ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAMME

International Renewable Energy Agency

Solar Heating and Cooling for Residential Applications

Technology Brief

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About IEA-ETSAP

The Energy Technology Systems Analysis Programme (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), first established in 1976. It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy/economy/environment/engineering (4E) analytical capability.

Its backbone consists of individual national teams in nearly 70 countries, and a common, comparable and combinable methodology, mainly based on the MARKAL / TIMES family of models, permitting the compilation of long term energy scenarios and in-depth national, multi-country, and global energy and environmental analyses.

ETSAP promotes and supports the application of technical economic tools at the global, regional, national and local levels. It aims at preparing sustainable strategies for economic development, energy security, climate change mitigation and environment.

ETSAP holds open workshops twice a year, to discuss methodologies, disseminate results, and provide opportunities for new users to get acquainted with advanced energy-technologies, systems and modeling developments.

Insights for Policy Makers

Solar thermal systems (STS) for residential applications are a mature technology that have been successfully deployed in a number of countries for more than thirty years. In countries like Barbados, Cyprus and Israel, 80%-90% of residential homes have domestic solar water heating systems on their roofs. Globally, however, only 1.2% of space and water heating in the buildings sector is covered by STS.

With heat demand in residential buildings accounting for 60%-87% of energy demand in buildings located in cold climates, and 30%-40% for buildings in warmer climates, there is a substantial potential for STS for domestic water and space heating. Furthermore, energy demand for heating (either hot water or space heating/cooling) is the major reason for increases in residential energy demand in countries with growing household incomes. Solar thermal systems particularly make sense for three categories of countries: 1) countries that rely on gas or oil imports to cover their heating needs; 2) countries with growing economies where the use of electric boilers for water heating is straining the expansion of the electricity system to satisfy electricity demand: and 3) countries with high cooling demand during sunshine hours.

An STS is a relatively simple technology and in most countries local manufacturers — often small-to medium-size enterprises — produce, install and maintain the equipment themselves. A number of countries, including Austria, Barbados, China, Spain, Argentina, Uruguay, Brazil, Greece, Turkey, Israel, Australia, Finland, Denmark and South Africa, have already successfully developed local manufacturing capability, thus providing jobs and spurring economic development. Consequently, price and quality of solar thermal systems differ substantially across countries. For example, Chinese thermo-syphon systems for domestic hot water are almost ten times cheaper than small-scale American solar water heating systems, but, in general, their expected lifetime is also lower. A number of more advanced designs are emerging, with higher efficiencies and lower costs. STS are also integrated into district heating systems, or combined with heat pumps to provide both heating and cooling. STS combined with solar PV systems are currently in the demonstration phase.

Due to stagnation or saturation of national markets, a number of manufacturers are selling their products abroad; thus, an international market for STS is slowly emerging. In this context, international standards and regional certification schemes for quality assurance will be key for continued deployment. Both Latin America and the Arab Region are developing new certification schemes based on existing schemes in Europe and North America. International standards for performance and durability testing of STS and their components have been developed by ISO, the International Standardization Organization. Due to inherent differences in technology availability and the costs of quality assurance in each country, these standards have yet to be widely adopted or strictly enforced. Most countries have adapted these standards to their national technical capabilities and market needs. It is thus clear that the lack of an international or regional certification scheme must soon be addressed, taking market situations and quality assurance needs into consideration.

Key challenges for wider deployment of solar thermal systems are:

- For developed countries, high up-front installation costs compared to well-established conventional technologies like gas and electric boilers;
- The more complex process and associated costs of integrating solar thermal systems into existing housing; and
- The competition with heat pumps for heating and cooling services, and with solar photovoltaics panels for rooftop space.

STS have been very successful in countries where governments have mandated their deployment into new construction sites, thereby effectively removing these entry barriers. A new challenge is that solar thermal systems now also compete with: 1) heat pumps as an alternative technology in electric heating markets; and 2) with solar PV panels for rooftop space. Some governments heavily subsidise conventional energy, and that obviously creates a formidable economic barrier for deploying STS.

So far, government policies have been instrumental in deploying solar thermal systems. Back in the 1980s, a number of governments introduced subsidies for STS deployment but later abandoned their support after the oil crisis subsided. In contrast, countries like Austria, Barbados, China, Cyprus, Germany, Greece, Israel and Turkey managed to develop and maintain local capabilities due to cost effective products and continuous support through mandates for STS deployment in new construction sites. For countries with a growing housing stock, mandates for STS could be a key instrument in their successful deployment. A relatively new development is government support for small domestic solar water heating systems deployment in low-income families or social housing projects. This support reduces energy expenditures, increases job opportunities, and provides a means of increasing energy demand through renewables. Other alternatives, such as low interest loans or the establishment of solar-based district heating, are also attractive ways to foster further STS deployment.

Technical Highlights

- **Process and Technology status –** Solar thermal systems (STS) convert solar radiation into heat. These systems are used to raise the temperature of a heat transfer fluid, which can be air, water or a specially designed fluid. The hot fluid can be used directly for hot water needs or space heating/cooling needs, or a heat exchanger can be used to transfer the thermal energy to the final application. The heat generated can also be stored in a proper storage tank for use in the hours when the sun is not available. Solar thermal technologies are also used to heat swimming pools and to provide hot water for commercial buildings and industrial process heat. The solar collector is the key component of a solar thermal heating and cooling system. Two dominant designs exist: flat-plate solar collectors (FPC) and evacuated tube solar collectors (ETC). Their designs differ widely depending on the prevailing meteorological circumstances, heating and cooling demands, load profiles and costs. Solar heating and cooling technologies have been commercially available for more than 30 years and have achieved penetration levels of up to 90% in residential homes in Cyprus and Israel where they have been mandated for hot water production in newly built homes since the 1980s. However, the largest market is in China (85% of newly installed capacity in 2012).

- **Performance and costs –** The cost competitiveness of solar thermal heating and cooling technology is defined by three main factors: the initial cost of the solar thermal system, proper maintenance and the price of alternatives. The cost of solar thermal systems differs by a factor of three to ten across countries and strongly depends on the quality of the solar collector, labour costs and local ambient climate conditions. In the US, the costs of STS need to decrease by a factor of three to five to become economically attractive compared to gas boilers. In Europe, the cost of solar thermal systems is already cheaper than natural gas and electricity heating and cooling in Central and Southern Europe. Similarly, in Denmark, STS for district heating (with costs of USD 0.04/kWh_{th}) are competitive with gas-supported district heating systems. In China, the life expectancy of STS is assumed to be less than half that of systems in other countries (IEA-SHC, 2014a), but the capital costs at USD 200 are only somewhat more expensive than electric water heaters (USD 50) or gas water heaters (USD 100). In many emerging economies, STS offer an economic alternative to the increasing use of electric boilers.

- **Potential and Barriers –** STS for residential applications operate at temperatures ranging between 20-90°Celsius, and can reduce the fuel consumption by 50%-70% for hot water and by 30%-60% for space heating in energy-efficient houses (Faninger, 2010). Considering that about 55% of energy consumption in the buildings sector is for space and water heating (IRENA, 2014a), STS have a large market potential. Globally, however, only 1.2% of heating demand in buildings is covered by solar energy (IEA-SHC, 2014a). Future residential heating demand is highly dependent on technical factors (*e.g.,* the architectural layout of buildings, energy efficiency, insulation and building materials used) and demographic development (*e.g.,* income, age, urbanisation, and population growth). In general, space heating demand is expected to remain stable or decline in developed countries due to home insulation and energy efficiency improvements, while water and space heating/cooling demand is expected to increase in developing countries due to rising incomes and a desire for increased comfort. In some countries (*e.g.,* China, Israel and Turkey), solar water heating systems (SWH) are often the most economical option. In other countries (*e.g.,* European countries), the deployment of STS has mainly been driven by subsidy schemes and mandates. The financial crisis and associated decline in construction activities around 2008 has dampened the deployment of STS in developed countries, but the market is growing in emerging and developing economies. National and local government support for STS installations in low-income and social housing areas is an important driver, as well as the development of local manufacturing industries. However, deployment will also depend on other renewable energy alternatives such as heat pumps and solar PV systems. Cooling demand only accounts for a relatively small fraction of energy demand in buildings, but solar thermal cooling requirements for new buildings are assumed to increase globally with up to 82% growth between 2007-2020 in Europe (RHC, 2011). Furthermore, Solar Thermal Cooling is an important market in countries and regions with high cooling demands (*e.g.,* in the Middle East). The main drivers are price competitiveness and government support, especially for deployment in newly constructed housing. Besides the relative high upfront costs, barriers include: 1) lack of appropriate regulatory frameworks to guarantee that STS meet the technical requirements to ensure aproporiate and reliable operation; 2) pervasive inertia on the part of most residential users to switch from conventional heating and cooling systems that provide reliable supply; and 3) the lack of knowledge STS capabilities among architects and within the construction and energy industries. With local manufacturing, as well as the international trade of STS increasing, international performance standards for STS will be important to ensure continued deployment.

Process and Technology Status

Solar thermal systems (STS) collect energy from the sun and transform it into heat used to raise the temperature of a heat transfer fluid. This fluid, which can be air, water or a specially designed fluid, can be used directly for hot water or space heating/cooling needs. The heat generated can also be stored in a proper storage tank for use in the hours when the sun is not available. In all cases, thermal energy can be transferred by means of heat exchangers designed according to the final energy application. Solar thermal technologies are also used to heat swimming pools and to provide hot water for commercial buildings and industrial processes.

Solar thermal technologies encompass a wide range of applications (*e.g.,* water heating, space heating/ cooling and air conditioning for homes, businesses and industrial process heat), but some of the basic components, such as solar collectors and storage tanks, remain in principle the same for most types of solar thermal applications. This technology brief focuses specifically on *residential applications*.

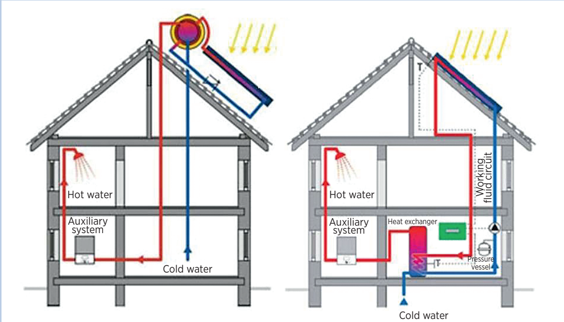
A solar collector is the key component of a solar thermal system. A distinction can be made between thermo-syphon (or passive) systems and pumped (or active) systems.

Thermosyphon systems use natural convection to drive the water from the solar collector unit to the hot water storage tank. The relatively cooler water from the bottom of the storage tank is circulated back into the solar collector (see Figure 1, left side). Thermo-syphon systems account for almost 75% of installed capacity and are mainly used in warm climates, such as in Southern China, Africa, South America, Southern Europe and the Middle East and Africa (MENA) region (IEA-SHC, 2014a). They are less suitable for cooler climates because of the high heat loss from external hot water stores and the danger of freezing during winter time.

Pumped systems use a pump to circulate the heat fluid from the collector to the storage tank. They accounted for 11% of the global market in 2012, dominated the North American market, and accounted for more than half of the market in Australia, Europe, Latin America, North America and the MENA region. Figure 1 shows a typical pressurised solar domestic hot water system for a single-family house (right).

Furthermore, STS can be either *direct* or *indirect*. When the heat transfer fluid inside the collector is used directly in the final application, the system is called "direct". When the heat transfer fluid goes through a heat exchanger, which in turn

Figure 1: Difference between a thermosyphon system used to heat water directly (left) and a pumped indirect solar thermal system (right).



adapted from: Terra (2007)

heats another fluid, then the system is called "indirect". In the case of STS cooling, the warmed fluid is used in a thermally driven chiller to cool the air.

In larger systems, an external heat exchanger is used. This heat exchanger is connected to an oil, gas or electricity boiler and is located in the upper part of the hot water store. The advantage of a direct system is that there is no need for an additional heat exchanger, thus reducing heat transfer losses. This reduces costs but requires high quality service water and additional protection against freezing in cold climates. Finally, the storage tank can be pressurised or unpressurised with the former achieving higher efficiencies in some studies (Islam, *et al.,* 2013).

Both thermosyphon and pumped systems can be *direct* or *indirect*. In the case of a direct system, water is the heated fluid and the pump is usually controlled by sensors to regulate the water flow from the collector to the tank. Indirect pumped systems use two circulation loops. A closed-loop system runs the heat transfer fluid from the collector to a heat exchanger. In systems for residential applications, the heat exchanger is usually an immersed heat exchanger integrated in the storage tank. If an external heat exchanger is used (*e.g.,* in larger systems), a second pump is needed for the loop between the heat exchanger and the storage tank.

Solar Collectors

Solar collectors, depending on their design features, can generate temperatures of more than 400°C using mirrors, lenses and trackers, but for residential

Figure 2: Flat-plate solar collectors (left) and evacuated tube collectors (right) installed on a single roof

www.solarradiant.com

applications, mainly low-to low-medium temperature collectors (below 150°C) are used. Currently, there is a large variety of designs and different types of solar collectors on the market, which can be classified in two main categories (IEA-SHC, 2007; Faninger, 2010; Fisher, 2011;):

Flat plate collectors (FPC) consist of tubes carrying a fluid running through an insulated, weather-proof box with a dark absorber material and thermal insulation material on the backside that also prevents heat loss.[1] The simplest collector is an unglazed collector without backside insulation, typically used for heating swimming pools and other low-temperature aplications, while glazed FPC have higher efficiencies,[2] lower heat loss, high working temperatures and higher initial cost. Other FPC types include:

- FPC with transparent insulation material (80-120°C);
- FPC with double glazing (80-120°C);
- FPC with external concentrators (80-150°C);
- Polymeric solar collectors (20-60°C); and
- Integrated collector storage (ICS) systems.

1 An unglazed collector does not have a box or insulation, only an absorber.

2 Thermal performance of collectors can be measured with different methods (steady state or quasi-dynamic), and based on gross collector area or absorber area (see ISO 9806:2013). Therefore, efficiency data can only be compared if similar methods have been used.

Commercially available, glazed polymer FPC have been developed in the US, Israel, Austria and Canada as a low-cost alternative to STS made from glass, aluminium and copper elements. Around 10 000 systems were in place by the end of 2010 (NREL, 2012; Koehl, *et al.,* 2014).

Evacuated tube solar collectors (ETC) use parallel rows of glass tubes, each of which contains either a heat pipe or another type of absorber, surrounded by a vacuum. This greatly reduces heat loss, particularly in cold climates. The absorber can be made from metal or glass, the latter also known as a "double-wall" or "Sydney style" tube. Apricus ETC have both a double-wall glass tube and as well as a heat pipe. The production and use of ETC is increasing due to increased automation of the production process (NREL, 2012).

Both flat plate and evacuated tube collector technologies are mature and have an enormous potential for residential heating and cooling applications. There is a huge variety of alternatives within each type of technology and the selection of one technology over the other must meet technical and economic criteria in that order.

A third category is the **integral collector storage (ICS)** system, which uses both the collector and the storage tank to absorb solar heat, but this system is prone to heat loss during non-sun hours (Islam, *et al.*, 2013). In the United States, there are a number of ICS systems on the market, such as the SunCache Systems (passive) and FAFCO Systems (active) (DoE, 2012). These systems are around 50% cheaper than FTPCs and are protected against freezing but mainly represent a good choice when hot water is used mostly in the early evening hours (*e.g.,* in some tropical locations).

Globally, FPC account for around 26% and ETC for 65% of installed capacity. The other 8% of installed capacity are unglazed systems. Finally, air collectors used to provide space heating account for less than 1% of installed capacity. (IEA-SHC, 2014).

The share of ETC in installed capacity is rapidly growing since ETC already accounted for 82% of the 2012 market share in the Asian Region. More specifically, ETC account for 93% of the solar thermal collector market in China. ETC are also the preferred technology option in: India (63% of the market) as they are cheaper than available FPC; South Africa (57% of market); and in a number of Eastern European countries (45%-67% of market). Other Asian countries, the Middle East, Latin America and Europe mostly use FPC. In the USA/Canada and Australia/ New Zealand, unglazed water collectors account for 89% and 71% of the market, respectively, and are commonly used for swimming pool heating applications. In Latin America and sub-Saharan Africa, they account for 43% and 40% of the market, respectively (IEA-SHC, 2014).

Solar thermal systems applications

In the residential sector, the main market consists of small systems (3-10 kW_{th}) for single family homes, predominantly systems for domestic hot water provision. In some European countries, there is an increasing share of systems for both domestic hot water and space heating. Only about one percent of the market consists of large systems connected to district heating (>350 kW_{th}).

Solar domestic hot water systems

Solar domestic water heating technology has become a common application in many countries and is widely used for domestic hot water preparation in single or small multi-family homes. The technology is mature and has been commercially available in many countries for over 30 years. Typical solar domestic hot water systems used for single-family homes in North America and Northern Europe (*e.g.,* Germany) have hot water storage with volumes of approximately 300 litres, a collector area between 4-6 m^2 and can supply 60%-90% of the annual hot water demand depending of the type of collector and local solar radiation conditions (Müller-Steinhagen, 2008). In hotter climates, thermo-syphon systems are often used with a smaller collector area of around 2-4 m^2 and a 100-300 litre storage tank (Stryi-Hipp, 2011a). In comparison, thermo-syphon ETC used in China have a hot water storage tank of around 120-200 litres and a collector area of around 2 m^2(Islam, *et al.*, 2013).

Solar space heating systems

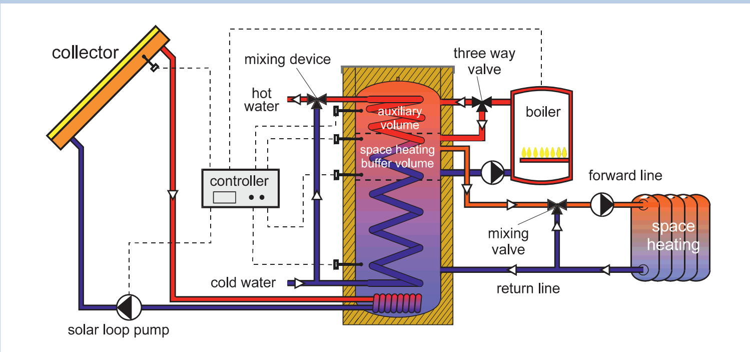
In recent years, systems that combine water and space heating—called Solar Combi-Systems (solar CS)—have been developed. Solar CSs are used to provide hot water as well as space heating and consequently require significantly larger solar collector areas. They emerged in the European market and show great promise for further market success. Countries with the highest market shares are Sweden (72%), Norway (67%), the Czech Republic (32%) and Germany (32%) and Austria (28%) (IEA-SHC, 2014). Figure 3 shows an example of a common design with a solar combi-system as the key component (Müller-Steinhagen, 2008).

A solar CS can be designed to provide about 60% of total space heating and hot water demand in a single-family home (*e.g.,* the Solar House 50+ concept achieves 60% solar share with a 30-60 m^2 solar collector and a seasonal heat storage system of 6-10 m^3 (Stryi-Hipp, 2011b)), although typically the solar share is closer to 25%. The circulation water in the space heating system is used as a storage medium. Larger systems require a 20-40 m^2 collector area and the volume of the hot water store is in the range of 2-4 m^3 (Drück, *et al.,* 2004). For energy efficient homes (*e.g.,* a typical German home with 140 m^2 heated floor area), the required solar collector field has an area ranging from 10-20 m^2 and a hot water storage tank with a volume in the range of 0.7-1.5 m^3 and can save 20%-30% of the primary energy required for domestic hot water and space heating (Müller-Steinhagen, 2008; Stryi-Hipp, 2011a). A roadmap on the development of solar CS systems targets an increase in the solar fraction from around 25% to 60% without increased solar costs by 2020 (ESTIF, 2014).

Future developments of solar space heating systems

Innovations aim to make STS thinner, cheaper and more durable and to better integrate them into rooftops. Furthermore, the European Solar Thermal Technology Platform expects that Active Solar Buildings – defined as at least 50% heated and cooled by solar thermal energy – could become a building standard by 2020 and that this figure could reach 100% by 2030 (ESTTP, 2008). However,

Figure 3: Typical schema of a solar heating combi-system



Müller-Steinhagen, 2008

Figure 4: Marstal Solar District heating plant (33 360 m²), Denmark

Photograph: AltOmSolvarme

this would require long-term storage – possibly thermo-chemical heat storage – to ensure that solar irradiation in the summer can be used to cover heat demand in winter (Finck, *et* al., 2014; Kramer, *et al.,* 2014). Further developments in building design and insulation, energy efficiency improvements of heating and cooling appliances and future R&D within solar heating and cooling technologies will be critical to achieving this objective.

Large Solar District Heating Systems

One possibility for enhanced penetration of solar heating systems is through district heating. In these cases, the heat gathered by the solar collectors is fed into a district heating network either directly (without heat storage) or via large heat storage facilities, which are charged with solar heat during the summer season and discharged in late autumn and winter. Large solar district heating systems with collector areas from 1000-37 000 m^2 and seasonal heat stores with a water-equivalent storage volume of 3 000 m^3 to 61 000 m^3 provide up to 50% of the heating and hot water demand of large building complexes and towns. For smaller communities, solar district heating systems with seasonal storage have proven able to provide over 90% of the total annual space heating requirements (Drake Landing Solar Community, 2012: Annual Report for 2011-2012). Similarly, these large-scale systems could be used to support district cooling. Ordinary FPC or ETC may be used, but large solar heating systems could also be based on concentrated solar technologies or solar combi-systems.

However, only one percent of the worldwide installed solar collector surface is currently connected to district heating systems. By the end of 2013, 192 large-scale solar thermal systems were connected to heating networks 40 of which were solar district heating systems with nominal thermal power >3.5 MW_{th}. Thirty of these large-scale plants are located in Denmark. The world's largest solar district heating system is a 35 MW_{th} plant (50 000 m^2) being built in Vojens, Denmark. The largest operating solar thermal district heating plants is also in Denmark with a nominal thermal power of 26 MW_{th} consisting of 2 982 collectors (37 573 m^2) and a 61 700 m^3 seasonal pit heat storage.[3] (IEA-SHC, 2014). In Denmark, costs for these plants have decreased such that they are below those for gas-fired district heating (REN21, 2014). An additional 145 000 m^2 is planned to be added before 2015 (EurObserv'ER, 2014). Another large solar disctrict heating plant (25 MW_{th}) is in Saudi Arabia and provides space heating and hot water to a university campus. Other countries that are potentially interesting for this application are Spain (Guadalfajara, *et al.*, 2012) and China. For example, solar district heating could replace coal-fueled district heating in China's urban areas, which currently constitute around 40% of total energy demand in China's buildings (Li, 2009).

The advantage of large solar thermal systems lies in their reduced costs in comparison with the installation of many individual, smaller solar heating systems. The disadvantage (outside areas with existing successful deployment like Denmark) lies in the higher cost of planning, the lack of demonstration projects and the necessity of a more complicated system integration and control (Buchinger, 2012).

Solar Cooling

Solar cooling has been growing rapidly from around 60 systems in 2004 to more than 1 000 systems installed in 2013 (IEA-SHC, 2014). Furthermore, 17 large-scale solar district systems are connected to cooling networks in Europe (IEA-SHC, 2014). However, compared to the potential of using solar energy to generate cooling, deployment levels are very low. Most deployment (80%) is in Europe and a number of companies like EAW, Invensor, Sortech, SolarNext (Germany), Pink (Austria) Broad (China), Thermax (India), Yazaki, Kawasaki, Mistubishi (Japan) and Jangsu Huineng (China) have released small, commercial solar cooling

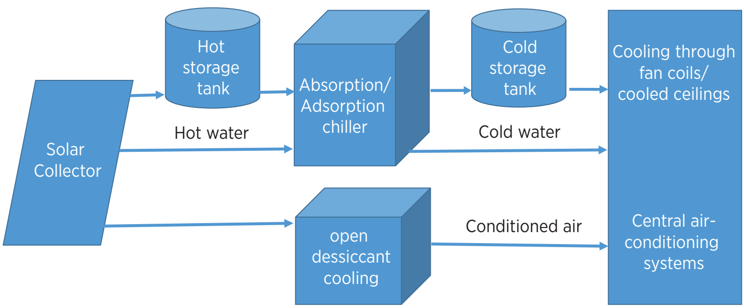
3 http://www.solvarmedata.dk/index.asp?secid=228

systems called "cooling kits" (Augsten, 2014; Jakob, 2014; REN21, 2014). In the Sunbelt region, where cooling demands are quickly rising, there are still only a few demonstration plants and studies available (Schwerdt & Ali, 2014; Ssembatya, *et al.*, 2014), In those regions, rapid growth in the use of air conditioners for cooling is creating peaks in electricity demand. Solar cooling technology can provide an effective solution to reduce the peak electricity consumption as it operates when the cooling demand is highest.

Solar cooling can be complementary to solar heating, especially in regions that require cooling in the summer and heating in the winter. In this particular case, an increase in collector area to allow for cooling would simultaneously allow for a larger solar share of domestic water and space heating by a typical solar combi-system in winter. This approach avoids any long stagnation periods during summer or winter and, at the same time, increases economic efficiency. The increased efficiency of advanced flat-plate and evacuated vacuum tube collectors makes it possible to add a thermally driven, adsorption or absorption cooling system to an existing solar combi-system, resulting in a so called "solar plus combi-system" (Faninger, 2010).

There are three kinds of solar cooling systems: absorption chillers, adsorption chillers, and dessicant cooling systems. The technologies of solar space and water cooling are the same as those developed for gas cooling systems. In Europe, mostly ETC and FPC are used to provide heat, which can subsequently

Figure 5: Possible configurations for solar-driven cooling systems



be converted into cooling using a thermally driven chiller or air-conditioning technologies. All told, 71% of these cooling systems run on absorption chillers, 13% on adsorption and 16% on desiccant systems (Jacob, 2014).

Absorption/Adsorption chillers

Absorption chiller systems are most commonly used in combination with solar collectors (71% of installations), and are expected to compete at scale with air conditioning systems in the next 20-30 years (Marques and Oliveira, 2014). The process is nearly identical to that of a refrigerator, whereby a refrigerant is used to cool the environment. Instead, no compressor is used and the regeneration of the refrigerant in the absorber fluid is driven by a heated fluid from the solar collector. In solar cooling systems, high temperature liquid collectors are typically used. Absorption chiller solar cooling systems include: Closed Adsorption Chiller Systems or Absorption Chiller Systems using H_2O/LiBr and NH_3/H_2O as a refrigerant/absorber working pair (Eicker and Pietruschka, 2009).

Adsorption chillers use solid sorption materials instead of liquid refrigerants. Their advantage is their simple mechanical construction and robustness, as well as their higher efficiency at low operating temperatures. However, they are generally bigger/heavier and more expensive than absorption chillers, especially in large power ranges (Haw, *et al.,* 2009)

Desiccant solar cooling

In a *desiccant system*, the moisture absorbing material (desiccant or "drying material") is located in the air stream going into the living space. As the air passes through the desiccant, which is usually located on a wheel that slowly rotates into the air stream, moisture is removed from the air, thus decreasing the humidity level in the air stream to the point that an evaporative cooler can then cool the air, making it more comfortable. The desiccant is regenerated through the solar heat provided by the STS (RHC, 2011). Desiccant solar cooling is particularly promising for those countries where cooling demand in summer typically correlates with the peak of solar irradiation and where the humidity is high. There are a growing number of large-scale, solar air-cooling projects that have been successfully demonstrated in different countries and that highlight the huge potential for solar-assisted cooling.

Currently, solar cooling technology is relatively expensive, especially if only used for space cooling. In moderate climates with both heating and cooling demand, it is more economical to combine space cooling with space heating and/or water heating to maximise the return on investment and not leave the system idle when cooling is not required. Solar cooling technology could be ready for commercial deployment within coming years if intensive R&D and relevant policy supports are provided.

Hybrid Solar Heating Systems

Another way to increase the share of renewable energy in household energy consumption is a combination of solar thermal systems with heat pumps or solar PV systems. Although the individual components of these hybrid systems are mature, international research and development are still required to identify the optimal configurations under different environmental conditions.

Solar-assisted heat pumps would use solar thermal systems to reduce the temperature lift required for the heat pump, thus improving its performance and efficiency. Most studies show significant increased system performance for these combined systems (Carbonell, *et al*., 2014). Alternatively, heat pumps can be used to boost the temperature of solar heated water to allow for direct use (IEA-SHC, 2014b). More than 90 solar-assisted heat pump systems have been installed in Europe, especially in Austria, Germany and Switzerland (IEA SHC, 2013).

Photovoltaic/solar thermal hybrid (PVT) systems first use solar PV panels to convert sunlight into electricity; then heat absorbers in the back of the PV panel to cool down the cells and use the heat for water heating. Most PVT systems are unglazed and use water as the heat transfer fluid, although there are also a number of designs using air, glazed PVT systems with alternative heat transfer fluids, concentrator-type PVTs, and PVTs integrated with heat pumps (Chow, *et al*. 2012; Matuska, 2014). PVT manufacturers, such as Dualsun, Sillia and ABCD International, are based in Europe, but there are also a number of companies in China, Israel, Turkey and the USA (Mitina, 2014). A demonstration project with PVT was recently finalised in Australia.

Installed Capacity and Market Potential

According to the 2014 report from the IEA Implementing Agreement on Solar Heating and Cooling (IEA-SHC), the estimated total cumulative capacity of solar thermal collectors in operation worldwide by the end of 2012 reached 234.6 GW_{th}, corresponding to 385 million m^2 of collector area (IEA-SHC, 2014).[4] Early assessments of the year 2013 suggest that the market grew by 57.1 GW_{th} to a total installed capacity of 330 GW_{th} in 2013, providing around 281 TWh (or 996 PJ) of heat (IEA-SHC, 2014; REN21, 2014). 46.2 GW_{th} was added in China alone in 2012, although 21% of the new collectors replaced existing capacity[5] (REN21, 2014). In comparison, the added capacity for solar PV and wind were around 37 GW_e and 35 GW_e, respectively.

Statistics shown in Figure 6 are based on data collected from 58 countries (including most of Europe, North America, Brazil, South Africa, India, China and Australia), representing about 63% of the world's population and 95% of the solar thermal market. In 2012, the top Six countries in terms of total installed capacity of glazed water collectors were China (180 GW_{th}), Germany and Turkey (both around 11 GW_{th}), Brazil and India (around 4 GW_{th}). In terms of the amount installed per capita, Cyprus, Austria, Israel, Barbados and Greece were the top five countries (IEA-SHC, 2014a). The high penetration levels in Cyprus and Israel (90% and 85%, respectively) are driven by legislation passed in the 1980s that require all new homes to have STS (ESTIF, 2007). In 2012, Cyprus introduced a subsidy scheme to support the replacement of solar collectors or entire systems to comply with the latest technical guidelines (Epp, 2012).

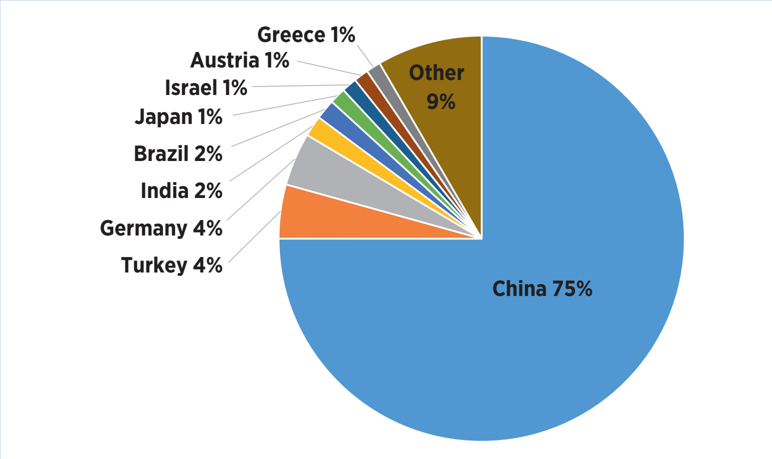
By the end of 2012, some 67% of the world's solar thermal (180 GW_{th}) was installed in China while Turkey ranked second and Germany third in the world by installed solar thermal capacity. India and Brazil accounted for 4 GW_{th} each while Australia and the USA accounted for around 2 GW_{th} of glazed capacity. The MENA Region (Israel, Jordan, Lebanon, Morocco and Tunisia) accounted for almost 5 GW_{th} (IEA-SHC, 2014a).

China remains the most important market for solar thermal systems. This is mainly driven by the low cost of STS, mandates for compulsory STS installation in urban areas in place since 2006, a subsidy scheme to peasants in rural areas equalling

4 The IEA-SHC uses a factor of 0.7 kW_{th}/m^2 to determine the nominal capacity.

5 Assuming a lifetime of ten years for Chinese systems, while lifetime expectancy for European systems is assumed to be more than 20 years.

Figure 6: Share of total installed capacity of FPC and ETC at the end of 2012 in MW_{th}



IEA-SHC, 2014a

13% of capital costs, and a goal to install 300 million m^2, or 328 $GW_{th,}$ of STS by 2020, of which 65% will be in residential applications. Targets for 2030 and 2050 are 557 GW_{th} and 895 GW_{th}, respectively, and the target for solar cooling is 16 GW_{th} by 2020, 41 GW_{th} by 2030 and 109 GW_{th} by 2050 (Ruicheng, *et al.*, 2014; IEA, 2012). In comparison, the Indian Government has set a goal of 42 million m^2 over the same period (Koldehoff, 2011; Foster, 2012).

Another important aspect of the rapid deployment of STS in China is the manufacturing market. Currently, more than 5000 companies produce STS in China, only 10 of which are major companies. Furthermore, due to the massive scale of deployment (600000 installations per year, versus 30000 in the US,) installations costs are low (Liu and Liu, 2013).

Following its rapid growth in 2007-2008, the global solar thermal industry was adversely impacted by the 2008 financial crisis and, as a result, the solar thermal industry in some countries experienced a sharp decline due to the economic recession and the decline in construction that followed (Figure 7). In Europe, the market decreased by 11.8% in 2013 compared to 2012 and by 33% compared to 2008 (ESTIF, 2014b). Consequently, only one single European company for surface coatings exists: Alanod-Almeco. Most European countries, except for smaller countries like Denmark and new entries like Poland, were still below deployment levels in 2008 (EurObserv'ER, 2014). Consequently, the deployment of STS stands at around 21 GW_{th}, far behind the indicative target of 102 GW_{th} set out in the national renewable energy plans of the EU countries (ESTIF, 2014b). For example, in Spain STS producers and installers relied on mandates for solar thermal installation in new buildings, but due to the lack of construction work, the market declined by 50% in 2012 compared to 2008 before stabilising in 2013 (ESTIF, 2014b). However, new policies, such as subsidies in Germany and France, a feed-in tariff for solar thermal in Italy and a renewable heat incentive in the UK, are aimed at reversing this trend.

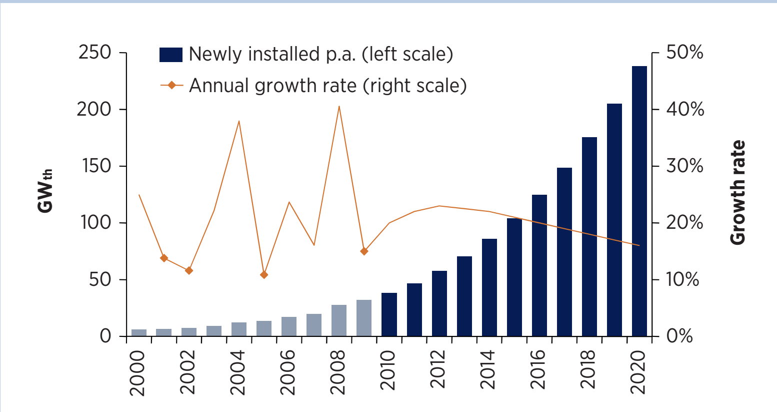
Outside Europe, the market has been growing in most countries. Sales of glazed water collectors have increased five-fold in India, four-fold in South Africa, tripled in China and doubled in Mexico while the market is up by 61% and 31% in the US and Australia, comparing 2012 with 2007. In Japan, market sales were 5% lower in 2012 compared to 2007 (IEA-SHC, 2009; IEA-SHC, 2014). In Brazil, the residential market grew by 16%-21% in 2012 (Epp, 2013a; IEA-SHC, 2014). With the rural market almost saturated (90% market penetration), STS deployment in urban areas is now seen as an alternative to the 30 million electric boilers for showers already installed, consuming 6% of national electricity consumption and a much higher share of peak demand.[6] Furthermore, Brazil has ambitions to export its locally-produced STS throughout the region and is working on a regional certification scheme to support trade (IRENA, in press). In the Indian market, STS grew by 26%-30% in 2013 (however, 61% of the Indian market is devoted to industrial applications) (REN21, 2014). South Africa is the most dominant market in Africa with ambitious plans to install 1.3 million solar thermal systems within the next five years. Furthermore, the national government is providing rebates for locally manufatured, pressurised STS to discourage the import of cheap thermo-syphon systems (Stier, 2014). There are also a number of relatively small markets that are rapidly expanding. For example, in Tunisia deployment in the residential sector has increased tenfold between 2004 and 2012 due to grants and loans to customers, the engagement of utilities and the financial sector, and improved quality control (Baccouche, 2014). Similarly, Kenya has mandated STS in large buildings, created local manufacturing capability and developed internationally-based national standards, a certification scheme, licenses for trained installers and inspections to ensure enhanced system performance (IRENA, in press).

6 www.eclareon.eu/sites/default/files/4_terencetrennepohl_forderbedingungen_fur_solarthermie.pdf

An interesting market for future STS deployment are the island and island-nations, many of whom enjoy high solar irradiation but have high electricity prices due to reliance on imported fossil fuels. Cyprus and Barbados are two island countries with very high STS penetration. In Cyprus, the long-term experience (initiated in the 1960s), a dynamic local solar industry, government subsidy schemes, quality and reliability control of local solar systems (Roditis, 2014) and high electricity costs are some of the main drivers for successful STS deployment (Frantzis, 2014). The Barbados Government has supported development of a local STS industry since the early 1970s through tax exemptions, levies on electric water heaters, mandates for STS deployment in housing developments and incentives to manufacturers (*e.g.,* tax breaks) and end-users (*e.g.,* rebates at ~50% of system cost) (CDKN, 2012). Since the Barbados market is now saturated, manufacturers are now exploring opportunities to export their products to other Caribbean islands. However, Barbados' Standards Institute has not implemented its standards yet, nor has it linked them to the international ISO standards for STS (IRENA, in press). Finally, the tourism sector on many islands provides a clear business case for deploying solar water heaters and solar air conditioning (IRENA, 2014b).

In addition to national legislation, city level initiatives are emerging as important drivers for STS deployment. In South Africa, Johannesburg developed a

Figure 7: Current and future development of the solar thermal heating market (worldwide)



Koldehoff, 2011

programme targeting 100 000 STS by 2014 (*i.e.,* 10% of the national target) while Cape Town is offering innovative loan structures targeting 150 000 installations (REN21, 2014). In Brazil and India, many cities and municipalites have amended their building codes to mandate STS while the city of Santa Fe in Argentina has mandated STS for all childcare centres (REN21, 2014). The Chinese Government supports a number of demonstration projects for "New Energy" cities with financial support for solar heating and cooling systems and more than 11 provinces and 23 cities, including Beijing, now mandate installation of STS in buildings (Ruicheng, *et al.*, 2014).

Heat demand forecasts are sensitive to future technological developments, such as future building standards, the energy efficiency of heat-supply technologies and the insulation of houses. Furthermore, future heat demand depends on demographic changes, such as population growth, urbanisation and changes in the populations' age, household size and behaviour patterns (O.O. Energiesparverband, 2011). In Europe, future heat demand in the residential sector is expected to decline due to improved insulation and energy efficiency, but in Asia total energy consumption in households is expected to continue to increase by 5%-10% per year (Li, 2011).

Furthermore, countries such as Brazil, Chile, South Africa, Thailand, Turkey and the US Territory of Puerto Rico), have put programmes in place to support STS installations in social housing or are developing fully funded STS for low-income households (Sun & Wind Energy, 2014a; REN21, 2014). In the Middle East, hotels, public baths and hospitals provide a growing market for STS, replacing diesel generators (REN21, 2014).

A global analysis of national plans for STS deployment suggests that solar thermal heat could increase to around 1 500 million m^2 (around 850 TWh) by 2030, an increase of 200%. In fact, the potential for STS in the residential sector is larger than current plans suggest and could reach around 2 600 million m^2 by 2030 (IRENA, 2014a). In comparison, a European energy "Roadmap" suggests that here alone, the potential for solar thermal is expected to be around 600 TWh in 2030, growing to 1 552 TWh in 2050 (corresponding to 2 716 GW_{th}) (RHC, 2011). At the global level, the IEA Solar Heating and Cooling Roadmap forecasts an installed capacity of around 900 TWh (or 1 600 GW_{th}) in 2030, and 2 000 TWh (or 3 500 GW_{th}) in 2050 (IEA, 2012).

Performance and costs

STS have been in existence around for more than 30 years and advances have been made during this time in the absorber coatings, heat exchangers and absorber plate design that reduce material needs and increase reliability (Nemet, 2012). However, STS quality is not uniform worldwide and there are a number of areas for improvement.

First, STS deployment has been hampered by a lack of quality control. STS are in many cases site-assembled systems and proper installation is relatively complex compared to the technology itself, which means that certified and trained practitioners are needed to ensure that the installation is working correctly (IRENA, in press). International ISO standards for testing the thermal performance of the collectors and systems are in place, for example, ISO 9806 (collector testing) and ISO 9459 (systems testing). Regional certification schemes and national standards bodies are adopting these standards domestically; however, they have yet to be consistently applied, mandated or inspected. For example, China has around 30 standards for STS engineering and installation but, to date, no performance standard (Ruicheng, *et al.,* 2012; Xuan, *et al.,* 2012). Furthermore, China has around 20 test labs and 200 certification bodies, but programmes for installation quality are not yet in place (IRENA, in press). The new ISO 9806 is the basis for a global certification scheme for solar thermal collectors now being worked out in IEA-SHC Task 43 (Serrats, *et al.,* 2012, Nielsen, *et al.,* 2012; Guthrie, *et al.,* 2012). Australia has established a cooling standard for product performance evaluations (REN21, 2014).

An important barrier to standardisation, however, is the dispersed manufacturing market that makes enforcement difficult. In most countries, the market is dominated by hundreds to thousands of small- and medium-size enterprises, sometimes simple assembly lines at the household level. For example, the Chinese manufacturing market is dominated by around 4 000 small-scale, local or even household-operated firms (accounting for 80% of all manufacturers) and only ten major firms are currently operating in China (Liu and Liu, 2013). Similarly, there is only a handful of multinational companies, like Bosch Thermotechnik that has production facilities in five locations around the world (Epp & Augsten, 2013).

A related aspect is the role of certification. Regional certifications for STS exist in Europe (Solar Keymark) and North America (Solar Rating and Certification Corporation: SRCC). Latin America (where the regional Pan American Standards Commission, COPANT, is creating a unified regional standard and certification scheme) (Rosell, 2013) and the Middle East (the Solar Heaters Arab Mark and Certification Initiative: SHAMCI) are working on regional certification schemes.

In Europe, the certification scheme, Solar Keymark, is based on European and ISO standards and makes it easier for manufacturers, distributors and users to export or import systems. However, certification schemes require test labs (which can cost EUR 0.5-2 million to build) and cost-effective procedures to test and certify new systems (which can cost EUR 10 000 per collector or system) (IRENA, in press).

As the market of STS grows internationally, quality infrastructure, including standards and certification, will become more important. On the one hand, a number of new entry countries, including Kenya, Russia, South Africa, Uruguay and Zimbabwe are or already have developed local manufacturing capabilities (REN21, 2014). On the other hand, manufacturing companies in Europe and China are increasingly exporting their products. For example, due to the collapse of the Spanish national market, local manufacturers have increased their exports from zero to almost 50% of their production within five years (Epp, 2013b). Also, although the STS in China are still seen as inferior products due to limited quality control and product standardisation, 30% of the Costa Rican market in 2013 was still based on imported Chinese ETC (REN21, 2014; Liu and Liu, 2013).

Another area for improvement is that of proper maintenance and performance evaluation for installed systems. High-quality STS that are well-maintained may last for over 30 years while low-quality STS that are poorly maintained do not last more than five years. Furthermore, few STS are metered and this hinders system improvement and optimisation, resulting in system malfunctions (Foster, 2012). With fewer than fifteen firms providing meters for residential STS systems globally, and with an additional cost of up to USD 1600, a lack of affordable meter solutions imposes an additional barrier on SWH development.

Table 1 shows that the average costs for small domestic solar hot water solar systems (including auxiliary heater) vary widely (USD 250-2 500/kW) between different countries (IEA, 2012). Collector and mounts account for 50% of capital costs while tubing and insulation account for 16% and the storage tank for around 11%. Other system components are the valves, sensors and gauges, heat exchangers and pumps (NREL, 2012). The wide STS cost range results from the variety of technology types, quality, material and labour costs. In some emerging economies, prices could be less than half of the costs indicated in Table 1.

Figure 8 provides an overview of the costs of thermo-syphon systems from a number of manufacturers that sell their products in multiple countries or even worldwide (Sun & Wind Energy, 2014b). The data show that the cost does not only depend on size but that for each solar collector type, there is still a large cost variation. These are due to the specific applications of each system, which can differ in terms of the type of system (*i.e.*, open, closed), absorber coating, tank material and insulation,

Table 1: Investment costs of STS in different regions.

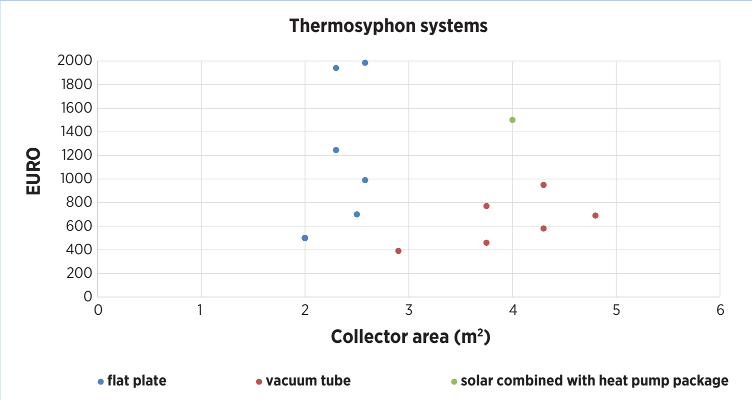
	Country/ Region	Investment costs[a] (USD/kW)	Collector yield (kWh/m²a)	Collector size (m²)
Thermo-syphon direct	Australia	1100	850	3.5
	China	100-250	770-860	4
	India[b]	130-180	850	2-4
	South Africa	630-650	900-1000	2.5-4
	Turkey	130	770-900	4
Thermo-syphon indirect	US[c]	2300	550-700	
Pumped direct	US[c]	1700	550-700	
	South Africa[d]	760-820	900-1000	2.5-4
Pumped indirect	US[c]	2300	550-700	6
	Central Europe	850-1900	395	
	North Europe	1600-2400	360	4-6
ICS collector	USA[e]	450-800	700	3-4.5
Solar CS[f]	China	980-1400	580	12
	Germany	1800-	530-622	12
STS district heat	Denmark[g]	350-400	450-480	10000

a without subsidies
b ETC are supposed to be 1/3 cheaper than FPC (Epp, 2013c), exchange rate 1 INR = 0.01661 USD, June '11.
c NREL, 2012
d Exchange rate 1 ZAR = 0.1 USD, June '14
e DoE, 2012
f Personal communication with manufacturers
g IEA, 2012

piping material (*e.g.,* copper, plastic, steel) and insulation, corrosion protection, the performance of the electric element and the warranty (*e.g.,* 5-10 years).

Due to the low capital costs, STS in China, the Middle East and South Africa are economical, but, according to NREL (2012), the costs of STS need to decline by a factor of three to five in order for them to become economically attractive compared to gas boilers in the US. In Europe, solar heating cost reductions of 35% in 2017 and

Figure 8: Comparison of final customer prices for internationally traded thermo syphon systems



Sun & Wind Energy, 2014b

50% in 2020 are targeted to reach fossil fuel parity (ESTIF, 2014a). Potential areas for cost savings include the use of polymer-based components instead of copper and aluminium, the integration of heat pumps for higher performance and passive STS to eliminate maintenance of pumps and controls (NREL, 2012).

Another important factor is the share of solar contribution to the total heating demand ("solar fraction"). If the annual solar fraction can be increased, for example, by providing cooling in the summer, then the economic viability of STS may increase. For example, the difference between the price of gas and the price of heat generated by residential solar heating systems is between USD 0.08-0.10/kWh_{th} at a solar fraction of 15% and between USD 0.20-0.25/kWh_{th} at a solar fraction of 60% (ESTEC, 2011).

The capital costs of solar cooling technologies are dominated by the solar block (37%), followed by the thermal chiller (29%). Other cost components are installation (19%), storage (8%), and the heat rejection loop (7%) (Tsekouras, 2014). Total system costs are in the range of USD 4 350-5 550/kW (Eicker, 2011; Jakob, 2014). Capital costs are in the range of USD 425/m^2 or USD 1 915/kW for a 100 kW thermal chiller. However, the costs of the adsorption chiller are highly dependent upon the scale ranging from USD 1 560/kW for 20 kW cooling capacity to USD 3 600/kW for 200 kW cooling capacity (Tsekouras, 2014).

Drivers and Barriers

Solar thermal heating in residential buildings provide a relatively cheap option for reducing dependence on electricity or fossil fuels, especially over the long term. The market for solar cooling, on the other hand, is in a nascent stage. The main market drivers for wider deployment of solar thermal heating and cooling technology are increased public awareness and appropriate government support and incentives (*e.g.,* investment grants, certification, mandates, outreach and training) for installation of solar thermal heating and cooling for residential buildings. Government policies and support from the construction industry for STS integration, in particular for new buildings, is essential, especially in emerging and developing economies with growing housing demands and increased hot water usage.

Another important driver for STS deployment is the possibility of creating local manufacturing capability for solar thermal systems, as exemplifed by countries like Kenya, South Africa, Uruguay and Zimbabwe. Finally, advancements in the use of STS for cooling can create an important market to replace air conditioning in hot climates.

The main barriers for deployment of solar thermal heating technologies, especially in developed countries, are the relatively high upfront costs compared to well-established conventional systems, such as gas boilers and electric water heaters, as well as competition from other renewable energy technologies, such as heat pumps (NREL, 2012). Furthermore, the integration of STS into existing buildings is often viewed as cumbersome. With the rapid decline in the price of solar PV panels, there is also competition for rooftop space. Adequate financial mechanisms must be created to motivate the use of more solar thermal heating and cooling systems. There is also a legal barrier in cases where residents require permission to install solar heaters on their homes, especially if the permit process adds costs, increases delay times, or negatively affects administrative and/or technical conditions.

With regard to solar district heating systems, interest in reducing the use of fossil fuels (*i.e.*, coal, oil and natural gas) in district heating is the major driving force for continued efforts to increase the use of solar district heating plants. Low costs for waste heat (*i.e.*, industry, combined heat and power), together with the lack of requirements, financial incentives and local knowhow, all pose major threats to the development of solar district heating systems.

Finally, there is a lack of public awareness and knowledge about solar thermal technology and the broad spectrum of application options, ranging from small solar water heating systems for the residential sector to MW-scale solar thermal systems for district heating and industrial process heat. Public recognition and acceptance are necessary prerequisites for the diffusion of solar thermal heating and cooling technology in residential and public buildings, as well as in heavy industry and the service sector. Policy makers can play an important role in lowering this barrier.

Table 2 – Summary Table: Key Figures and Data for Residential Solar Heating and Cooling

Technical Performance		Typical current international values and ranges			
Energy Input/Output		Sunlight/Thermal energy (Heat/Cooling)			
Technology Variant		**FPC**	**ETC**	**Unglazed**	**Air**
Annual Installed Capacity (2012), GW_{th}		8.4	42.7	1.6	0.1
Total Installed Area , Mio. m^2		101	249	32	2
Total Cumulative Capacity, GW_{th}		71	174	23	2
Regional Distribution[1]		**China**	**Europe**	**USA/ Canada**	**World**
Distribution by Collector, %	Flat Plate Collector	7	86	11	26
	Evacuated Tube Collector	93	9	-	65
	Unglazed Collector	-	5	88	8
Distribution by System, %	Pumped systems	15	62	94	25
	Thermosyphon systems	85	38	6	75
Distribution by Application, %	Solar Combisystem	2	18	2	4
	DWH (single unit)	90	62	21	78
	DWH (multiunit)	8	12	-	9
	Pool Heating	-	5	75	8
Avoided CO_2 emissions, Megatonnes CO_2/a		52	13	4	79
Annual collector yield, TWh/a		150	37	12	228

1 Distribution based on total installed capacity 2012 (IEA SHC 2014)

Costs	Typical current international values and ranges						
Typical Breakdown Heating (US)	Collector: 51% Storage: 11% BoS Costs: 38%						
Typical Breakdown Cooling (Greece)	Solar loop: 37%; Storage: 8%; Thermal chiller (100 kW): 29%; Heat rejection loop: 7%; Services: 18%						
System	**Thermo-syphon direct**					**Thermo-syphon indirect**	
Country/Region	**Australia**	**China**	**India[b]**	**South Africa**	**Turkey**	**Southern Europe**	**US[c]**
Investment costs[a], USD/kW	1100	100-250	130–180	630-650	130	630	2300
Collector yield, kWh/m²a	850	770-860	850	900-1000	770-900	685	550-700
Collector size, m²	3.5	4	2-4	2.5-4	4	2.5-4	6

Costs	Typical current international values and ranges				
System	**Pumped Indirect**			**Pumped Direct**	
Country/Region	**US[c]**	**Central Europe**	**North Europe**	**US[c]**	**South Africa[d]**
Investment costs[a], USD/kW	2300	850-1900	1600-2400	1700	760-820
Collector yield, kWh/m²a	550-700	395	360	550-700	900-1000
Collector size, m²	6	4-6	4-6	6	2.5-4

Application	Large Scale SWH	Solar CS[e]		SWH district heat	Solar Cooling
Country/Region	Europe	China	Germany	Denmark	Global
Investment costs[a], USD/kW	350-1040	980-1400	1800	350-400	1600-3200
Collector yield, kWh/m^2a	685	580	530-622	450-480	395-685

a Without subsidies
b ETC estimated to be 1/3 cheaper than FPC (Epp, 2013c), Exchange rate 1 INR = 0.01661 USD, June '11.
c NREL, 2012
d Exchange rate 1 ZAR = 0.1 USD, June 2014
e Personal communication with manufacturers
f Sources: NREL 2012, IEA SHC 2014, Tsekouras 2014, ESTTP 2011

Cost Reduction Measure	Projected System Cost (USD)	Description
Base case	5 600	Base case is 40 ft,[2] selective collector, two-tank glycol system
Eliminate HX-to-tank pump	5 363	Replace the pump between HX and tank with a natural convection loop between HX and tank
Polymer tank + HX	4 337	Replace pressurized tank with unpressurized membrane tank and polymer HX
Use of brine/direct	4 037	Use non-freezing brine in storage and collector loop, eliminating glycol and the collector side HX
Integrated cross-linked polyethylene piping	3 252	Use cross-lined polyethylene piping in the solar loop, replacing soldered hard copper
Valve package	3 098	Integrate valving at tank (bypass, solar only, pressure relief, check valve, loop fill valves) with an integrated, factory-assembled package.
Polymer selective	2 418	Replace selective metal-glass collector with low-cost selective polymer collector.
Marketing	1 958	Reduction in marketing cost, at 20% of system cost, due to the above system cost reductions.

1 Table adapted from NREL (2012)
2 Projected system cost after applying the measure

Projections (2050)	Typical current international values and ranges		
Applications	SWH & Solar CS	Solar Cooling	Pool Heating
Installed Capacity, GWth	3 500	1 000	200
Energy demand (sector), EJ	8.9	1.5	0.4
Sectoral demand, %	14	17	-
Avoided CO_2 emissions	800 Megatonnes CO_2e per annum		

Table generated from IEA data, 2012

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