commissioned. The difficulties that so often occur in between—leaks, parts runs, scheduling delays, inspections—can be chalked up to experience if the commissioning is flawless. Commissioning day is your chance to close out the job on a high note. After the system is charged, there is nothing more satisfying than spending some time watching it run, fine-tuning the control settings and admiring your handiwork.

Commissioning is also an opportunity to take photos of the completed system for use in case studies and other marketing efforts. Avoid the urge to set and forget the system and move on to the next job without taking steps that enable you to showcase your hard work. Your business benefits, as does the solar thermal industry itself. Publicizing solar thermal technology is a responsibility shared among solar thermal installers, integrators, equipment manufacturers and resellers. Do your part by commissioning the right way every time and showing the world that you have done so. ⏚

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