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Solar Heating and Cooling: Technologies and Case Studies

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Toby Couture Good morning, everyone. Welcome to the International Solar Alliance expert training course. This is session 44 of this training series, focusing on solar heating and cooling. In this session we're going to look more closely at solar heating and cooling technologies followed by some case studies of where some of these technologies have been used in different markets around the world.

I'm Toby Couture from E3 Analytics and I'll be giving this training session. The supporters of this training series are the International Solar Alliance and the Clean Energy Solutions Center. This training is part of module 8 out of this training series, focusing specifically on the issue of solar heating and cooling.

Quick overview of the presentation before we dive in. We'll look at the learning objective, we'll cover the core of the presentation followed by a few concluding remarks. I've included a number of references and resources for further reading. And then as with all the other training sessions, there will be a knowledge check at the end with some multiple-choice questions at the end of the session.

So let's dive in. the main learning objectives are first to understand the basics of solar heating and cooling technologies; understand how they work; what their main advantages and disadvantages are; understand which technologies are currently most widespread are being used most wisely; and to understand different case studies of solar heating and cooling technologies in practice; different applications, where they've been installed, and some of the performance characteristics.

So broadly speaking, solar heating and cooling systems can be small-scale, targeted at single-family homes or single applications like car washes or other sites that have very high hot water usage; they can be medium-scale for schools, hospitals, universities, and the like, institutional buildings; or they can be large-scale, targeting industrial applications and even providing process heat for industrial processes. In some cases, in a growing number of cities in particular around the world, solar heating and cooling technologies are starting to provide heating and cooling energy to entire districts and entire communities. One of the more well-known examples is in Copenhagen, where many of the city's—the overwhelming majority of the city's buildings and residences and businesses are connected to the district heating network. Solar is being used in growing quantities using solar collectors that feed the heat, the thermal energy directly into the district heating network and contribute to transitioning that heating network to growing shares of renewable energy over time as they phase out the use of coal, in particular in the heating system.

So there are ways of using solar heating and cooling technologies at a wide variety of different scales for different applications. So much like solar PV technologies, they are highly modular, they're highly adaptable to context, and they can be used in just about every market around the world.

As we'll see, there's been much focus in particular on solar heating technologies and comparatively there's been much more written about solar heating technologies, much more analysis done, as well as much more technological innovation, development, R&D, as well as just fundamentally more companies focusing on the solar heating market versus or when compared to the solar cooling market. But as we'll see by looking a little bit more closely at the solar cooling market, there's actually some interesting market potential there and this is likely to be a growing market opportunity, an increasingly exciting market opportunity in the years ahead.

In certain countries around the world, like Barbados, Cypress, and Israel, to name three, between 80 and 90 per cent of residential homes have domestic solar hot water systems. So very high levels of adoption, far higher than in many countries in Europe or in North America, very high levels of adoption. Part of this has been driven by building codes and by mandates, essentially obligations to install or to adopt solar hot water systems. And we'll look at this a little bit more closely in the session on solar heating and cooling policies. So if you're interested in understanding a little bit more about how policy tools are being used to scale up these market then in encourage you to have a look at that session as well.

In cold climates heat demand alone represents somewhere between 60 and up to 87 per cent of energy demand in residential buildings and between 30 and 40 per cent of energy demand in warmer climates, mainly due to hot water use. So heat is a big deal. Estimates are that across cities in Europe building-related heat demand represents somewhere around 50 per cent of total energy demand. This is a very significant share of total energy demand. We often think of—when we think of energy we think of oil and we think of electricity;

the reality is thermal energy needs, just heating alone, is a tremendous part of our energy mix, and that's why we're focusing these sessions specifically on looking at some renewable energy options for heating and cooling that are becoming more prominent and more prevalent in the market.

Now part of this is also driven by economics. Solar heating systems are increasingly affordable. The return on investment can be as little as three to six years, depending on the market segment and depending on energy costs, so either natural gas costs or electricity costs, depending on how heating or cooling is provided. So it can be quite attractive. And as the technologies continue to develop they're also getting better, getting more efficient, we're getting more advanced products, including some hybrid technologies, as we'll have a closer look at in some of the slides ahead, that are really enabling new efficiencies to be harnessed out of technologies that have been around in fact for decades.

Solar heating and cooling systems can help residences, businesses, as well as governments and institutions save money on their heating and cooling costs. That is increasingly the market driver in this market segment. As the costs of natural gas increase in many markets and as the cost of electricity continue to increase it becomes more attractive to start looking at solar heating and cooling rather than relying on the sources that have traditionally provided heating and cooling demand.

Now it's important to underscore that in most cases, at least in developed OECD countries, solar heating and cooling technologies are used as a supplement to heating and cooling needs. There are only select applications where solar heating and cooling can fully displace reliance on other sources of heating and cooling as backup. So in many cases the electricity will be there as stand-in, either as a backup source or there will be small natural gas boilers, particularly in commercial applications to provide the backup energy to top up the heating or cooling needs is the solar resource is not adequate or if we sent several cloudy days or very extreme temperature shifts. So that's important to keep in mind as we focus through this, in many cases, just as all hospitals and many hotels around the world have backup diesel generators in case the grid goes down; similarly, heating and cooling systems often have backup and have redundancy built into them.

Water heating, space heating, and space cooling account for an estimated 70 per cent of the energy used in the average US household. So again, this really helped put into perspective the tremendous market opportunity, tremendous potential for doing more of that with renewable energy sources. The great thing is the sun is available, it is in most cases adequate to meet a substantial share of household energy thermal needs, and that's why we're seeing as technologies get better and as awareness grows, we're seeing a growing number of companies and homes, and indeed governments investing directly in doing this to meet their own needs.

In most countries the sector has suffered a little bit from being led mostly by SMEs, small companies without global reach, without significant R&D departments, essentially producing fairly rudimentary solar thermal systems using local components. It's often manufactured locally with less quality control and a high variation in system performance, as well as system design between countries. And you'll see this if you travel in different markets in Africa or indeed in different markets in Asia the technologies differ quite widely, the costs are all over the map, and there is a fairly significant difference in product performance. So unlike solar PV, solar photovoltaics, which have become very much a globalized commodity, which have international standards and fairly high and consistent performance metrics across the board, monitoring different aspects of output and degradation and so on, the level of standardization and the level of consistency and sort of performance-monitoring going on for solar thermal systems is significantly less than for solar PV.

So that's another important reality of this market, it's fundamentally patchier, fundamentally greater variation in system performance and system design between different markets.

And to take one example, the traditional thermo-siphon systems used in China, which are sort of often take the form of a vacuum tube collector, are somewhere between ten times cheaper than Australia's systems, but again, have a shorter lifespan and are not as reliable as some of the more established products in the market in Australia. So you can see the very significant difference, not only in price, targeting different market segments to make it affordable in different markets with, again, significant differences in how these systems measure up against each other.

Again, to compare that with solar PV you would never see a tenfold difference in solar PV module costs from one market to the next. The industry is much more globalized in contrast, again, to this solar heating and cooling market, which is again, very much more localized and hasn't yet seen the emergence of global players in quite the same way as we've seen with solar PV. And consolidation is underway, particularly in China; we're seeing a major push in China towards consolidating more in the direction of solar flat plate collectors instead of the traditional vacuum tube or evacuated tube models, as we'll see in a moment. So there could be more consolidation in the market and we could see larger companies emerge out of this that start to take on a more global presence.

So one commonly seen option that I've just referred to is these evacuated tube or vacuum tube models, and single tubes are connected to a pipe, and the tubes are empty, essentially used just to flow thermal energy. And they must be traditionally mounted at an angle to allow the condenser and the internal fluid to return to the heat absorber. So there is essentially a heat absorption mechanism that allows the distribution of the thermal energy to be delivered via conduit.

These are commonly seen; you still do see them quite widely in different markets around the world. But slowly they're starting to be replaced in key markets like China by flat plate collectors. And China remains by far the world's largest solar thermal market, representing somewhere around 85 per cent of the total global installed capacity for solar thermal collectors, so by far and away the biggest single market. And that's why in a way what happens in China has potentially significant implications for the industry elsewhere in the world.

However, the most common technology elsewhere in the world and increasingly even in China, is becoming the solar flat plate collector, where essentially you have a flat plate, looks a bit more like a solar PV array, just without the solar cells, with a heat-conducting fluid that delivers the heat to a storage tank. These flat plate collectors are typically more efficient, with less heat loss, easier to maintain, ad also are less prone to breaking. One of the issues with the thermal collectors, those are the evacuated tubes, is they're a bit more vulnerable to damage and to maintenance issues.

Another option that you may have seen before is sort of the DIY variation, the do-it-yourself model. Some models of solar collectors can be made at home, particularly for space heating or air heating, not so much building your own water-heating solar thermal collector is possible, and there are lots of homemade models of those too, but more commonly, particularly in northern climates, where it's cold during the winter, is the models that are built essentially out of black-painted tin cans, like pop cans that can be arranged in a way to generate heat, the heat circulates up, and the thermal energy can be pumped into the home or building directly through a hole in the wall. So essentially a way to collect the ambient or radiant solar energy that gets cast on the collectors. And in northern climates the coldest days are often the sunniest days. So in Canada or in Norway or Sweden, when you have -20° C, -30° C you typically have clear skies, which again, speaks in favor of using solar thermal technologies that can still use some of that thermal energy and convert it into heat that can be produced and pumped into the house.

Now these systems, again, are rarely, if ever, used to fully displace thermal energy needs in the building or house; they're mainly used as a supplement, to supplement space heating and reduce reliance on firewood or on natural gas or other heating fuels.

Now in all of these cases, at least the ones using a fluid to heat, the systems are accompanied by a storage tank, and the storage tank can either be mounted directly on the roof or near the building, or in some cases even within the building itself.

Another technology that's starting to emerge is solar thermal collectors that use concentrating solar technology principles. So where you essentially concentrate the beams of solar light onto a particular point, either via parabolic lens or via a concentrating sort of disc, like a dish. And these different technologies heat—concentrate the heat to such a high level that you can actually get very high, even boiling temperatures that can then be used to produce a higher quality or a higher gradient of heat and be injected into different thermal energy applications, including even for an industrial process heat. So we're seeing a growing number of industrial applications starting to use these kinds of concentrating tube—or concentrating solar thermal technologies because they produce, again, a higher temperature gradient that can be used both to operate the system and reduce electricity usage, but also, again, can be used for applications that need higher temperatures, in particular in the industrial sector, in abattoirs, for example, for meat processing there are lots of applications that need that hot water at a high temperature. And these additional—the concentrators enable that.

These concentrating solar technologies also enable more solar energy to be harnessed out of the smaller roof space, so you get higher thermal gain from the usable roof space. Now again, these technologies, however, are not always applicable, depending on the local circumstances. If there is a high incidence of dust or a high incidence of smog in the city these kinds of concentrating collectors are often not a good solution, because they require un-refracted, or only very lightly refracted sunlight in order to function optimally. So if you have significant smog during the daytimes in the city these kinds of collectors are unlikely to perform as expected. So they work best in climates with relatively clear skies in areas where it's relatively clear whether and where sand and ambient dust is not as big of an issue.

Now this presentation is focusing on solar heating and cooling, so enough about heating; let's talk about cooling. Active solar cooling technologies are more recent than solar thermal or solar heating technologies, and as a result are somewhat less established in the market. They're also less well-known. Some of you may be saying, "Wait a minute, solar cooling, what does that mean?"

Now active solar cooling technologies do exist, are starting to gain ground in the market, and for a range of reasons that we'll look at more closely, their importance is likely to grow significantly in the years ahead. It's important to underscore that passive solar cooling principles instead of versus active cooling technologies have been used for millennia, including the use of shade, narrow streets to—particularly in the Middle East you see this common in cities—in ancient cities in the Middle East, narrow streets encourage shade, which keep the streets cooler and keep also residents and households cooler because you concentrate shade in a tighter area. Now that's passive solar cooling. What we're talking about here is not the use of passive solar design principles, rather active solar cooling technologies.

One key advantage of active solar cooling technologies is that their production coincides well with high cooling demand. So during the hottest days or typically when you have very high solar installation and you can use that solar energy directly to produce cooling or what some people call cool instead of warmth.

Now cooling is a massive and growing source of demand, as we'll see in a moment. As income levels rise, particularly in lower and middle income countries around the world, air conditioning demand is exploding; we are seeing very rapid growth in air conditioner sales, which are driving very significant electricity demand growth in urban areas and is increasingly causing power outages on a regular basis in the early evening hours as people come home from work and turn on their air conditioning units.

Now the fact that this is starting to happen at scale in many emerging markets is going to be a major challenge for electricity markets in developing countries around the world, because again, as income levels rise, people—one of the first purchases that households make to improve their quality of life in the house is an air conditioner. The total number of air conditioners, just to use one example, in use in India has grown from roughly 2 million in 2006 to approximately 30 million in 2018, and the market continues to explode. So very significant growth, which is leading to very significant electricity demand growth, particularly, again, in those early evening hours, which is exacerbating power reliability issues and contributing to power outages.

Now one solution would be to couple air conditioning units with solar PVs so you can produce solar power and store it and potentially run air conditioners off of batteries. That's one quite expensive solution that most households currently, at least in developing countries, often do not have the resources to invest in. Air conditioner units are becoming increasingly affordable. There's also a very large spectrum of costs. But one of the bigger innovations that's likely to shake up the market in the coming years is shifting the actual air conditioning technologies to use other principles, to be based on, for example, the production of ice. We're seeing an emerging market now in air conditioning that can be produced as it used to be during the 19th Century and early 20th Century, before air conditioning electric technologies really took off, where essentially it consisted of harvesting ice from frozen lakes during the winter, and hotels and other clients would buy large quantities of ice, store them in cool rooms and essentially use them to cool their buildings, cool their hotels for their guests during the hot summer months.

Now we're seeing a return of that in certain applications. And again, this underscores—points to a fairly significant market potential for new ways of designing air conditioning units because the ice can be produced during the daytime. The ice and the cooling energy can be stored during the daytime, when solar production is at its highest. So you can use daytime solar energy to produce ice in air conditioning units, or at least a high-density form of cooling energy, be it ice or some other format, and that cooling energy can then be used to dispatch, to gradually dissipate that cooling energy into the house or into the home or business, or indeed institutional building at a later time, thereby taking some of the stress off the grid and potentially helping alleviate power outages.

So one of the biggest challenges in markets like India and China and Indonesia and much of Africa and Latin America is that the sales of air conditioning units continue to be dominated by traditional electric air conditioning units, not buy these newer and more adapted—they're better adapted models of air conditioning units, and that itself is already creating a range of issues.

So tremendous market opportunity for shifting not only to solar cooling technologies, but also fundamentally reengineering the air conditioning technologies themselves.

Air conditioning accounts for approximately 40 per cent of electricity demand in cities like Mumbai in India. And over half of Saudi Arabia's entire peak summer electricity demand is attributed to air conditioning. Over half is just a tremendous electricity demand is just from air conditioning. That underscores, again, the tremendous importance and tremendous opportunity in solar cooling and other air conditioning technologies. Of the 2.8 billion people worldwide that live in the hottest parts of the world, only an estimated 8 per cent currently have air conditioning systems. Again, compared to adoption rates of over 90 per cent in parts of the US and Japan, though very, very, again, significant market potential.

An analysis of 52 of the most vulnerable countries in the world recently found that 1.1 billion people worldwide face immediate cooling-related risks; risks to their health and also risks to fundamentally to public safety. And this is not just in Africa and Asia. A heat wave that hit Europe in 2003, now that the numbers have been crunched, is estimated to have been responsible for over 14,800 deaths in France alone, with the death toll Europe-wide estimated in the range of 70,000. So even in Europe and in North America the need for reliable sustainable cooling is tremendous. And this is likely to become an increasingly urgent issue as temperature extremes continue to become more prevalent.

This graph captures the productivity impacts of heat caused by excessive heat, and we'll connect this to an anecdote in a moment. But it's worth just taking a moment and looking at this. These are the estimates of daylight working hours lost due to excessive heat by region. So if you look, in 1975 the numbers in South Asia are already over seven hours lost due to excessive heat. And you can see the spread across as that number grows as heat carries an ever-greater economic toll fundamentally on productivity in different parts of the world. So again, this underscores the tremendous importance of cooling. Historically we focused almost exclusively on heating and this really needs to change. The importance of cooling is just too great to ignore.

One visionary who saw the shift and who recognized the importance of cooling is the founder of Singapore, who made air conditioning a leading development priority. When he came into power in 1959 he mandated the installation of air conditioners in all public buildings, specifically in order to improve the productivity of the civil service in Singapore. And here he's quoted saying "Air conditioning was the most important invention for us, perhaps one of the signal inventions of history. It changed the nature of civilization by making development possible in the tropics." And again, you can really see here why, as we've seen in some of the previous slides, why cooling is so important; the impacts on productivity, on workable hours, and just fundamentally on human wellbeing. And this case of Singapore is often used to underscore how fundamentally energy and in particular in this case cooling demand, cooling supply is so important to economic growth more broadly.

So there are some advantages of using renewable forms of cooling instead of just using traditional air conditioning technologies that are connected to electricity that are connected to the power from the grid that may come from coal or from a range of other sources, including natural gas and so forth. There are advantages of using solar technologies directly for producing cooling energy. And we'll look a little bit more closely at some of those technologies in a moment, but first some of the advantages.

The availability of high solar radiation when the cooling is actually needed, in particular on sunny days. Thermal energy often drives the system, which leads to higher overall efficiency, so you don't need as many active pumps because the solar energy is enough to drive the mechanics of the system. Solar cooling technologies have lower operating costs, lower electrical power ratings, are relatively durable, produce cost savings, and can be used in combination with other cooling and air conditioning systems. So they can act as a supplement to other cooling solutions just as some solar heating technologies are used as a complement to other heating sources.

Some of the disadvantages, clearly potentially high upfront installed cost. Depending on the application there is a lack of skilled experts and installers, as well as high-performance products. And you require suitable roof space. In many cases, particularly for hospitals or hotels, back-up systems are often required to build in redundancy. But those disadvantages aside, this is, again, remains an area of tremendous need and tremendous opportunity.

So let's look at some of the technologies more closely to get back to that question of what do we actually mean by solar cooling. Many of you have no doubt heard of solar thermal technologies, but solar cooling is the relatively new kid on the block. We'll look here at three: absorption chillers, with a B; adsorption chillers, with a D; as well as desiccant-based cooling systems, and essentially they use drying or dehumidifying to produce cooling.

So let's look at these. First, absorption chillers. They use hot water from solar collectors to absorb already pressurized refrigerant from a refrigerant mixture. The mixture is either a couple examples here, water lithium bromide and ammonia water. Condensation and evaporation of this refrigerant vapor provides the same cooling effect as that provided by mechanical cooling systems or traditional air conditioning systems. They still require electricity, but a small fraction compared to the electricity needs of a conventional air conditioner. So think of it a bit like a heat pump; a heat pump uses thermal exchange, but it still needs to be collected to electricity in order to operate. So it's still a small electricity demand, but still electricity demand, just much smaller than would be used with an electric air conditioner. And again, this electricity can be supplied directly via solar PV. So many solar cooling systems have both the solar cooling collectors and technologies combined with a PV panel to directly supply the appliance.

You see here a picture on the left of an absorption chiller and an adsorption chiller on the right, which we'll look at more carefully in a moment. I'll leave this on the screen just so you can look a little bit at the mechanics and how these work, the heat and the rejected heat, the condenser, the evaporator, and how the basic mechanics of the system works. For more information on this I've provided a link to a report that gives a nice overview of some of these technologies here.

Now adsorption chillers use a solid instead of a liquid, like a silica gel. There are two compartments: one evaporator and one for the condenser. They still require electricity, but a small fraction, again, compared to the electricity needs of a conventional air conditioner, as there is no internal pump to require to pump the fluid around, because the material used as adsorption source is a solid, not a liquid. These are often larger, for larger capacity chillers range from 50 kilowatts to 500 kilowatts. So again, more for commercial buildings, institutional buildings, like universities, hospitals, and so forth. These adsorption chillers are fairly robust and fairly simple in construction and in their design. There's no dangers of crystallization. One disadvantage is that they are considerably heavier than the alternatives.

Third we'll turn to the desiccant-based systems. These are open cycle systems that use washer as a refrigerant in direct contact with the air. The cycle is thermally driven. They combine an evaporative cooling principal with air dehumidification by means of a desiccant, so some kind of drying material that absorbs. You may think of a desiccant like sometimes in clothing or shoes that you may buy, there's little sachets, little bags or pouches with desiccant type silica solids that suck moisture out just to keep products fresh or to keep them from developing moisture. That's essentially a desiccant, sucks moisture out of the environment.

And as you know, one of the main drivers of heat is humidity levels. So when humidity is very high it's very hot, and that's what makes temperatures so difficult to bear in urban environments, particularly in the tropics when there are high heats, because the humidity is so high that it's very difficult, even without needing to get up to 50° C the humidity can make it feel much, much hotter. So the basic principle of these desiccant technologies is take some of that humidity out of the air and achieve cooling that way.

Liquid or solid materials can be used as desiccants, and commonly they use different rotating desiccant wheels that are equipped with silica gel or lithium chloride as absorption material. And the wheels can turn alternating and produce—essentially enable more humidity to be withdrawn from the air.

These solar-assisted cooling technologies using a desiccant use solar thermal energy to dry out or to regenerate the desiccant. That's essentially the basic principle. And they produce conditioned air directly. So the systems help maintain a more pleasant ambient air via the operation of the system. And here's a diagram showing essentially how this works with the example of a desiccant wheel; the ambient air—so the human air enters in, goes through the desiccant wheel, the heating coil, and a fan to pump the system, and then the returned air you see here going through above the top with a filter, the heat recovery wheel, and then again the desiccant wheel and the fan.

So that's in a nutshell essentially the mechanism is sucking humidity, sucking moisture out of the air in order to contribute to a cooling effect. And these can be powered by solar and solar thermal technologies.

The advantages of desiccant-based systems, clearly increased comfort, as again, temperature and humidity are controlled independently and the humidity can be adjusted to reduce the temperature. They have lower operating costs than traditional air conditioning units. They use much less energy than traditional air conditioning units. There's also heat recovery options, the resulting air quality is improved, and there's reduced building maintenance due to high humidity levels. So high humidity in an institutional public building, schools, hospitals, and so forth is a major source of the buildup of mold, of fungal growth, as well as a bacteria, and by reducing the humidity levels inside buildings a much more pleasant ambient environment is created, but also again, an environment that's less prone to the development of bacteria and molds, which can reduce long-term building maintenance costs.

A fourth option that we'll flag quickly before moving into some of the case studies is the hybrid use of solar PV combined with solar thermal applications. You see here two different diagrams essentially showing different variations on the same principle. Solar PV modules are layered in on top, and beneath the solar module the residual heat that's left that radiates through is used to heat a coil essentially that produces thermal energy. So these hybrid systems are becoming increasingly widely used, and indeed some argue that this will be the default—that this is the future of solar, is hybrid systems. Why would we just install PV module only applications when we can use the same limited roof space and do both in one integrated system? And this partly has been enabled also by transparent solar PV modules. So we're seeing new technologies in the market that are effectively transparent, but enable you to collect electricity without blocking the sunlight. So those are perfect applications here.

Obviously clear advantages of these hybrid technologies, you get more energy output because you get more electricity and heat from the same surface area. But interestingly, a further benefit here is that you get increased solar PV output because the solar thermal system collecting the heat actually helps cool the PV panels, which increases module efficiency. So solar panels often have higher efficiencies, like cooler temperatures, so not at 30° or 40° C as is commonly thought; they actually convert electricity better at somewhat cooler temperatures. So the cooling effect of collecting some of that thermal energy can actually improve PV module output. So you get not only thermal energy on top, you even get a bit more PV output as well from the electricity.

And finally, of course, it can reduce the visual impact on buildings of having two different kinds of panel types. So for example, solar thermal evacuated tubes or plates, flat plates, as well as solar PV. So instead of having both integrated into one and get two birds with one stone.

So having looked at some of these different technologies, again, this presentation we only have one hour, so we don't have time to cover everything, don't have time to be comprehensive. You may be wondering "What about this technology? What about that technology?" We had to limit to a subset and I've tried to give a flavor of some of these different applications in these case studies selected from different jurisdictions around the world. So let's dive into these case studies before we wrap up.

So here in Washington, DC a residential solar system was installed in a private home with a large outdoor pool. The system is configured to transfer heat from the house into the pool while evacuating excess heat through the collectors. Active year-round and can operate 24 hours a day, so this is really a thermal regulation system, not only just used to generate heat to trap heat, it's also used to evacuate excess heat, thereby producing a cooling effect within the house.

Household annual electricity consumption dropped a stunning from 80-megawatt hours per year to 7-megawatt hours per year with the introduction of this system, again, driven by the massive savings on the air conditioning load. The system meets about 92 per cent of the home's space, water, and pool heating needs, as well as 100 per cent of its cooling needs. So this kind of integrated thermal regulation system really shows the benefits of this kind of integrated application, where you can get such high energy gains from the application of the system.

Now this is quite a large system for a residential home. The rated power output on the thermal side is 15.5kW thermal, larger obviously than most houses would need, but again, you can see here that when integrated into this kind of thermal network with the ability to evacuate excess energy from the house out into the pool the gains can be quite—in terms of energy savings, can be quite traumatic.

Here another residential home in Florida, 40 kW. Again, a very large application for a residential household. The US likes their houses—many homes in the US are quite large by international standards. 40 kilowatts of hybrid solar PV-thermal panels were installed at a large private home, generating both electricity and collecting the heat. So this one of these solar hybrid applications that we just saw. It's referred to as solar PV-thermal or PVT, can produce up to four times the total energy of solar PV alone.

And on this project they found that the cooling effect of the thermal collectors boosted the PV system output by as much 20 per cent, though you can see here that this is not just small potatoes; the difference here can be quite significant. The combined output of both systems is 57.8 kW for combined PV and thermal, and the yearly energy savings combined are at—talking here, 50 MWh, which again is a very significant amount of power. So if you think 50 MWh, if you think of an average megawatt-hour costing somewhere between $100.00 and $200.00, you're talking between $5,000.00 and $10,000.00 of energy savings per year. So the payback time, you know, if you're factoring in, okay, how much would a system like that cost, when you're saving that kind of money you can pay the system off quite handily.

Another case study here of a large apartment complex, 52 units, using a hybrid solar PV and thermal system, part of a comprehensive renovation project. Residents in the complex benefit from more comfortable living spaces as well as lower energy bills using both solar electricity on site as well as solar thermal for hot water needs. The rated power output of the system is almost 33 kWh, annual energy savings of over 20 megawatt hours.

Another case here of a large residential complex in Bozeman, Montana, 136 units, specifically for lower-income households. Again, residents benefit from lower energy bills than the state or regional average and cleaner energy supply. Each individual unit is accompanied by a 216-gallon storage tank, 818 liters, which is a very massive storage tank, but again, is there to produce and design to meet the majority, if not all of the households' hot water needs. Total power output for the 136 units is 212 kW and the yearly energy savings estimated at somewhere in the range of 138 megawatt hours, a very sizeable savings for the complex.

Here an example in a lodge in Palo Alton in California. There are some other examples from around the world. These are mostly folks in the US because the data and case study material is more readily available from the US than many other markets. The system provides hot water for the facility's pool and the aim of the project in this case is specifically to reduce natural gas consumption, because gas prices are a major cost driver for the lodge.

Rated power output 78 kW with an annual savings of somewhere in the range of 400 megawatt hours of thermal energy. So quite sizable, quite substantial.

Another example here from California, in Bakersfield. A hybrid solar PV and solar thermal system, those integrated panels that we saw, including 42 hybrid collectors plus 18 PV-only panels heats the hotel's water and pool, and the backup heating is provided by two heat pumps as well as two backup gas boilers. You can see here some of the stats on the power output as well as the savings.

Example from Hawaii at an inn. A large system delivering—again, a hybrid system delivering hot water as well as heating and cooling, including electricity. The system comes equipped with a large storage tank, rated power output of 56 kWh with yearly energy savings of about 56 megawatt hours.

An example here from Massachusetts at a college for a large athletic center here, featuring an Olympic-sized swimming pool, large collectors. They received a rebate from the state government. They had a commercial-scale solar hot water rebate program. The system provides the entire facility's hot water needs, includes a 360-gallon story tank capacity. You can see here some of the specs at the bottom with yearly energy savings around 72 MWh thermal.

Here an example in Arizona at a school covered with double-glazed collectors. Lithium bromide chillers with a capacity of 1.75 megawatts provides the cooling. During the summer the system meets all of the school's cooling needs with backup occasionally needed from the old electric chillers on site.

The system, interestingly, has been financed and developed on an ESCO basis, essentially with a company that owns the cooling system and provides cooling energy as a service to the school at a discount to the utility cost of service. So essentially the school is saving money by paying the ESCO cooling company less than what they would pay from their utility. And the local utility goes one further, even pays subsidies for the avoided energy use because it helped the utility differ grid upgrade investments. So again, some win-wins there.

You can see here a couple examples of different schools, different installations with different specs, looking at the chiller capacity, collector capacity, the collector surface area, as well as the approximate cost of the system and the storage size. You can see here this is from an IRENA report on large scale solar cooling systems and gives you a snapshot.

One example—one to include of the desiccant-based cooling systems recently installed in a shopping center in Australia in the state of Victoria, cooling loads represent as much as 60 per cent of the total energy demand of large commercial spaces like these shopping centers. The system uses a closed loop design with two desiccant wheels to remove moisture from the air, effectively acting as a dehumidifier, as we saw. A high-temperature wheel uses solar heat for regeneration of the desiccant, while a low-temperature wheel functions without any external heat to deliver greater energy efficiency. And there's an indirect evaporative cooler that reduces the temperature of the dehumidified air without altering the moisture content of the air. Quite an advanced system. You can read a bit more about this here at the link provided below.

The interesting thing about this system is that it was installed using a concentrating solar thermal system. Heat is stored in a thermal tank and there's desiccant technology is the foundation of the solar cooling application. They estimate that this concentrating solar cooling approach uses 40 per cent less roof space than traditional single-stage desiccant air conditioning system would.

Another example here at an industrial site. So we've looked at single family residential, we've looked at, mind you, large single-family residential. We've looked at multi-unit residential, we've looked at a couple of institutional and school and shopping center applications. Here's one final one on a commercial industrial facility at a beef processing facility.

This project was structured also as a kind of ESCO-type arrangement with a bilateral power purchase agreement struck at a price 40 per cent lower than what the company was paying before. Essentially the company benefits from savings from day one and the solar thermal system provides zero—essentially was financed at zero upfront cost to the company, because it's developed, again, by this third-party ESCO-type company.

The rated power output is quite large, almost 800 kilowatts. And the estimated annual energy savings are in the range of 700 megawatt hours of thermal, so very sizable energy savings for the facility, as well as we can see here, as a significant cost-savings. Because the structure is designed to guarantee savings from day one.

An example from Europe, in Graz, Austria. And we're almost done with these case studies and we need to wrap up. A large-scale district heating system powered by solar thermal in part connects a number of different neighborhoods and collector area of over 15,000-square-meters with weekly time scales to provide long-term thermal storage. So the storage system is designed essentially to really enable longer multiple day-over-week time scales of thermal energy storage. Some examples here from different parts of the contribution in this project in Graz in Austria with different systems that have been installed over time.

And finally in Munich, in Germany, a residential area that uses district heating network based mainly on solar thermal was built between 2005 and 2007 on former military barracks. High efficiency housing, 3,600-square-meters of solar rooftop collectors, as well as a 6,000-cubic-meter tank for hot water storage. So very sizable hot water storage tank that meets approximately 50 per cent of the community's heat demand. So again, there's a growing market here and we can see for the larger scale storage units that can store thermal energy over days, weeks, and indeed in some cases even months over time.

Now let's wrap up with a few concluding remarks. As we've seen, there are countless applications for solar heating and cooling technologies in a range of different facilities using a range of different heating and cooling technologies, often in combination with one another. Sports and recreation facilities, spas, hotels, shopping centers, commercial sites with large hot water needs, like the beef processing facility, schools, hospitals, public buildings, residential homes, and even multi-unit residential buildings. Again, a wide range of potential end uses.

The market particularly in solar cooling is virtually untapped, which means there's tremendous potential for growth and for producing more sustainable, more renewable forms of cooling. District thermal applications are also opening up new market potential and solar cooling is growing very rapidly in certain parts of the world, led by a few markets like Australia and certain parts of the US, and we're likely to see a lot more of this in the years ahead.

But as with every other sector in the renewable energy industry, it's necessary to have the skills, to have the technologies, to have the workforce that can deliver the technologies and install the technologies needed to make this transition. So there's much more work needed to help make solar heating and cooling technologies mainstream in markets around the world.

So, with that, thank you very much for your attention. Some further reading for those of you who are interested in diving a little bit more deeply into this. A few reports on policy and on technologies, some publications here on this one from some European case studies as well as some technology overviews, and some examples from the IEA as well as IRENA, looking at different solar heating and cooling applications.

So with that, I'm Toby Couture from E3 Analytics. I'd like to thank the International Solar Alliance for supporting this training series, as well as the Clean Energy Solutions Center. Before we wrap up, please stick around for the knowledge checkpoint with a few multiple-choice questions. Thank you very much, again, for your attention, and wishing you all a great day.