Sustainable Energy Resources for Consumers Webinar on Solar Water Heating Transcript

The following is a transcript of a Webinar recording on solar water heating, which was presented on Nov. 16, 2010 for [Sustainable Energy Resources for Consumers Grantees] and sponsored by the U.S. Department of Energy. [Watch the video recording].

Elizabeth Doris:
Thank you very much. This is Liz Doris with the National Renewable Energy Lab. I manage some of the technical assistance here at the lab, including the SERC technical assistance, which is the subject of today's call. You can access SERC technical assistance by emailing SERC_TA@nrel.gov. And we will respond to you as soon as we can, and hopefully get you the assistance you need to implement your QE funded SERC grant.

We're really excited today because we're gonna kick off a general education webinar series on different technology types. We're trying to do this with the most popular technology types that are using by SERC grantees. And so we're gonna start today with hot water heating. And if you have questions during the webinar, please feel free to ask them through the typing function – because we're on silent. And we will try to answer them at the end of the webinar. If you don't get your questions answered, please feel free to email SERC_TA@nrel.gov, and we will do some follow-up work where we can.

So without further ado, I'd like to introduce our speaker today. Andy Walker is a professional engineer and PhD. He is a senior engineer with the National Renewable Energy Lab, and he has worked on a number of different programs in his tenure here at NREL, including the Residential Home Builder Program, the Exemplary Building Program, and the FEMP Program – the Federal Energy Management Program. He's an expert on all sorts of different financing, design, and different renewable technologies and energy efficient technologies.

And today he's gonna talk to us and run through his presentation on hot water heating technologies. We're gonna post these slides after the webinar, on the SERC website – the DOE SERC website, which we'll email out to everyone who was invited to this. There's a technical assistance page there, which hopefully you're familiar with. And also posted on that site will be some specifications for RFP – some sample RFP specs that you can also look at, which we'll post after this. So with that, Andy, I will hand it over to you.

Andy Walker:
Okay. Thank you for the introduction, and thanks to all of you for joining us this afternoon on the topic of solar water heating. I'm kind of sorry to hear that you're all in listen-only mode. Because I'd like to try to make sure that this webinar meets your needs exactly. So maybe we can use the Q & A function. At the top of your Live Meeting window, you should see a Q & A button. And if you click on that, you should be able to type a question. And I'm gonna leave that window open, so I can see any questions that

come in, and we'll try to make sure to cover topics that you're most interested in, and provide you the information that meets your needs.

To overview the technology, solar water heaters can be considered one of three types, depending on the temperature at which they efficiently deliver heat. Low temperature collectors are like unglazed plastic mats. Mid-temperature collectors could be glazed, flat plate collectors. And then high-temperature collectors could be evacuated tubes or focusing collectors. We'll discuss the different characteristics and the pros and cons of each one of these types of collectors.

In terms of where we're at now, this information is a little bit old. Some of the other information in these slides is a little bit old. But when I went to update it, the message behind the information really didn't change. So I think we can still refer to it. Natural gas costs about one-third as much as electricity for heating water. And yet there's about an equal amount of natural gas water heating and an equal amount of electric water heating.

And I think the reason for that is an electric water heater is much cheaper to install. You don't need to run a gas line to the unit. You don't need to run a flue through the roof. So in retrofits, or even in new construction, a lot of times, people go with small electric water heaters distributed throughout a building. And so electric water heating is still a big fraction of the total. Propane and oil make up a little bit.

But solar is that tiny little one percent. About three percent of the buildings have solar. And for each one of those, the solar water heating provides about one-third of the energy. So nationwide, about one percent of our nation's water heating comes from solar. And that's a pretty small number – maybe a pitiful number. But on the upside, it shows all the potential that this technology could grow into.

These are schematic diagrams of each of the different types of collectors. The unglazed collectors don't have any cover glass because they operate at a really low temperature. As the temperature at which it delivers heat goes up, we need a cover glass to attenuate heat loss of the face of the collector. And we also add some insulation – either polyisocyanurate or fiberglass insulation or both to the back side of the collector. The whole thing is often supported in an extruded aluminum frame. Evacuated tubes improve the quality of the insulation by evacuating all of the air out of the assembly.

There are basically three ways in which heat escapes from a solar collector: conduction, convection, and radiation. Conduction and convection both depend on air as a medium to convect the heat away from the pipes. But by eliminating the air in the system, they get a much lower heat loss. And then we can augment the performance of that evacuated tube by putting it in the focal line of a parabolic trough-shaped mirror, to get very high temperatures. This would often be the case for industrial process heat. Although for large water heating projects, it could be the least cost option to do it that way.

We want to select an application that makes sense. And one of the criteria is the purpose for which it's providing hot water. Is it a five-day-a-week operation? Or a seven-day-a-week? If it's seven days, that's 40 percent more time that we're using the solar heat. So applications like prisms and hospitals and residential applications – apartment buildings down to single-family homes – are all good, because they use the hot water seven days a week and 365 days a year.

An example of a bad application might be a school which is closed in the summer, when the solar resource is at a maximum, and also closed on weekends. So it's not using the heat in those cases. If an area has an active solar market, it can really affect the prices. For example, whether you've got a local installer that can just come out to your building and install it, or whether they have to drive three or four hours to get to your site – all of these things can affect the price, and the price can then affect the economics of it. I started in the solar business back in 1980.

And back in those days, we used to rack mount solar heating panels up on roofs in the optimal orientation, no matter how the roof was situated. And so we ended up with some pretty ugly looking installations, with solar collectors sticking up like rabbit ears, off the ridge of a roof or something. So nowadays, we take aesthetics much more seriously. And it's often recommended to lay the panels flat down, flush on the roof. Even if it's not the perfect orientation, it's often more acceptable from an aesthetics point of view.

So the unglazed collectors are used almost exclusively for swimming pool heating. They can only heat water to about 10 degrees C or 20 degrees Fahrenheit above ambient temperature. So there's a very vibrant market in Southern California, Arizona, Florida, and places like that for solar water heating. And we'll see that actually makes up the bulk of the market. But I think the focus of this webinar is on solar water heating for domestic applications, so we won't talk too much about swimming pool heating.

We'll jump right to flat plates. These are capable of heating water up to a higher temperature, and are most often what you would find in residential solar hot water applications – these types of flat plate collectors. There are several domestic manufacturers of these types of solar collectors in California and Florida and other locales within the United States. And as we've already discussed, they consist of a copper absorber plate, which absorbs the solar radiation.

Often that has a special surface on it which has a high absorptivity in the solar spectrum, but a low emissivity in the infrared heat loss spectrum. A tempered cover to attenuate radiation, and also protect that heat absorbing surface. Copper flow passages to heat the fluid as it circulates through the collector. And the whole thing is insulated in an aluminum frame. These types of flat place collectors are very good for almost all domestic hot water applications. They've got a proven track record.

Their cost is about as low as it's probably gonna get, given the materials and the manufacturing techniques. A disadvantage might be that it's inefficient in cold climates. The evacuated tubes are better insulated. But these flat plate collectors are well enough insulated that they can be used in the continental United States. They're a little bit difficult to install because they often weigh more than a person could carry up on a roof, or even two people could carry up on a roof. So that has some implications for the installation. A lot of times, a crane is necessary to position the collectors on the roof, so that the laborer can install them.

And as we'll discuss when we get to evacuated tubes, the tubes can be carried up individually, and can often be installed without a crane. I don't know. It says "Not Waterproof" here. But actually, of course, these would be waterproof for mounting outdoors, and should be able to resist rain and such. And these are photographs of evacuated tube collectors. So you can see that heat absorbing surface is inside a tube, from which the air has been evacuated.

These are very, very popular in Germany. The sunniest place in Germany is cloudier than the cloudiest place in the U.S. So they think they really need the superior performance of these evacuated tubes, in order to collect useful heat. They're also very popular in Asia, where Chinese manufacturers have adopted this technology. This is a cutaway view of an evacuated tube, and it shows how the heat gets out of that evacuated tube. There's a device called a heat pipe within the evacuated tube. Fluid boils on one end and condenses on the other.

That fluid – initially, back when these were first invented – was Freon. But nowadays, manufacturers just use deionized water as the heat transfer fluid within that heat pipe. And then the red end of that – the condenser bulb up at the top – that gets hot. And that would be clamped into a manifold, which could either heat your potable water or heat another heat transfer fluid, such as a glycol solution, which could circulate around the system and then heat your potable water by means of a heat exchanger. We'll talk about that more when we look at some of the system schematics coming up.

Some concerns about solar water heating systems might involve the long-term degradation and performance, the wind loading, mounting systems, lifespan, what happens during a power outage, and maintenance considerations. We'll try to discuss each one of these with a slide. But wind loading can be controlled by, again, mounting 'em flush on the roof, so that the wind loads aren't as extreme.

But even if you had to tilt 'em up, as shown in this photograph here, or even at a steeper tilt angle, the American Society of Civil Engineers publishes a standard by which to calculate what that wind loading is gonna be. And so that would be part of the design of any system. The mounting really should be in such a way that doesn't cause long-term problems for the roof. Installers for most residential applications – they have a habit of just using lag bolts to drill into the rafters, and install them in that way. That, of course, involves penetrating the membrane of the roof.

We can try to seal that with neoprene gaskets and with liquid sealants. But if you have a chance to invest a little bit more in the installation, you can put blocking between the rafters of the roof, and drill into those, so that you're not potentially, over time, compromising the structure of the roof with your solar installation. And in new construction, there's the possibility of putting permanent curves in the roofing system, and then mounting the solar collectors to those curves, so that you could conceivably service the roof without removing the solar panels.

One big problem is that if a house needs a new roof, it's often part of the process to take the panels down, redo the roof, and then put the panels back up. Well, that's a considerable expense. And we lose a lot of solar systems, because homeowners don't make that reinvestment of putting the solar panels back up when they have a new roof installed. And we're gonna close up with a pretty detailed discussion of the maintenance requirements of these types of systems.

I'll forget this slide, in the interest of time. So this slide is just kind of exploring the pros and cons of the flat plate versus evacuated tubes – solar collectors again. And one of the characteristics of these tubular-shaped solar collectors is that their output is more uniform throughout the day than the flat plate. The flat plate starts out less in the morning, peaks at noon, and ends up less at noon. So evacuated tubes are less at noon, but they're more uniform throughout the day. That can sometimes be cited as an advantage to them.

In order to discuss the efficiency of these solar collectors, we need to do a little bit of math. The energy that's coming in from the sun is the intensity of the incident solar radiation that's indicated by the "I" symbol here, in watts per square meter and the area of the solar collector in square meters. So if I multiply watts per square meter by square meters, I get the watts of incoming solar radiation that I have to deal with.

The fraction of that radiation that makes it through the cover glass is the transmissivity of the cover glass indicated with the symbol Tao here. And the amount – the fraction of that which is absorbed on that black absorber surface is the absorptivity alpha. So that incident solar radiation x the collector area x times the transmissivity x the absorptivity is the optical gain of the collector – how much of that radiant solar energy was captured.

And then this solar collector is kind of like an insulated box sitting up in the attic, so it's gonna have heat loss, just like any insulated box, like a house, would have. And that's quantified by the u value, or the thermal loss coefficient x the area of the solar collector x the temperature difference between the temperature at which the solar collector is operating at and the ambient temperature. So in that first equation, the useful heat is the optical gains minus the thermal losses. So the radiant heat gain minus the heat losses is the useful heat.

Efficiency is often defined as what we get out divided by what we put in. And what we put in, in this case, was the solar energy – the I x A. So if we divide through by that, we come up with an expression of efficiency. It's Tao alpha minus a heat loss term. The Tao alpha is just a materials property, so that's essentially constant. But the heat loss increases as the temperature of the solar collector increases. So if you look at that equation for efficiency, you'll see the equation of a straight line. And there's this organization called the Solar Rating and Certification Corporation, which is an objective third-party testing lab that tests each solar collector and gives it a nameplate rating, in terms of those two parameters – the optical efficiency and the heat loss. So that's the y-intercept and the slope of each one of these lines.

And when asking which of these solar collectors is best, the answer to that question is: it depends on the temperature at which we're using heat. For low temperature applications, which is the right-hand side of this horizontal axis, the unglazed collector is not only the cheapest, in terms of not having much materials involved in it, but it's also the most efficient.

And how could that be – that an uninsulated collector is more efficient than an insulated collector? Well, if you're at a low enough temperature, the cover glass can actually be counterproductive. It reflects some solar radiation, and it absorbs some solar radiation going through the glass. So the unglazed collector, at really low temperatures – again, only 10 or 20 degrees Fahrenheit above ambient temperature – are actually more efficient. I started out by saying that these are used exclusively for swimming pools.

But there are two manufacturers – Bathco and Suncatcher – that supply this technology for heating domestic hot water as well. Of course, that's only gonna work in a warm climate, like Southern California or Arizona or Florida or someplace like that, and only for a small fraction of the house's hot water load. But as a cream skimming approach, it's a way of keeping the cost of these systems down.

And then as we get into higher temperatures, we need a flat plate collector, which will go between 10 degrees C and 50 degrees C, which would be about 20 degrees Fahrenheit and 100 degrees Fahrenheit above ambient temperature. So this is well within the range of being able to heat domestic hot water up to 120 or 140 degrees Fahrenheit for us pretty easily. But, in fact, these flat plate collectors can get all the way up to 180 degrees Fahrenheit in the summertime, and deliver heat at that temperature pretty efficiently.

But then if we want to get higher temperatures than that, or if we want to operate in a colder climate, or if we want to work with lower solar radiation levels – probably low ambient temperature and low solar radiation levels are the kind of thing that you would find in Germany – the evacuated tubes are recommended. And evacuated tubes would also be recommended for higher temperature applications, such as absorption cooling, such as industrial processes where maybe you're trying to wash glassware, and you have to deliver temperature at 180 degrees Fahrenheit, or some other higher temperature applications – industrial process heat and so forth.

And I'm watching the Q & A window, if anybody has any questions. Feel free to type a question. Here's the contact information for the Solar Rating and Certification Corporation. This is a useful resource for anybody who's in the business of purchasing solar collectors. Because, again, this is the third-party laboratory that tests the thermal performance of the solar collectors. But they also have quite a few quality control tests that they do, including testing the strength of the cover glass and stuff like that.

So in our request for proposals, we require that all the equipment – all the solar collectors be rated by this Solar Certification Corporation. Their rating system for individual solar collectors is called OG-300. OG stands for "Operating Guidelines." And then they also have an OG-300, which relates to testing of complete water heating systems. That would be the solar collectors, the pumps, the controls, the tanks, everything – a complete residential scale system. So if I was purchasing a small residential-scale system, I would say, "Refer to OG-300."

If I was purchasing a large commercial system, there's no way to get the complete system rated. Because it's one of a kind. But I can still get the individual solar collectors rated under OG-100. This graph shows how the solar heating market has evolved over time. And the bright yellow bars are the unglazed solar collectors. So you can see that swimming pool heating has really been supporting the solar water heating market for all these years.

The mid-temperature flat plate solar collectors for domestic hot water are the kind of middle orange bars. You can see that's a much smaller part of the market. And then the red would be for evacuated tubes. Between 1981 and 1986 was when the first round of federal tax credits was in place. And we can see there was a pretty robust flat plate market during those years. But then when the tax credits expired in 1986, a lot of those companies went out of business, and, basically, the bottom kind of fell out of the market.

The red bars that you see there are high-temperature applications – utility-scale projects in California, which really don't count when we're talking about domestic water heating. But you can see that since 1986, there's been a natural growth in the market. And it is kind of rebounding, and now we have the tax credits back in effect which apply to solar water heating, potable tanks, and other renewable energy technologies as well.

So in recent years, you can see that there is some growth in that orange bar – the flat plate. We can also see the high-temperature collectors taking on a bigger part of the market. Just looking worldwide – just in case you were curious about how America compares with other countries around the world – China is, by far, the world leader in both manufacturing and use of solar water heating. It's a very popular technology and an alternative to using more expensive fuels like oil and propane, since they lack the central infrastructure to deliver cheap natural gas to a lot of these residential customers.

And then some of the other ones – China is also probably the biggest, most populous country in the world, so that might explain part of it. But when we look at some of the other countries which are leaders in this – Turkey, Japan, Israel – I happened to be at a conference in Jerusalem recently. Went up on the hotel roof and looked around, and every building has solar water heating up on the roof in Israel. It's actually a law that any new buildings incorporate it.

But the U.S. is behind, with only two percent of the market share. But we think there's a lot of growth potential in the U.S. as well. Some of the policies that some of these other countries have been adopting, in terms of incentives, are starting to make it into the U.S.

Now we have a 30 percent investment tax credit for solar that homeowners can take advantage of. There are also requirements for government agencies to do more and more solar water heating on their projects.

For example, any new federal building is required, by law, to get at least 30 percent of its energy from solar water heating. So I would expect that two percent, for the U.S., to increase. Now if there aren't any questions about the different types of solar collectors, we can move on to discuss how these collectors fit into different types of systems. And, again, feel free to use the Q & A function on the Live Meeting, if you have any questions.

One of the simplest schematics is to integrate the storage into the solar collector. Then you just feed it with cold water, and take the preheated water off the top. No matter which of these schematics we're considering, we always have an auxiliary heater, which could be our regular electric gas or propane or oil fired water heater. The reason we need that is it's not cost-effective to try to get 100 percent of the energy from the sun. There are always those three or five cloudy days, and it's not cost-justified to build a system with a storage tank big enough to carry us through that.

It's more cost-effective to shoot for about two-thirds or three-quarters of the load with solar, and to meet the other one-third or one-quarter of the load with our conventional fuels. That combination tends to minimize the overall life cycle cost. The CopperHeart is a manufacturer in Florida that makes these collectors with four-inch copper tubes, so they integrate the storage right in there.

The disadvantage is that there's only a sheet of glass between your hot water and the cold night sky, so there's a lot of heat loss at night. We have to use this schematic as far north as Atlanta, Georgia. The collectors themselves are warranted against freezing. But you have this connecting piping which is just potable water, which is not protected from freezing.

If we wanted to provide a better insulated place for our storage tank, we could put it up near the top of the collector, insulate it with fiberglass or foam, and put it in a steel jacket to protect it from the elements. And then a natural circulation of hot water into the storage tank and cold water sinking back into the collector will create a thermosiphon loop, and heat up that tank during the day. And then we can draw water off of that tank whenever we want.

This schematic also features the auxiliary electric heater. But there's one manufacturer that installs the electric element up in that thermosiphon tank, so that you don't need to take up space inside your house for an additional electric water heater. Some of the pros and cons of these different schematics are also listed on the slide. Neither one of the ones that we've considered, so far, have breeze protection, and they also don't protect against minerals in the water.

Both of these schematics circulate potable water through the solar collector. And as minerals build up in those tubes, if you live in a location with a lot of dissolved minerals in the water, then that'll affect the life of the system. It's really hard to clean the minerals out of the tiny flow passages within the solar collector.

These are some photographs of some thermosiphon systems which use the evacuated tube concept. If we wanted to put the storage tank down inside the conditioned space – maybe our roof's not strong enough to support it, or maybe we want to put it where our other conventional water heating equipment is, down in the basement of the building – then we need to pump to overcome the buoyancy of the hot water, and drive the hot water down into the storage tank.

This schematic still shows circulating potable water up to the collector, so it's a schematic that you would find in a non-freezing climate. This is the schematic that we've used pretty extensively in Hawaii, where potable water is circulated straight through the collector. But if we lived in a freezing climate, we'd need to circulate a non-freezing fluid. By non-freezing fluid – it is an antifreeze solution, but it is not the same type of antifreeze that you would find in your automobile radiator.

It's called propylene glycol, which is an ingredient of candy bars and soda pop, and it can be ordered in a food-grade version, which is safe for use in a potable water system, in case there was any contamination between the antifreeze loop and your potable water, it wouldn't introduce a hazard. So it's very important that we specify propylene glycol, and maybe even food-grade propylene glycol as the antifreeze solution. And that can be mixed either 25 percent or 40 percent in water to form the fluid in this closed loop, which circulates up to the collector, and then down to the heat exchanger.

And now we've introduced a strategy for dealing with the minerals. Because if minerals do build up, they'll only build up on the potable water side of the heat exchanger. And the idea there is to valve off the heat exchanger and rinse it out with an acidic solution, which dissolves the minerals. And so even in a hard water location, there's a maintenance provision for dealing with the mineral build up, and these types of schematics can be expected to last a long time, even in that environment.

But we've added an additional pump, and so the maintenance requirements of these types of systems can be high. And we've also added the antifreeze solution, which requires maintenance. Basically, annually we'd want to check the condition of that heat transfer fluid. And then probably after about ten years or so, it would have to be flushed and replaced with replacement heat transfer fluid. So the maintenance requirements for this type of system are higher.

Let me just back up to that schematic for a second. So you might ask yourself: "What happens when nobody is using hot water?" Let's say this building is closed for a long weekend or closed for a couple of weeks in the summer. The solar preheat tank is just gonna get hotter and hotter and hotter. And it has a temperature sensor on it. The function of this controller, on a day-to-day basis, is to measure the temperature at the collector outlet and measure the temperature of the solar preheat tank.

And when that temperature difference rises to about 12 degrees Fahrenheit, it will turn the pump on. And when that temperature difference drops to less than 4 degrees Fahrenheit, it'll turn that pump off again – turn both of the pumps off again. But the controller has a second function to it, which is – when the solar preheat tank temperature exceeds 180 degrees, or whatever you have set at, then it'll also turn the pumps off. This is a way of keeping the solar preheat tank from getting too hot.

And if we didn't have any other provisions, what would happen is the solar collector would just get hotter and hotter, if it's still sitting out in the sun, until it blew off the pressure relief valve. That's bad because it spews propylene glycol solution all over somebody's basement or all over somebody's garage or all over somebody's roof. But it's also bad because the pressure relief valve is really a safety device, not a control device.

So one schematic that we first used on a school in Phoenix back in 1995 – we knew this school was gonna be closed in the summertime, so we used this schematic which includes a drain-back tank. And now whenever the pumps turn off, for either reason – either because the collector is not hot enough to heat the solar preheat tank, or because the solar preheat tank has exceeded its 180 degrees Fahrenheit high limit – if, for either one of those reasons, the pumps turn off, then the fluid from the collector drains back into the drain-back tank.

Now the solar collector is sitting up there in the sun, dry, it'll get up to about 400 degrees Fahrenheit. But that's okay. Because the materials that it's constructed out of are designed to accommodate that temperature. So ever since we used this schematic on that school in Phoenix, I've been recommending it for almost all of our projects. It's very robust. It protects against both freezing and overheating. It has two types of freeze protection, and the fluid can flow back into that drain-back tank, which can be located inside your heated space or conditioned space. And so this is a very robust schematic which has a lot of advantages over the other ones that we've been looking at.

And then, finally, we first used this schematic on a hospital in Philadelphia. It was an eight-story hospital, and they wanted to add solar collectors to the roof. The conventional water heating system was in the basement. We issued an RFP and got three proposals back. Two of the proposals proposed running new piping all the way up the eight-story building. And that was prohibitive, both in terms of cost and, also, the disruption of the operation of the hospital.

So the third proposal proposed this schematic. Imagine that the hospital has a recirculation loop which delivers hot water to all the water consuming appliances in the building. The hot water comes up through all eight stories, comes into a penthouse on the roof, and then does a U-turn and goes back to the boiler plant for reheating. So this recirculation loop is circulating hot water 24 hours a day. The idea is to add a pump and a controller, and the solar panels just take hot water out of the recirculation loop, pass it through the solar collectors, and reinject it into the recirculation loop on the way back down to the boilers.

Now if we're gonna do that – if instead of preheating cold water, we're gonna reheat hot water – we have to have a very, very well insulated solar collector. And the ones that we used at that hospital in Philadelphia were evacuated tubes for that purpose. Since then, evacuated tubes have been used in this type of schematic on a lot of other important buildings, including the Pentagon.

Remember we said that there's a high temperature limit of the storage tank. And that might come from the factory set at 180 Fahrenheit. At my house, I have it set down to 140. Because I have kids, and I want to protect against scalding. But the primary defense against sending those high temperatures to the taps in a building is this tempering valve. So the presence and the reliability of a tempering valve is extremely important in any solar water heating system. Basically, it's a safety device; it keeps you from sending high temperatures to bathtubs or shower fixtures, where somebody might get scaled by the high temperature.

But it also has an advantage in the operation of the system, in that it extends the useful volume of the storage tank. In other words, I can take one gallon of water at 180 degrees Fahrenheit and mix it with one gallon of water at 60 degrees Fahrenheit, and produce two gallons of water at 120 degrees Fahrenheit. So it's basically delivering more tempered water than you have hot water storage.

I want to make sure we cover the importance of this tempering valve. This one that is shown in the photograph here – you can see how the hot water comes in one side. Cold water comes in the bottom. Then the mixed water comes out the other side. And the temperature at which you're delivering the mixed water is adjusted by turning that knob on the top of the valve.

This schematic shows how some of the other components might fit together, with a little bit more detail. This schematic is very similar to the system that I have on my house, so I'm pretty familiar with it. It has a coil submerged in the water tank as the built-in heat exchanger. You'll notice an expansion tank there. The closed loop circulating fluid from that heat exchanger up to the solar collectors is of a fixed volume.

So that expansion tank accommodates the expanding and contracting fluid, as it heats up and takes up more volume, so it expands into that expansion tank. And then when it cools down, it comes back out of the expansion tank. We have a safety valve, which is a pressure relief valve, a pressure gauge to monitor the pressure, flush and fill piping for filling up the system in the first place, and then flushing it out and replacing the heat transfer fluid. And that kind of shows the other components that might be involved in the system.

So in terms of system sizing, really we tried to estimate what the hot water use is, based on the number of people that are in a building. And I'll share some of the rules of thumb regarding that with you, and we'll step through this procedures to figure out how big a system might be, how much a system might cost, and how much you might be able to save by installing a system.

This example's purely hypothetical, so I'm gonna skip it, in the interest of time, and maybe spend some more time talking about the case studies that we have direct experience with. This is a system that heats a swimming pool in the building behind it at Forth Huachuca, Arizona. It's about 2,000 square feet of the unglazed solar collectors to heat a 3,500-square foot pool.

I've been involved in six of these swimming pool heating projects, and it's almost always the case – you can almost say it's a rule of thumb – that the optimal size of the solar collectors will be about half of the swimming pool surface area. There's a typo in this slide. It says it cost $35,000.00. It actually cost $53,000.00 to install this system. But I like to keep referring to this system, because it was installed in 1980 – 30 years ago.

But it's still, according to Bill Stein, who is the energy manager down there – he's in this photograph, standing out there with my boss, Bob Westby– it's still, even 30 years after its installation, producing useful heat for the Army. So it's one of the systems that we can point to as a long-term success. They all balance out some of the other less successful installations that we could also point to.

These are comfort stations at Chickasaw National Recreation Area. They involve the glazed flat plates. They're getting up to a higher temperature for showers and laundry. The small comfort stations have shower facilities, and the large comfort stations have both showers and laundry. The small systems are 195 square feet of flat plate collectors heating a 500-gallon storage tank. They cost about $8,000.00, and deliver about 9,000-kilowatt hours per year. The big systems are about twice as big, and cost twice as much, and deliver twice as much.

One interesting thing about these systems is they were installed without any auxiliary backup, so if the sun is shining, the campers have hot water. If the sun's not shining, they don't. The park just didn't want to pay an electric bill for the electric water heating. This is another residential application that we were involved in. These are on Coast Guard housing near Honolulu, Hawaii.

Each one of the Coast Guard housing units has its own individual water heating system. Sixty-two of 'em were installed, and we went back and monitored 50 of them. The average cost is about $4,000.00 per system, and that benefitted from an $800.00 per system rebate from Hawaiian Electric Company. Each one of those solar collectors is 40 square feet, so they're 80 square feet per system.

And we have some pretty good numbers on the performance of these systems. They deliver about 3,000 kilowatt hours per year. The demand savings was about 1.6 kilowatts per house. The solar fraction, or the percentage of the hot water load that's provided by solar, is 74 percent, and the efficiency is 24 percent. And the way we have such good statistics on these particular systems is that we did go back and monitor the performance of them.

And this graph shows the performance of houses with solar – it's the dark blue line. Houses without solar is the hot pink line. For the year that we analyzed the data, this is boiling it all down to one typical daily profile – so averaging all the days together. And you can see, for the houses without solar, there's a spike in the hot water use at about 6:00 a.m., when all the Coast Guard personnel get up and take a shower and go to work. There's another spike later in the morning, when all their dependents get up and start taking showers and using hot water.

Then there's a big evening peak, where everybody's doing cooking, taking baths, washing dishes, and maybe doing some laundry. So there's a big evening peak. And it's the evening peak that Hawaiian Electric Company was concerned about, because of the load on their electrical system peaks between 5:00 p.m. and 9:00 p.m. And you can see that in the afternoon there, by comparing the hot pink line with the dark blue line – that's where the solar systems are really providing a tremendous amount of savings.

And then by the morning, maybe the solar tanks have used a lot of their hot water. So the electric use of the houses with solar goes up in the morning, but still less than half of what it would be without the solar. Though the difference between these lines is, again, about 74 percent. On average, the solar is providing about 74 percent of the hot water for these buildings.

This is the laboratory in Edison, New Jersey, that needed to heat the water up to 180 degrees. They do testing of aquatic life, and so they have to wash the glassware really well and sterilize it between tests. And so they opted for the evacuated tubes. And notice that the evacuated tubes have another advantage. They're lightweight, and the also allow the wind to blow between the tubes, so the wind loading is less.

And, in this case, they're just mounted on these concrete blocks. The weight of the concrete blocks is what holds them down on the roof, so that they did not have to penetrate the roof with the rack attachments in this case. They also painted the roof white, in front of the solar collectors, to try to augment the reflection. This is that hospital in Philadelphia that I was telling you about.

So in the photograph on the right-hand side, you can see the insulated pipes coming from the recirculation loop, going through the header of the evacuated tubes solar collector, and then just going right back to the recirculation loop. So it's just taking water out of the recirculation loop, heating it up about 20 degrees Fahrenheit, on its way back to the hot water storage tank in the basement.

And this bar chart shows – we also monitored the performance of this system, and the bar chart shows the results of that performance measurement for one year. You can see that in the summer months, the system is performing at its best. In the wintertime, the solar delivery is only a fraction of what it would be in the summer months. That's due not only to the fact that the day is shorter in the wintertime, and the sun lower in the sky, but also the colder ambient temperatures are exacerbating the heat loss of these types of systems.

Remember this one's taking water into it at 120, and giving it back at 140. So it's operating at a really high temperature all of the time. And so in January, for example, the heat loss is a lot worse than it would be in the summer months. But over the course of the first year that we monitored its performance, it delivered 36 million BTU per year.

And I don't think this audience is gonna be interested in the real large scale systems, but we have been involved in several. This one happens to be heating water for a prison north of Phoenix. Army bases and other clusters of buildings where you have, say, multiple barracks or, in this case, cell blocks, along with a cafeteria that uses hot water and a laundry facility that uses hot water.

These types of central systems can be more cost-effective than putting solar hot water on each building. In fact, this system involves about two miles of underground piping to distribute the hot water to all of those prison buildings. In fact, the solar collector itself, as you can see in this photograph, is located outside of the fence of the prison. So it doesn't have to be secured in the same way that other equipment inside the prison does.

This one was installed under an energy savings performance contract, so the prison doesn't pay for the $650,000.00 initial cost of the system. Rather, they pay for the heat that's delivered by the system over time.

And we have a question. Will the PowerPoint and calculations be available after the webinar? And yes, they will be. The PowerPoint and recording of the webinar will be available on the DOE SERC website, and Elizabeth will send out the link for that. And then, also, I was asked to talk about requests for proposals, and I'm gonna post a sample specification on the same website with Liz.

So back to this example. The prison just pays for the delivered heat. And this has also been monitored very carefully. This shows the first five years of performance. And you can see by the yellow line in 2001 – the system was installed in 1999. And in 2001, there was a big failure in the system. A couple of things had to fail at the same time for it to get this bad. But you can see in October of 2001, the output of the system went down to a fourth of what it was before.

And I think if the prison would have installed this system at their own expense and maintained it at their own expense, they might have been tempted, at that point, to dismantle the system and write it off as an expensive experiment. But because it was a performance contract, and because the contractor didn't get paid unless the system was performing, they did come back in.

And you can see that by January of 2002, the system is providing as much heat as it did initially. And even though the output varies a lot from month to month, the yearly delivery is actually pretty uniform from this system. So I'd like to step through a simple evaluation procedure that people can use for your own –

(Interruption)

But first, we're gonna estimate the load, and then we're gonna – well, rather than read the steps, why don't we jump right into 'em. Water heating system costs vary a lot, depending on the size. That's one of the reasons to consider a large central system distributing heat to multiple buildings, rather than multiple systems on each building. We can get down to $40.00 to $50.00 a square foot in a large central system.

But small single systems – here we say $155.00 a square foot, from this particular reference. But in my experience, we have examples of up to $250.00 a square foot. So size matters, and one big system is certainly better than two small ones, in our experience. To estimate the load, it takes the mass of hot water that you're using times the specific heat of water, times the difference between the temperate at which you're delivering and at which the cold water comes in.

And off to the right-hand side are some rules of thumb for different types of buildings. So for a residence, 40 gallons per person per day is a pretty typical number. But you would think that you would take your efficiency measures to try to reduce that, before you did a solar water heating system. So if you did that, maybe 30 gallons per person per day might be a more accurate number for that. And then the specific heat of water is provided to you here, and 120 degrees Fahrenheit is typical of hot water delivery temperatures, and 55 degree is typical of cold water temperatures.

So if you multiply all those numbers together, you can come up with your load and kilowatt hours per day, which is how much energy use is associated with that hot water use. Then we turned our attention to the solar resource. We're gonna take that load and divide by the maximum solar resource. So this occurs in June, typically, for most of these locations.

And the idea of dividing by the maximum solar resources – we're gonna design the solar system to meet our load in June. That's the sunniest month of the year. And then the rest of the months, we'll burn some propane or use some electricity or natural gas. Now the rationale is then our system's not oversized in the summertime, and all that investment in hardware is working to pay itself off. This sizing strategy also tends to avoid operational problems of overheating, as we've already discussed.

So here's the list of 10 or 12 locations. You might be near one of these locations and can use these numbers. But we also include some maps in the PowerPoint that you can refer to. Some of these I'm gonna have to skip, in the interest of time. So the load we calculated based on the gallons of hot water use. That's the capital "L" in this equation. The I max is June – or maximum solar resource. And if we divide those two numbers, we can come up with the size and square meters that we need to meet our load in June.

But we can't convert all of that solar heat to hot water, so there's the solar efficiency that we're also diving for. We recommend, based on some modeling by a couple of NREL staff people, that you use 40 percent for that number. And so that'll give us an estimate of how big our system should be in either square meters or square feet. Then to estimate the annual energy savings, we use that second solar number – the average solar resource.

So rather than just the June maximum, this is the average of all 12 months of the year. Multiply that by our solar collector area and by our solar efficiency – again, the same number, 40 percent – this time we'll multiply by 365 days per year. And that'll tell us how much solar heat was delivered.

And then if we want to know how much fuel that saved, we have to divide by the boiler efficiency. And some typical efficiencies from the GAMA handbook are listed on the lower right-hand part of this slide. Gas can be as low as 43 percent, but as high as 86 percent. And the preface to the GAMA handbook tells you what to assume if you don't have a particular make and model of water heater.

So for gas, it's saying assume 57 percent. For electric, 88 percent. For a heat pump, 200 percent. For a propane heater, 57 percent. For an oil heater, 52 percent. So being in the 50 percent range – your fuel savings can actually be on the order of twice as much as your solar energy delivery. Then we'll take that solar collector area in square meters and multiply by our $150.00 or so dollars per square foot – that would be roughly $1,500.00 per square meter – to come up with our estimate of system costs.

And then in order to estimate our savings, we take that energy delivery number from the same slide and multiply it by our cost of energy. You should be able to get your cost of energy off your utility bills. But I also list here, from the Federal Trade Commission, a national average – 8.4 cents per kilowatt hour for electricity, 4 cents a kilowatt hour for natural gas, 4 cents for propane, and 2.5 cents for oil.

So even though these are units of heat, they're still expressed in units of kilowatt hours. But just think of it as kilowatt hours of heat, rather than electricity. Then your simple payback could be just your cost to your system divided by your savings. And that's often a metric that people refer to, is: "How many years do I have to wait to get a return on my investment?"

I'm gonna skip the details of this example. But if you want to calculate a payback for any of your projects, you can refer back to Slide 48 and follow this example – which happens to be for Cleveland, Ohio – substituting your numbers for the numbers of this example. And you can work it all the way from your estimate of gallons per day of hot water, all the way through to your payback period, including how much the system should cost and how much it should save.

But there are some other things to consider, in addition to the energy cost savings. A lot of people do these projects to save emissions – environmental benefits, rather than just the cost savings. One thing that I like to point out is that installing and maintaining these systems employs local plumbers, local electricians, rather than exporting that money outside of the community to import energy.

For example, here in Colorado, our utility is not owned within Colorado. So, basically, all that money is leaving the community, in terms of profit. It avoids the risk of delivering fuel – especially diesel fuel – to remote locations. A lot of oil is used for residential water heating, especially in the Northeastern United States. And whenever you spill oil on the ground, it doesn't just evaporate. It's an environmental cleanup, at that point.

Once you make the initial investment, there's no fluctuation in the cost of your energy, past that point. There's no risk of anybody interrupting your fuel supply. And one thing I like to point out is that, again, at my house, I have a gas heater, and I also have solar. So I've got redundant power supplies. And, in fact, the pump on my boiler went out. But I didn't panic because I still had heat and hot water from my solar system. So I could take my time in replacing the pump on my boiler.

We've done some math between all these parameters. And if we assume a system cost of $150.00 a square foot and a 40 percent system efficiency, we can go ahead and calculate what your cost of energy would have to be for a system to be cost-effective. And this first snap compares against electricity. So you can see kind of in the hot pink there, between – no, I'm sorry.

This one's comparing for gas, I think. The next one's for electricity. So when comparing against natural gas, in the hot pink areas, we'd have to be between $2.00 and $2.50 a therm; in the orange areas, between $2.50 and $3.00 a therm; and in the other parts of the country, as high as $4.00 to $5.00 a therm. Natural gas prices are getting back down to less than $1.00 a therm now. So in a lot of places, this indicates that solar water heating would not be cost-effective.

But we're not considering any incentives in this slide. So if we reduce it by 30 percent for a federal investment tax credit and take some of the other incentives into account, then we can start to see pockets of areas where it would be cost-effective. But these are kind of the numbers to keep in mind, that under this set of assumptions, this is the value of the energy delivered.

Then the next slide is when compared to electricity. And so here the dark – the Sunbelt states – Arizona, New Mexico – they're 5 to 7 cents a kilowatt hour. And expanding from there, 7 to 9 cents a kilowatt hour. And even the cloudiest places in the country are still in the 13 to 15 cents a kilowatt hour for electricity. And guess what? In almost all these areas, people are paying that much for electricity. So in general, if you're just placing electricity, solar water heating is cost-effective and can give you a favorable payback, even without incentives.

But then on top of that, we can add the incentives as icing on the cake to make that even more attractive. So basically a rule of thumb to keep in mind is: if you're displacing electricity or one of the other more expensive fuels, or fuels that are expensive to deliver to a remote location, then solar water heating can be cost-effective, even without an incentive.

I want to get to some of the O & M issues, so I'm gonna maybe skip some of these other slides. Please feel free to look back to them at your leisure, and let me know if you have any questions. We did a survey of 185 systems. All of these systems were installed between 1981 and 1986. So they had all been in operation for at least ten years by the time we did the survey.

And the good news is that about 70 percent of them were still operating. But the bad reputation that solar got, in those early days, was probably as a result of these 30 percent that were not operating. And we kind of drilled down and tried to figure out why they weren't operating.

That big green slice at the top – that temperature sensor mount – is simply the temperature sensor falling off the surface that it was supposed to be measuring. That could be remedied with a 50-cent stainless steel hose clamp. But installers had a bad habit of just tucking the temperature sensor in-between the insulation and the tank, and expecting it to stay there for forty years.

Some of these other problems were also very inexpensive to fix. But then some of them were – like the big gray part is leaks. Depending on what kind of leak that was, and where it was, it could be very expensive to replace. And tanks are very expensive to replace. But the following slide shows that 90 percent of those systems that had been disabled could be repaired for less than $500.00 a piece.

We also asked the inspectors to do a cost estimate on how much it would cost to repair each one of those systems. And that's shown on the horizontal axis here. So most of the system could be repaired for just a couple of hundred dollars. But operation and maintenance is something important to generate the long-term savings from these.

And then I was asked to provide you with some references that you might find useful in preparing requests for proposals. And I think you can take this list of standards and just paste it right into your RFP. The first four are ASHRAE publications that relate to the design, installation, and O & M of solar systems. And then the fourth one is how the solar collectors are rated.

There's a Uniform Solar Energy Code. It hasn't been adopted by most jurisdictions, but it's still a very useful reference, and useful to refer to in your request for proposals. Some of these other ones are pretty typical of any project that involves potable water systems. And then these two by the Solar Rating and Certification Corporation are the ones that are specific. OG-100 is specific to individual solar collectors, and OG-300 is referenced to complete residential-scale domestic hot water systems.

The AFCEE standard is the one that relates to wind loading of collectors on the roof. Then there are guidelines for how to install solar panels. The National Roofing Contractors Association – their publication actually relates to potable tanks. But I think in terms of making your roof penetrations waterproof, they also relate to solar water heating as well.

And thanks very much for your attention, and I hope that this has been useful in helping you plan solar hot water heating projects. I think they'd be a good use of the funds. I think the industry is mature and ready to deliver this technology – maybe not in every place in the country, but certainly in any major urban area. They work in all climates. It doesn't have to be a sunny climate.

A sunny climate helps. But the solar resource in the cloudiest place in the country, which is wet Washington State, west of the Cascades, is about half as much as the sunniest place in the country, which is the desert of South Central California. But there are other factors which can vary by more than that, and make up for that difference, including the cost of energy.

I don't know if you noticed, but Connecticut was one of the locations that receive a lot of shipments of solar water heating. It's not known as a sunny location. But the other factors in Connecticut, including the public incentives, more than make up for that. So solar water heating can be used anywhere. And with proper operation and maintenance, and with some budget and some provision for maintenance over time, they can deliver their savings for a very long time period.

The typical warranties for complete systems are only one year. But warranties for the individual components can be up to ten years. I would ask for a ten-year warranty on the solar panels themselves. But with proper care and maintenance, these systems can last 25 years. I have a system that I've been operating on my house since 1991, and I know that there are other systems that have been around for even longer than that. So thanks for your attention.

And, Liz, I guess with listen-only mode, we're not really able to accommodate a lot of discussion. But we'd like to offer you the chance to at least email us questions. We can still use the Q & A function on the Live Meeting, if there are any remaining questions.

Elizabeth Doris:
Yeah. And if you want to take a look at any of those – I just wanted to thank you very much, Andy, and thank everyone attending. For those of you who had to join late because of the snafu with the other webinar, we apologize for that. And we will have this recording up as soon as we can.

And, also, if you have any questions or follow-up questions, please feel free to email SERC_TA@ NREL.gov, and we'll see if we can snag some more of Andy's time to answer those questions.

Andy Walker:
Yeah. I'd be glad to do that.

Elizabeth Doris:
Thanks, Andy. Thanks so much to all of you. The next webinar is in two weeks. It'll be Andy presenting, again, on – oh shoot – I don't have it up right in front of me.

Andy Walker:
Solar _____ Preheat – or Solar Space Heating.

Elizabeth Doris:
Solar Space Heating. Thank you, Andy. And so two weeks – same time. And we will get the webinar information out, as soon as we can, for that one. Thanks very much for your time.

Andy Walker:
Thanks for listening, everybody.

Elizabeth Doris:
Thanks, Andy.

Andy Walker:
Bye-bye.

Elizabeth Doris:
Bye.

[End of Audio]