Nonconventional Technologies Review
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SOLAR THERMAL SYSTEMS: CURRENT SITUATION AND AMBITIOUS GOALS

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ABSTRACT: Solar thermal energy is a straightforward application of renewable energy. The unique advantage of solar heating and cooling technologies is that they are compatible with nearly all sources of back-up heat and almost universally applicable due to their ability to deliver hot water, hot air and cold air. It is estimated that solar energy technologies can provide more than 50% of low temperature heating and cooling demand for buildings in 2050 and contribute a significant share to the heat supply for the agricultural and industrial sectors. Thus, solar heating and cooling will contribute significantly to lowering CO_2 emissions worldwide and reaching the Paris Agreement goal. If the direct use of solar energy for heating purposes via solar collectors, as shown in the sustained energy scenarios, is to make a significant contribution to the energy supply, it is necessary that solar-heating technologies be developed and widely applied over and beyond the field of domestic-hot-water preparation only. In order to stimulate investment, governments must take the lead role in creating a favourable investment climate for widespread use of solar heating and cooling. Measures and directions are proposed in current review.

KEY WORDS: Solar thermal, solar cooling, solar district heating

1. THE CASE FOR SHIFTING TO A CARBON FREE ENERGY SUPPLY

Energy is the key theme for future world development. The energy demand worldwide is increasing rapidly, especially in the developing and transition countries, which seek to catch up with the economic development attained by industrialized countries during the last century. The great challenge now is to meet this energy demand in a sustainable manner.

Without a sustainable reinforcement of the global energy supply system sustainable development will not be possible. It is absolutely certain that without major changes in energy supply systems climate change will have significant impacts on human life. The costs of climate change will not only burden economic development worldwide, but will also lead to natural catastrophes, which remain as yet unknown. Every year that we delay in tackling climate change will make efforts even more cost intensive.

Another goal for the international community must be to overcome poverty in developing countries. More than 2 billion people have no access to modern forms of energy supply and thus have no opportunities to overcome poverty. Renewable energy sources, due to their inherent decentralised nature can contribute significantly to this goal. However, without rapid and resolute international policy support, the expansion of renewable energy sources will not be able to develop the necessary dynamics in time.

Nevertheless, it is imperative for many reasons that additional effort be made:

Climate protection: An average global temperature changes of more than 2 degrees relative to pre-industrialised levels and a mean long-term rate of global temperature change exceeding 0.2 per decade are intolerable parameters of global climate change. It will only be possible to remain within this climate window if energy systems are converted from the present use of fossil fuels to climate neutral energy sources. Renewable energies will need to play the main role in this context.

Keeping risks within a normal range: A sustainable energy system needs to build upon technologies whose operation remains within the normal range of environmental risks. Energy by nuclear fission fails to meet this requirement, particularly because of its accident risks and unresolved waste management, but also because of the risks of proliferation and terrorism.

Security of Supply: Humankind is approaching the exhaustion of conventional energy reserves. Renewable sources of energy have a considerable potential for increasing security of supply worldwide. Developing their use, however, will depend on extremely substantial political and economic efforts. In the medium term, renewables are the only source of energy in which the world has a certain amount of room for manoeuvre aimed at increasing supply in the current circumstances. In the long run renewable energy sources are the only energy source available.

Intensified efforts to improve efficiency are an indispensable element of global energy system transformation at all levels.

2. THE ROLE OF RENEWABLE ENERGY SOURCES (RES)

Renewable energy sources will be able to play a significant role in future energy supply worldwide. In the long term, renewable energies will dominate the world's energy supply system. The reason is at the same time very simple and imperative: there is no alternative. Mankind cannot indefinitely continue to base its activities on the consumption of finite energy resources.

Renewable sources of energy are in line with an overall strategy of sustainable development. They help reduce dependence on energy imports, or do not create a dependence on energy imports in countries that will have increased energy needs in the future, thereby ensuring a sustainable security of supply. Furthermore, renewable energy sources can help improve the competitiveness of industries and have a positive impact on regional development and employment. Renewable energy technologies are suitable for off-grid services, serving those in remote areas of the world without having to build or extend expensive and complicated grid infrastructure. Combined with the improvement of energy efficiency and the rational use of energy, renewable energy can provide everything fossil fuels currently offer in terms of energy services.

To reach such a target, advanced, intelligent and reliable policy measures have to be implemented at least in the majority of countries worldwide.

Policy measures such as the internalisation of external costs for conventional energy supply, ending subsidies to conventional, polluting energy sources and other initiatives have to be adapted to make the assumptions a reality.

If these measures are not adopted in significant parts of the world, the deployment of renewable energy sources will be much slower. But even then, the natural benefits of renewables will be used to supply 27 % of the world's energy needs.

EU in its **Clean energy for all Europeans package,** a comprehensive update of its energy policy framework to achieve carbon neutrality by 2050, has set an ambitious, binding target of 32% for renewable energy sources in the EU's energy mix by 2030.

3. THE SOLAR THERMAL TECHNOLOGY

Solar thermal energy is a straightforward application of renewable energy. The well known domestic hot water heating through solar energy is widely used in many countries but on a global level contributes to 0.4% only of energy demand for domestic hot water. However solar thermal energy is used also by other technologies such as space heating and space cooling, and hot water for industrial processes.

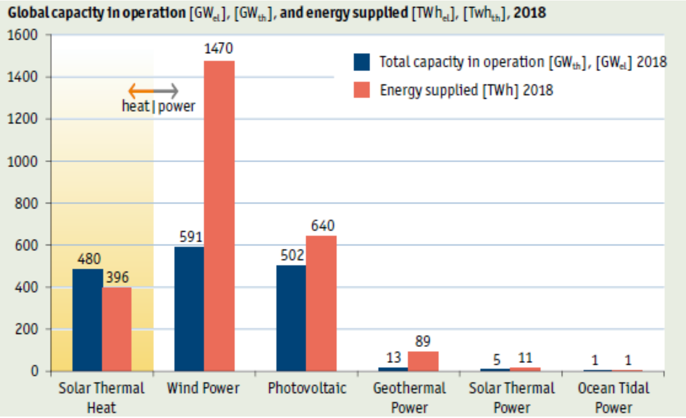


Figure 1: Global capacity in operation [GW$_{el}$], [GW$_{th}$] 2018 and annual energy yields [TWh$_{el}$], [TWh$_{th}$].

(Sources: AEE INTEC, Global Wind Energy Council (GWEC), European PV Industry Association (EPIA), REN21 - Global Status Report 2019)

The unique advantage of solar heating and cooling technologies is that they are compatible with nearly all sources of back-up heat and almost universally applicable due to their ability to deliver hot water, hot air and cold air.

They are also resilient against rising energy prices as most costs are incurred at the moment of investment, ongoing operating costs are minimal and there is almost no exposure to the volatility of oil, gas or electricity prices. Their local supply leads to reduced energy transmission, which enhances efficiency and cost effectiveness.

As most cash flows in this kind of projects occur locally, the jobs created occur also locally. In addition, one of their comparative disadvantages, the low technology incorporated, seems to be an advantage for local development as almost all sorts of solar thermal systems can be manufactured locally.

Heat is considered as a low-quality form of energy; thus it is crucial for solar thermal technologies to replace exhausted fossil fuels that are directly burned for heat production, and even more the high quality form of electricity used for hot water and space heating. Thermally driven cooling technology can used and “smooth” peak summer electric cooling loads relieving electric grid. Most important is that solar cooling technologies benefit particularly from the strong correlation between supply of the solar resource and energy demand for cooling.

It is estimated that solar energy technologies can provide more than 50% of low temperature heating and cooling demand for buildings in 2050 and contribute a significant share to the heat supply for the agricultural and industrial sectors. Thus, solar heating and cooling will contribute significantly to lowering CO_2 emissions worldwide and reaching the Paris Agreement goal.

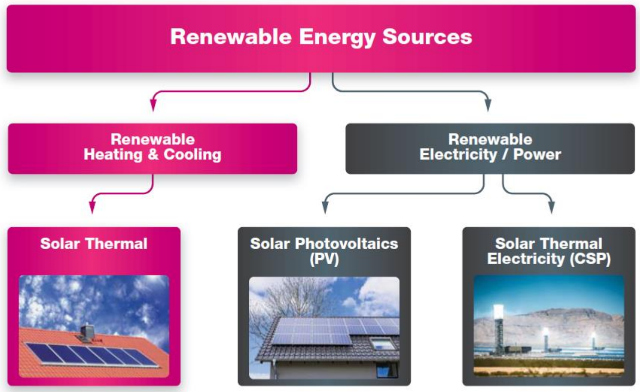


Figure 2: Classification of RES forms of energy

The solar thermal heating and cooling sector today is experiencing steady growth in industrialised countries with mainly small-scale applications. There is nearly no geographical limit for solar thermal uses. In future the extension to large scale applications for heating and cooling is expected and this thereby helps to increase the share rapidly. According IEA-SHC organization the cumulated solar thermal capacity in operation by end of 2018 was 480 GWth (686 million square meters). Compared to the year 2000 the installed capacity grew by a factor of 7.7 (from 62 GW_{th}). The corresponding annual solar thermal energy yield in 2018 amounted to 396 TWh (from 51 TWh), which correlates to savings of 42.6 million tons of oil and 137.5 million tons of CO_2. Between 2005 and 2016 a significant growth was noticed, however this rate has been recently decreased globally. Despite this trend, some countries still show a notable increase in their installed solar thermal capacity.

Small-scale solar water heating systems for single-family houses and apartment buildings represent more than 90 % of the worldwide annual installations, even if the number of megawatt-scale systems for district heating as well as for industrial applications are increasing from year to year.

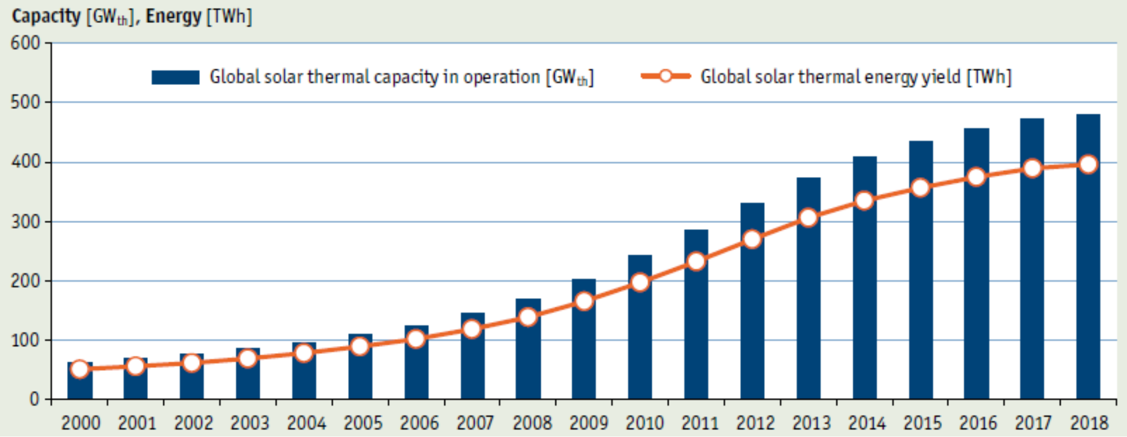


Figure 3: Global solar thermal capacity in operation and annual energy yields 2000 – 2018

4. THE CONTRIBUTION OF SOLAR THERMAL ENERGY TO THE OVERALL HEAT DEMAND IN EUROPE

Heat is the largest energy market in Europe, larger than electricity and transport. Europe consumes half of its energy for heating and cooling in buildings, for domestic hot water supply, for industrial process heat and for heat in the service sector. Heating requirements for hot water and space heating, make up for 75% of that number. The majority of heat is currently produced from imported and polluting fossil fuels (mainly natural gas) or from electricity largely generated by fossil fuels or nuclear power (88%), while solar thermal gives only 1% (in the 12% which comes from renewable energies), thus theoretically exists a huge potential of fossil fuels substitution. The energy consumption for cooling & air conditioning is dramatically increasing. For the first time in history, the peak electricity demand in several countries is no longer in winter, but in summer.

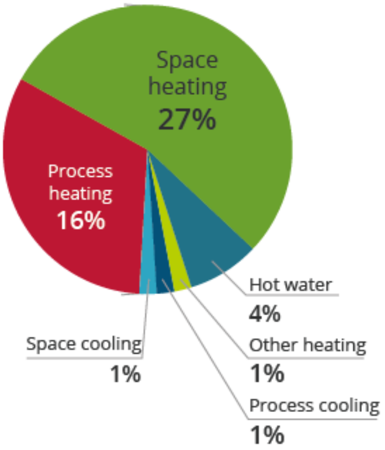


Figure 4: Share of different types heating and cooling in Europe

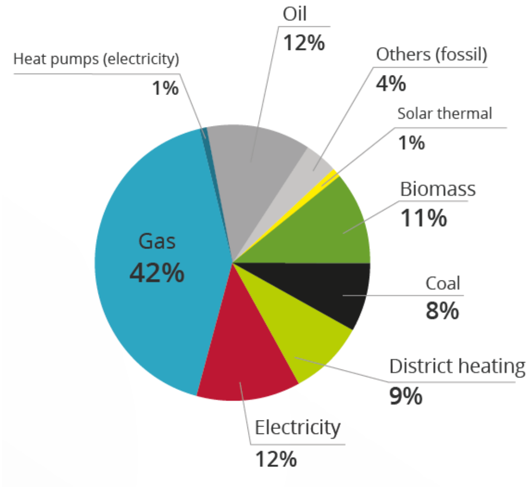


Figure 5: Share of different energy forms for heating and cooling in Europe

It would be unfair for some countries (as Scandinavian & Baltic ones) not to mention their serious efforts and success stories in RES heating and cooling as the next diagram shows.

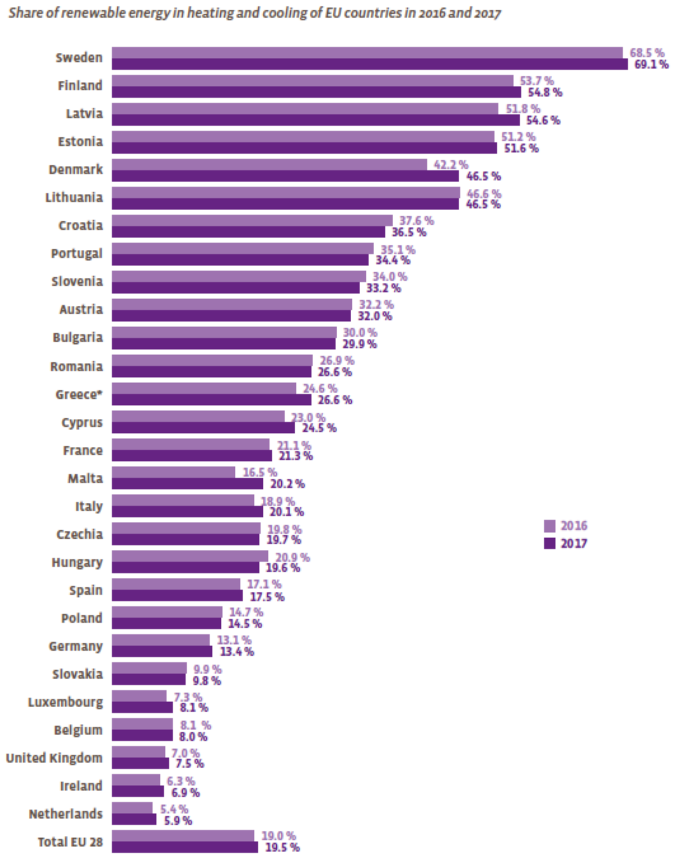


Figure 6: Share of RES for heating and cooling in different European countries

Among different RES technologies, used for heating and cooling, solid biomass prevails, while heat pumps show a continuous growth.

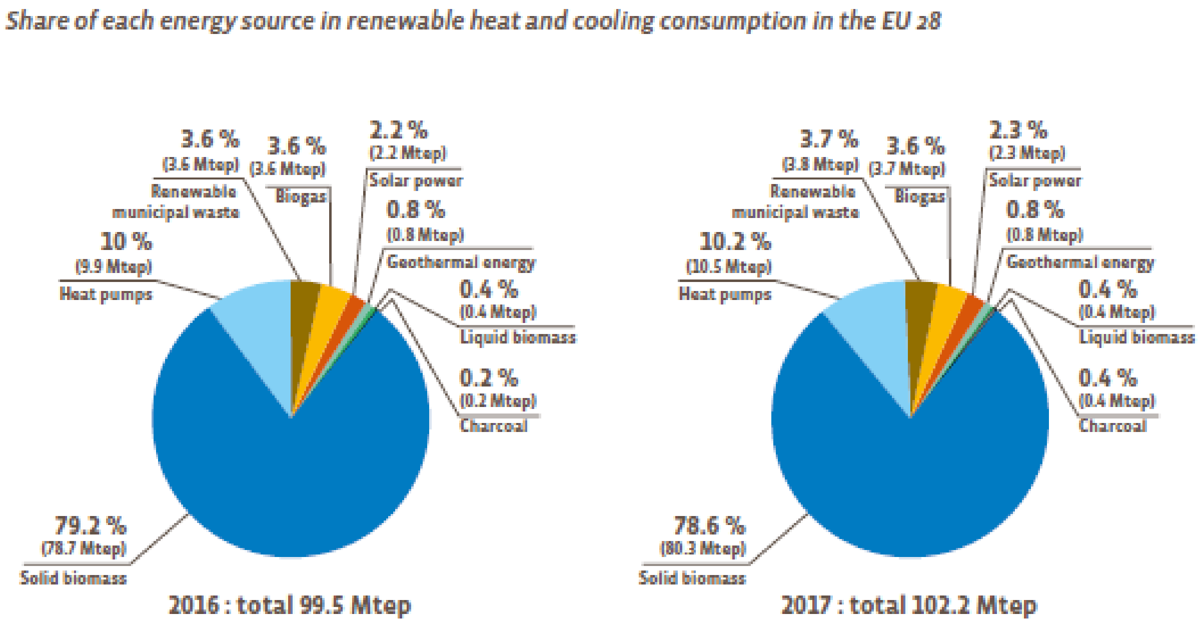
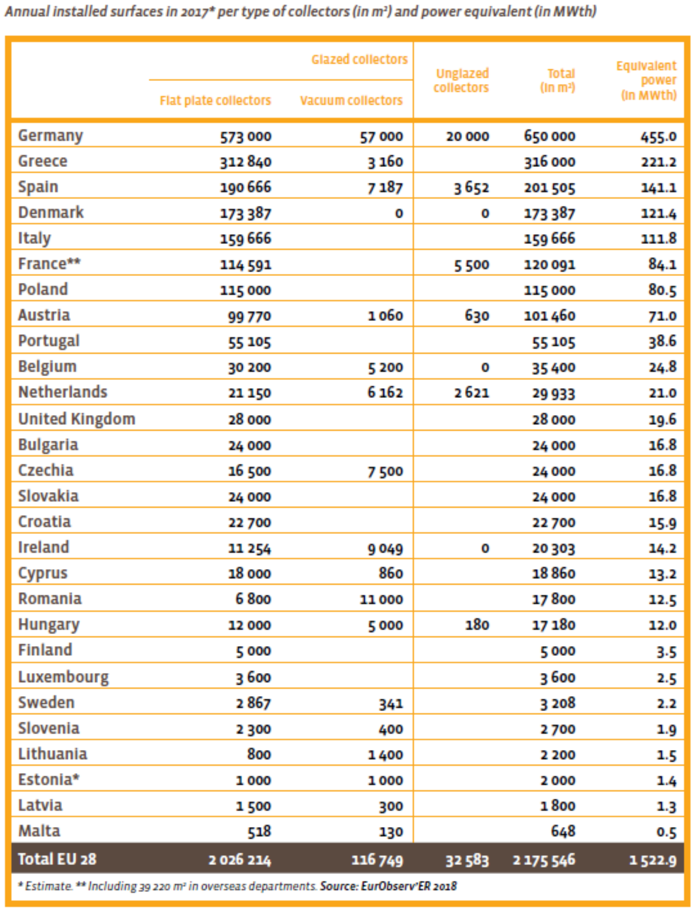


Figure 7: Share of different RES for heating and cooling in Europe

The current efforts on solar thermal applications in Europe can explain the amount of solar collectors installed in 2017 as shown in the table below



Annual installed surfaces in 2017 per type of collectors (in m²) and power equivalent (in MWth)*

	Glazed collectors		Unglazed collectors	Total (in m²)	Equivalent power (in MWth)
	Flat plate collectors	Vacuum collectors			
Germany	573 000	57 000	20 000	650 000	455.0
Greece	312 840	3 160		316 000	221.2
Spain	190 666	7 187	3 652	201 505	141.1
Denmark	173 387	0	0	173 387	121.4
Italy	159 666			159 666	111.8
France**	114 591		5 500	120 091	84.1
Poland	115 000			115 000	80.5
Austria	99 770	1 060	630	101 460	71.0
Portugal	55 105			55 105	38.6
Belgium	30 200	5 200	0	35 400	24.8
Netherlands	21 150	6 162	2 621	29 933	21.0
United Kingdom	28 000			28 000	19.6
Bulgaria	24 000			24 000	16.8
Czechia	16 500	7 500		24 000	16.8
Slovakia	24 000			24 000	16.8
Croatia	22 700			22 700	15.9
Ireland	11 254	9 049	0	20 303	14.2
Cyprus	18 000	860		18 860	13.2
Romania	6 800	11 000		17 800	12.5
Hungary	12 000	5 000	180	17 180	12.0
Finland	5 000			5 000	3.5
Luxembourg	3 600			3 600	2.5
Sweden	2 867	341		3 208	2.2
Slovenia	2 300	400		2 700	1.9
Lithuania	800	1 400		2 200	1.5
Estonia*	1 000	1 000		2 000	1.4
Latvia	1 500	300		1 800	1.3
Malta	518	130		648	0.5
Total EU 28	**2 026 214**	**116 749**	**32 583**	**2 175 546**	**1 522.9**

** Estimate. ** Including 39 220 m² in overseas departments.* ***Source: EurObserv'ER 2018***

Figure 8: Annual installed collector surface in Europe 2017

The next worthwhile finding is that residential and services sector, accumulate the majority of heating and cooling needs, thus the building energy consumption is of major interest in solar thermal technologies challenges. A large part of the buildings in Europe could cover up to 100% of their energy demand for heating by combining biomass, solar thermal and/or geothermal energy. Heating and cooling are necessary elements of any comprehensive strategy to develop renewables and to achieve sustainability in the energy sector.

If the direct use of solar energy for heating purposes via solar collectors, as shown in the sustained energy scenarios, is to make a significant contribution to the energy supply, it is necessary that solar-heating technologies be developed and widely applied over and beyond the field of domestic-hot-water preparation only.

Developments in the building sector (low energy and passive energy houses) show it is possible to quickly reduce the specific heating requirements of new buildings. As studies illustrate existing buildings have medium-term potential for reduction of 20% with regard to heating energy requirement.

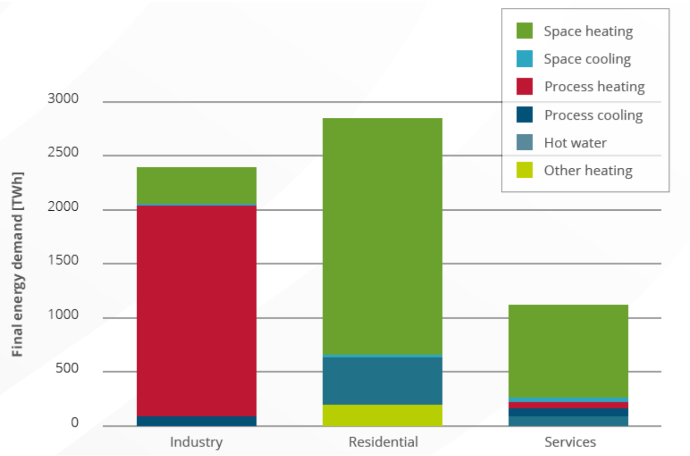


Figure 9: Share of energy consumption for heating and cooling by sector in Europe

5. SOLAR THERMAL APPLICATIONS

5.1 Solar Heat in Buildings

The core application of solar heat is the production of domestic hot water. In countries with colder climates, space heating in dwellings is also a common application.

Small-scale solar water heating systems and to a certain extent solar combi-systems (see below) for combined hot water preparation and space heating for detached single-family houses and apartment buildings, for multifamily houses, for the hotels as well as for public buildings represent still more than 90 % of the world wide annual installations.

These systems are either thermosiphonic, as shown in Fig.10 using natural convection, which circulates liquid without the necessity of a mechanical pump, or forced circulation Fig.11 using pump to circulate water and/or heating fluid in the system

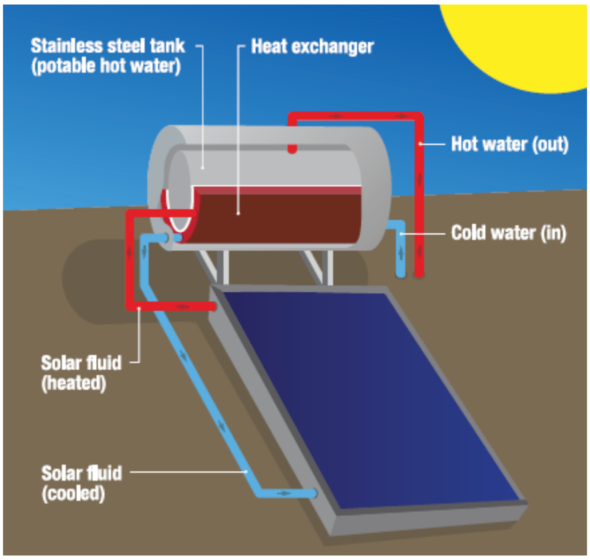


Figure 10: Thermosiphonic solar collector

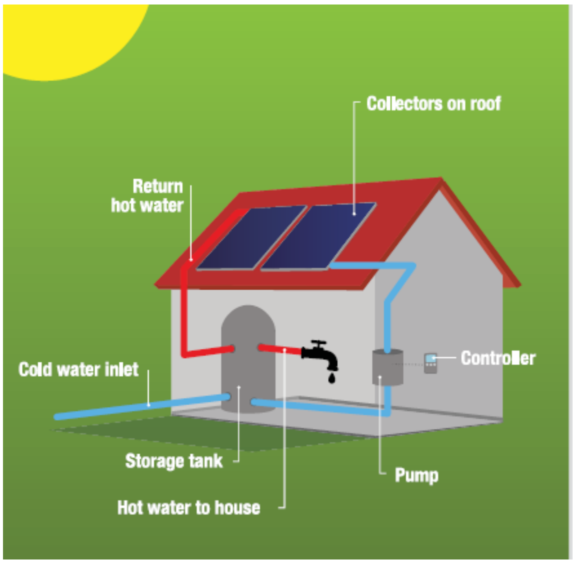


Figure 11: Forced circulation solar collector

Widely used in European markets, the forced circulation systems offer a variety of options in terms of application. They provide both hot water and space heating and are also known as combi-systems. Solar combisystems are solar heating installations providing space heating as well as domestic hot water for the inhabitants of the building. The primary energy sources are solar energy as well as an auxiliary source such as biomass, gas, oil and electricity, either directly or with a heat pump. The solar contribution, i.e. the part of the heating demand met by solar energy varies from 10 percent for some systems up to 100% for others, depending on the size of the solar collector surface, the storage volume, the heat load and the climate. As a general rule, collectors should be operated at the lowest possible temperature in order to have a good efficiency; at high temperature they have significant heat losses. Other individual requirements arise from the auxiliary heat source selected.

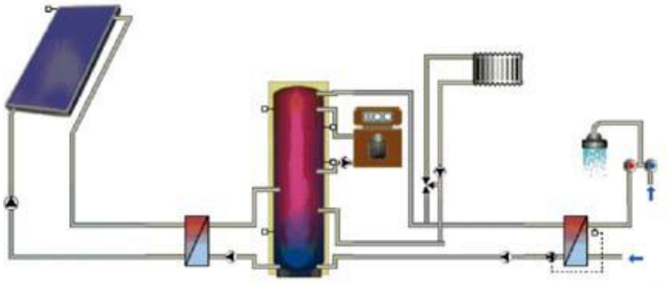


Figure 12: Solar combisystem layout

In the Scandinavian countries Denmark and Sweden, as well as in Austria, Germany, Spain and Greece, large-scale solar thermal plants connected to local or district heating grids, or installed on large residential, commercial and public buildings have been in use since the early 1980s. In recent years, China and other countries have also installed a number of large-scale systems.

Figure 13a: Large-scale system for multi-family houses

By the end of 2018, 339 large-scale solar thermal systems (>350 kW_{th}; 500 m²) were in operation (Figure 6). The total installed collector area of these systems equaled 1,747,200 m² (1,200 MW_{th}, excluding concentrating solar thermal systems that add up to 177,950 m²).

The biggest sub-sector of the systems described above is **solar assisted district heating**. And, Denmark is the leader by far not only in Europe but worldwide, in the number of systems and in the installed capacity.

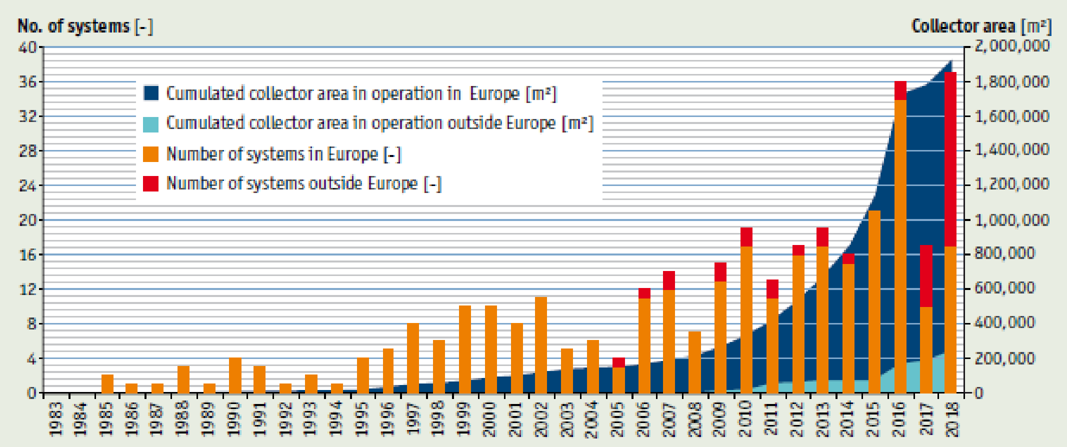


Figure 13b: Large-scale systems world wide – annual achievements and cumulated area in operation in 2018 (IEA SHC Task 45,AT, Bärbel Epp - solarthermalworld.org, DE)

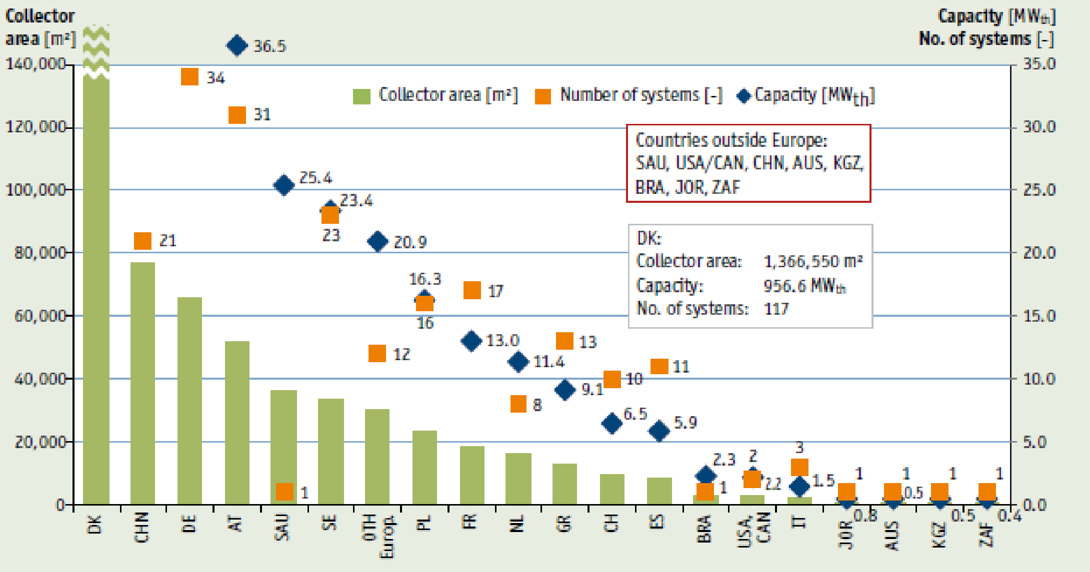


Figure 14: Large-scale systems (with evacuated tube collectors and flat plate collectors included in the diagram, concentrating solar thermal systems add with 177,950 m²) for solar district heating and residential buildings – capacities and collector area installed and number of systems in 2018 (as previous)

Figure 15: A 0.7 MW_{th} solar thermal system supplies heat to the Berlin district heating network.

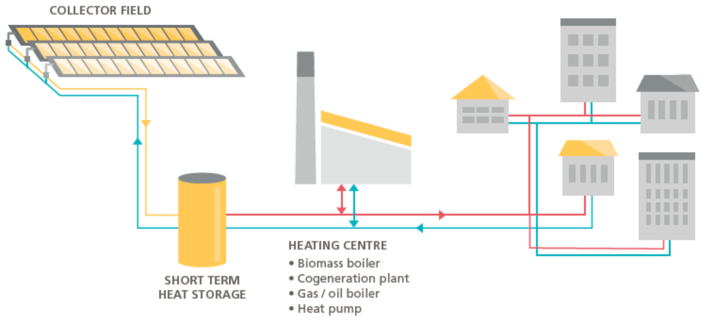


Figure 16: Schematic configuration of solar district heating plant

5.2 Solar Cooling and Air Conditioning

Worldwide, the energy consumption required for cold and air conditioning is rapidly increasing. As already mentioned, thermally driven technologies can employ solar energy. The advantage of solar energy for cooling is the match in time between solar radiation (supply) and demand. Expensive electricity in peak times can be saved. Furthermore, solar thermal energy is an outstanding option for storing solar heat to meet cooling demands in the evenings, nights and mornings. A typical solar cooling system also provides space heating and hot water, besides cooling. One of the main requirements of such systems is to have an effective heat rejection system. This means that applications requiring both heating and cooling are rather well suited for this technology (for instance, dairy farms, hotels or residential houses with heated swimming pool).

Thermal absorption chillers with a cooling capacity larger than 350 kW continue to improve in performance and decrease in cost. The significant improvements in the performance of large flat plate collectors at temperatures up to 120°C and system adjustments have been key in the overall performance improvements. In addition, economies of scale have played an important role in the cost competitiveness of solar cooling applications for large of ice buildings, hotels, hospitals, and commercial and industrial applications.

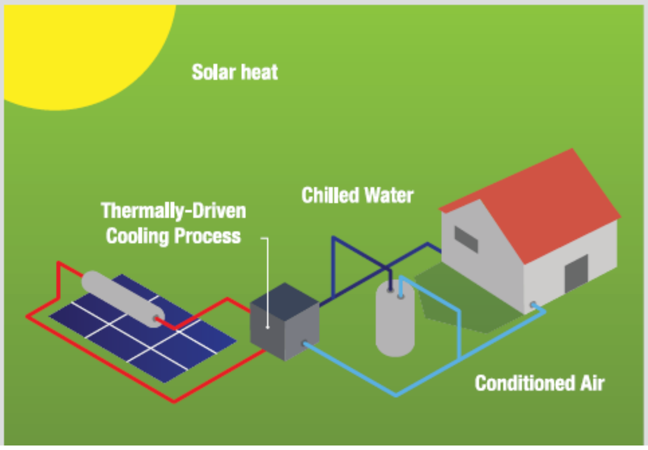


Figure 17: Schematic configuration of solar cooling plant

The electricity needed by a system, e.g. running pumps and the cooling tower, is quite low. Depending on the climate, it may give electric COPs (kW_{th}/kW_{el}) of 20 to 40 in systems with optimized variable speed drive performances. Thus, the electric demand for air conditioning in a building is cut down by more than 80 % compared to conventional HVAC equipment.

Even though the technical and economic conditions for solar cooling and air conditioning have improved significantly in recent years, this remains a challenging market, which is reflected in the comparatively low number of solar cooling systems built in recent years.

The world's largest solar cooling application is located in Arizona, USA and was commissioned in May 2014. The installation covers a roof-mounted solar thermal collector field with a capacity of 3.4 MW_{th} (4,865 m^2) that supplies heat to a single-effect lithium bromide absorption chiller with a cooling capacity of 1.75 MW. Three large solar cooling systems were installed in 2018. These include two systems in Italy, which are using evacuated tube collectors and one system in Jordan, were Fresnel collectors are used to provide the heat for the chiller.

Mega watt-scale solar supported district heating systems and solar heating and cooling applications in the commercial and industrial sector have gained increasing interest all over the world in recent years. This positive trend is expected to continue, but it should be mentioned that megawatt-scale plants still represent only about 1 % of the overall global installed capacity.

6. TECHNOLOGY DEVELOPMENT: ACTIONS AND MILESTONES

In the last five years, more than 17,000 research articles have been published on solar thermal collectors, with more than 14,000 experimental works, thus demonstrating a great interest in this research field.

6.1 Solar heat - Flat-plate and evacuated tube systems for heat applications

Here we have mature solar thermal technologies, commercially available for the building sector, so the technological challenge rest to provide new products and applications, reduce the cost of systems and increase market deployment. As all efforts have to follow the application of bioclimatic and passive building design, in order to deal with the minimum demand of energy, development of new building elements and design comes first in technological challenges. In that way by 2030 it could be economically viable to build new low-energy houses that satisfy their small residual heat demand with solar heat. A number of R&D and technology development challenges should be addressed in order to make this feasible.

Material technology can reduce the life-cycle cost and improve the economics of solar thermal systems. Plastics for the collectors, coating for absorbers and new polymer materials that resist deterioration from UV exposure are most promising solutions. More efficient heat transfer (due to fluids or heat exchanger design) can also be taken into account.

However, also optimisation of the installation management can reduce costs. Transition towards standardised kits and plug-and-function solar thermal systems has been proposed in order to reduce installation costs and also improve performance and reliability of the systems.

As industrial sector consumes around 16% of heat in Europe (see Fig 4) the idea to use thermal solar energy is rational and given that 30% of process heat demand in the European industry sector consists of low temperature heat, less than 100°C the technological approach seems even more beneficial. Of course use of process heat between 100°C and 400°C can also produced by thermal collectors, however current solar collectors covering these temperature levels are not yet market mature e.g. double glazed flat-plate collectors with anti-reflection coated glazing, stationary CPC collectors and Maximum Reflector Collectors. Also material resistance to high temperature levels and the components durability need to be studied further.

The boom in the market however seems to come from the large scale solar heating systems which are increasingly applied in Europe and can offer additional potential in a relatively unexplored market. System designs have thus far been unique engineering projects. Large scale system deployment can benefit from the development of more standardised pre-engineered solutions and increased knowledge of system design. Solar district heating is a huge market and the existing know how can feed the deployment of such systems.

Figure 17: World's largest solar district heating plant in operation in 2018 (110 MW_{th}) in Silkeborg, Denmark.

6.2 Solar cooling

Reducing costs is of great importance in the solar cooling industry. Standardization of systems can reduce the investment costs of technologies that continue to be used at too small market volumes. Today we can find in the market pre-engineered solar cooling kits with cooling capacities between 2.5 kW and 40 kW that are suitable for single-family, multi-family, and commercial properties. Unfortunately, a real and significant market has not yet emerged from these innovations. R&D is necessary in order to develop low-cost systems with minimal maintenance requirements, integrate them with existing equipment and optimise operation in new developments and with higher COPs at low driving heat temperatures.

Solar thermally driven cooling cannot consider as mature technology and a number of RD&D

challenges need to be addressed to enable increased deployment. They do require optimised thermally driven cooling cycles (sorption chillers and desiccant systems), with higher coefficients of performance, lower cost and easier hybridisation with other waste heat, backup heating and backup cooling technologies. RD&D into new sorption materials, new sorption material coatings for heat exchange surfaces and new heat and mass transfer systems are the main interest issues. Increasing use of desiccant, double effect and even triple effect cycles with storage will enable a wider range of applications to be addressed and simplified options for end users.

The future of solar thermal technology in small and medium scale systems lays in the development of both heating (space heating and domestic hot water) and cooling, compatible with compact thermal storage. For large systems (more than 50 kW cooling capacity), technical developments are required to improve efficiency and cost competitiveness. That will involve system packaging and standardisation, and innovations to simplify system operation and maintenance.

6.3 Thermal storage

As already mentioned, solar district heating (and cooling) is a promising huge market. Such systems require also large-scale seasonal storage as the combination of large scale solar district heating (or cooling), heat pumps and combined heat and power production can work effectively with dynamic renewable electricity production – using large thermal storage as a buffer for variations in load and production of both heat and electricity.

Seasonal storage is a field where sensible heat storage using water, is applied but it requires large scale stores and subsequent water volumes, and the development of new, cost-effective, compact season-scale heat storage technologies is crucial for the commercialisation of solar thermal systems. To meet these requirements new materials and technologies must be developed. Today research is focused in thermochemical systems and phase change materials (PCMs). Development of optimised heat and mass transfer devices (reactors) for sorption and thermochemical storage also needs attention. The capacity to operate consistently over a high number of charging and discharging cycles is critical for most thermal energy storage applications, so the stability of materials in the systems is very important – not only the storage medium itself but also materials used in systems components such as containers, reactors, heat exchangers and pipes.

Thermal storage working on medium temperatures, between 100°C and 300°C, enables the integration of solar thermal technology into industrial processes and the optimisation of these processes. Heat exchangers and reactors have to be developed for charging and discharging the new materials.

6.4 Parabolic trough collector

Most collectors in existing solar district heating plants are large area flat plate collectors. The efficiency of flat plate collectors decreases sharply with the increase of the operation temperature. Parabolic trough collectors have a constant and high efficiency regardless of operation temperature. Fig. 18 shows the principle of a combined solar heating plant with flat plate collectors and parabolic trough collectors. The combination of flat plate collectors and the parabolic trough collector technology in series is a perfect match as both systems deliver exactly what they do best: flat collectors have a higher performance at lower temperatures and produce more heat around midday, whereas parabolic trough collector is most efficient at high temperatures and provides a more balanced heat production throughout the day. The solar heating system for Taars Varmevark (DK) applies flat collectors to preheat the water which is thereafter boosted by the parabolic trough collector technology to achieve the required supply temperature of the district heating network. The mix of the two technologies allows better daily energy distribution. A hybrid solar district heating plant with 5960m^2 flat plate collector field and 4039m^2 parabolic trough collector field in series was put into operation in August of 2015. The district heating network supplies heat to 2000 habitants/840 buildings.

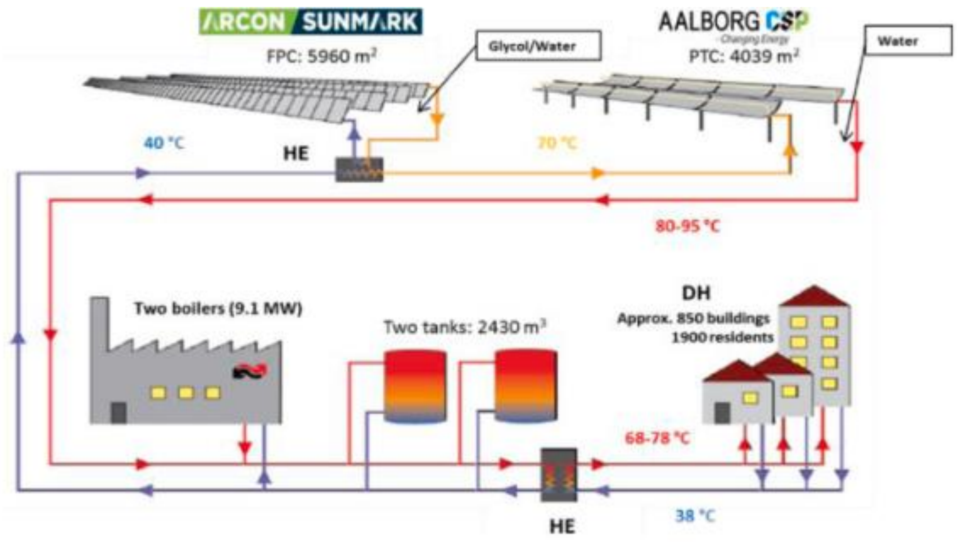


Figure 18: Taars plant: a combined solar district heating plant with flat plate collectors and parabolic trough collectors in series (Source: Aalborg CSP A/S)

7. SUPPORT INCENTIVES

The direct economic value of a solar thermal system for its owner consists of:

- The economic value of the energy it saves
- The independence from conventional energy supply

Other benefits as reducing CO_2 emission but also as alleviating concerns about electricity peak load costs should also be considered. Governments should take a broad perspective when (re)considering their countries' solar heating and cooling potential.

Where solar heating and cooling technologies are not yet able to compete with conventional fossil fuel alternatives, effective and predictable economic incentive schemes are required. These should take into account the advantages of renewable heat as a displacement technology (for example in reducing fossil fuel use or load on the electrical network), as well as the characteristics of different types of end users. Further, SHC technologies must be able to compete on a level playing field with other renewable and nonrenewable technologies by being equally eligible for incentives, market support and qualification to participate in trading schemes.

The costs of a solar thermal system include:

- The investment to buy and install the system
- The costs of maintenance and decommissioning

Life cycle assessments of solar thermal systems have shown very low environmental impacts and thus external costs, almost all of them in connection with the manufacture of the product or its raw materials. But nearly all materials can be recycled.

Over the lifetime of a system, the largest part of the cost (usually well over 90%) occurs at the time of investment, since the maintenance and decommissioning costs are very low.

The economic benefit, however, is spread over the lifetime of the system, which is usually over 20 years. Alternatively, in the case of conventional heating and cooling systems, the operational (mainly fuel) and maintenance costs are much higher than the investment costs.

This high share of upfront investment costs is a major barrier for increased use of solar thermal and other renewable as well as energy efficiency measures. For many private individuals, the absolute amount of upfront investment costs is the key barrier. And, future lower heating costs tend to be undervalued against the initial investment costs.

For many commercial decision makers, it is the payback time, which is seen as crucial. Even in the case of high returns on investments (over the lifetime of the system), many companies avoid solar thermal because the payback time is higher than 5-7 years.

Furthermore, the calculation of a payback time depends largely on the assumption made for the price of conventional fuels when replaced by solar. In the absence of reliable price forecasts, many investors calculate with stable prices of conventional fuels, which may lead to lower estimations of the future energy costs savings through solar thermal systems.

Even in countries where the solar thermal market has reached a certain market size, the decision to purchase and install a system can still be more complicated than installing a conventional heating system. Only in mass markets has solar thermal become a mainstream technology.

7.1 Main Forms of Financial Incentives

- Direct grants (direct support to reduce the initial investment (upfront cost) - the most common form of incentive, definitely the case in Europe)
- Solar heat tariff (tariff paid to the end users for each unit of renewable heat they produce - largely inspired by the feed-in tariff introduced in many European countries for electricity)
- Tax reductions (direct tax looks at reductions in income or corporate tax and the indirect looks at VAT reductions)
- Loans at reduced rates (not a significant impact on the development of the solar thermal market-could be very useful if targeted at large solar thermal systems). A special form of loans are the “Guaranteed Solar Results” contracts where the solar thermal company builds, owns and operates the (large) solar thermal system and the customer only pays for its usage, just like he would pay for oil or gas.
- Tradeable Certificate Schemes (green heat or energy efficiency certificates)

To deploy solar thermal at a larger scale, financial incentives are necessary and are an effective mechanism, provided several key success factors are taken into account, as the continuity of the financial incentive scheme, clear target (e.g. certain market segments), quality criteria and a continuous monitoring and evaluation in order to fine-tune the scheme operation and prevents major problems in the future.

7.2 Addressing non-economic barriers

From the demand side perspective, barriers hindering the uptake of solar heating and cooling include a general lack of information about solar heating and cooling technology and potential.

Increasing transparency on energy costs – including external factors that are not included in the market price for energy such as the costs of natural resource depletion, health impacts from pollution and climate change – should help consumers and project developers to receive accurate price signals reflecting the true cost of energy use.

Solar water heating technology is not highly complicated and the required capital investment for manufacturing is low, so businesses can enter the market relatively easily. This means that countries can easily adopt policies and strategies to increase solar adoption and create employment opportunities, thereby improving local economies.

However, without careful oversight of quality through testing and certification of products, systems and personnel, lower-quality products and lack of after-sale service could damage the reputation of the industry. In addition, the lack of product standardisation at regional or global level can make it difficult for companies to enter global markets. Support mechanisms should take quality standards into account, thus ensuring an efficient and judicious use of public funds.

In retrofit applications on existing buildings, small scale installers of conventional heating and cooling systems often act as “gatekeepers” between suppliers of products and building owners. Thus offering training and education in solar heating and cooling technology for architects, installers and installation engineers would encourage SHC deployment, educating consumers to request SHC technology and encouraging SHC supply channels so that the technology is available for immediate supply and installation.

A well-known barrier for the uptake of solar heating and cooling systems in the building sector is the “split-incentive” dilemma. For example, rental property owners have little incentive to invest if their tenants pay the energy bill. Conversely, the tenant may not be interested in a solar system investment either, as they may move out of the building before recovering their investment via reduced energy costs. One solution to this barrier might be to introduce regulations under which investment costs for renewable energy improvements made by building owners may be recovered through a cost-share arrangement and effected through higher rental prices. For tenants, the decrease in energy costs due to solar energy improvements can be structured to offset the rental price increase.

From the supply or new construction perspective, barriers to the increased uptake of solar heating and cooling systems are caused in part by the nature and complexity of the heat market. The relatively small size of individual suppliers of solar heating and cooling equipment and the fragmentation of the building product supply chain inhibits a holistic approach to new building design and construction. The stand-alone nature of the small scale solar heating and cooling suppliers and competition with the larger conventional heating and cooling industry can have a negative impact on the deployment of solar heating and cooling technology. The solar heating and cooling industry and the conventional heat industry could both benefit from synergy and added value in cases where solar heating and cooling could be incorporated into the product ranges of the conventional heating industry.

8. POTENTIAL OF SOLAR WATER HEATING AND MARKET DEVELOPMENT

The economic and market potential is very dependent on the cost of the energy. On one side it is important to take into account the initial investment required and the cost of the energy supplied in comparison with other alternatives in the market. The following figure provides such a comparison of costs, taking into account the type of application and location and proving also reference cost ranges for gas and electricity.

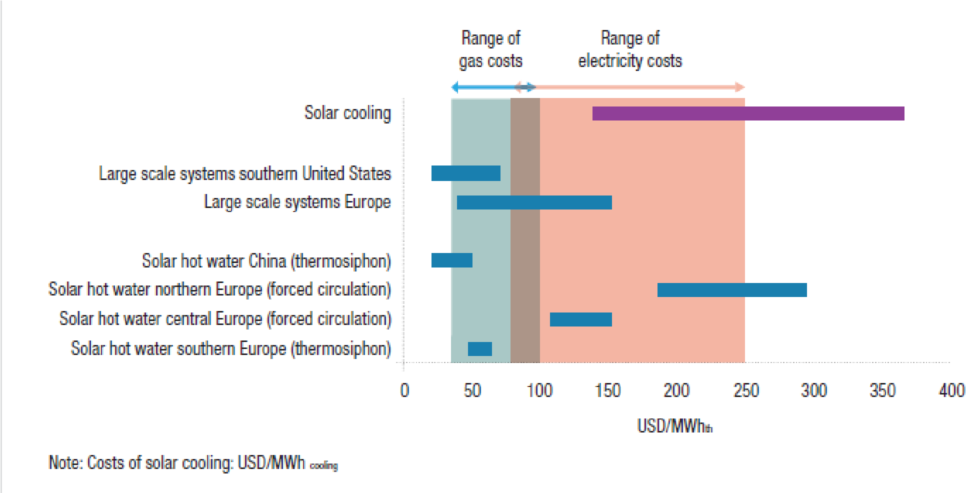


Figure 19: Costs of solar heating and cooling (USD/MWhth) [IEA 2012]

The energy costs of a solar thermal system are very dependent on the investment cost. In practical terms, and because the operation and maintenance costs are low, the investment on the equipment must be compared with the savings in energy over the years. An assessment done in Europe, estimates a learning curve of 23% for solar thermal collectors, i.e., the cost of the collectors went down by 23% at each doubling of the total installed collector capacity.

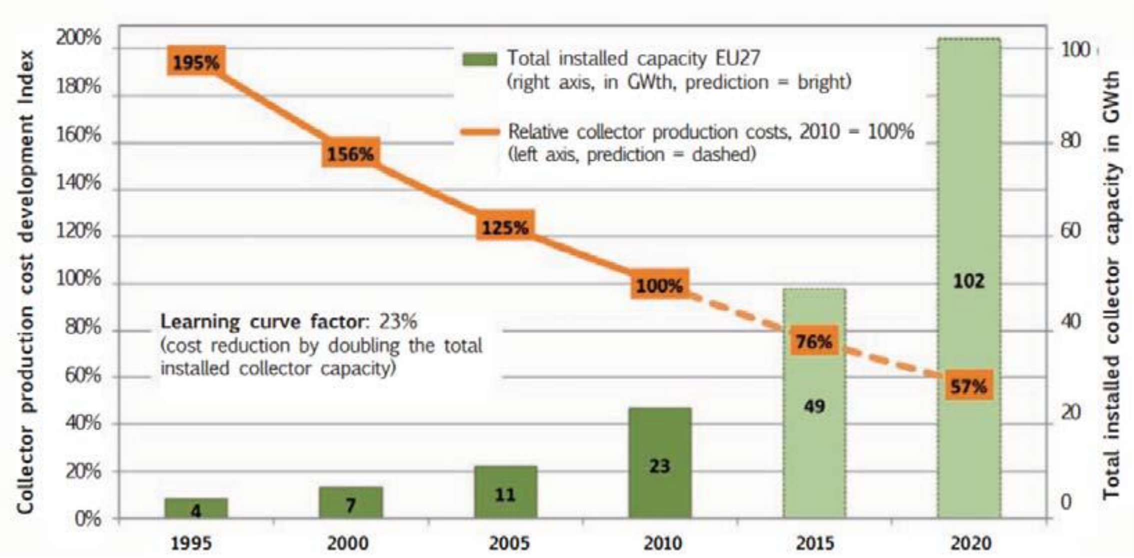


Figure 20: Learning curve for solar thermal collectors in Europe, from 1995 to 2010 and estimation up to 2020

The economic potential is commonly expressed by several indicators, such as cost benefit analysis (CBA), payback period and internal rate of return (IRR).

The following diagram shows the initial investment and cumulated net benefit of two different systems, A and B. A, costs 4.500 currency units and breaks-even after 9 years. B costs 8.000 currency units and breaks-even only after 11 years. However, B has a higher rate of return, and after 16 years, the cumulated net benefit of B is higher. After 20 years it is already 900 units and at 25 years the ROI is 2000 currency units higher than that of system A.

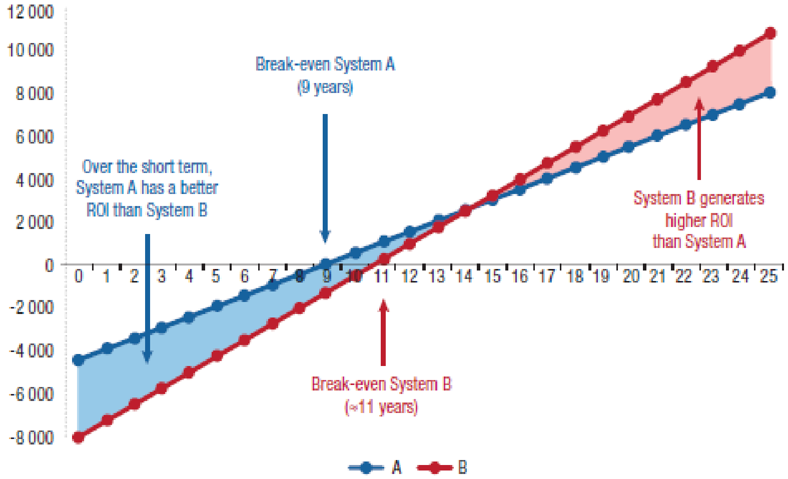


Figure 21: Exemplary economic analysis of two different solar thermal systems A and B

9. CONCLUSIONS

In order to stimulate investment, governments must take the lead role in creating a favorable investment climate for widespread use of solar heating and cooling. In particular, governments should:

- Create a stable, long-term policy framework for solar heating and cooling; establish medium term targets to maximise the effective use of mature and nearly mature technologies, and long-term targets for advanced technologies that have yet to reach the market.
- Introduce differentiated economic incentives on the basis of competitiveness per technology by means of transparent and predictable frameworks to bridge competitive gaps. Incentives could for example be based on feed-in tariffs or renewable portfolio standards for commercial heat and subsidies or tax incentives for end-user technologies. Economic incentive schemes should be independent of state budget procedures to avoid “stop-and-go” policies where, for example, sudden withdrawal of incentives can destabilize the market.
- Address barriers such as information failures, up-front investment of technologies, lack of quality standards and the ‘split-incentive’ problem (where the investor in SHC technology does not reap the benefits of reduced energy costs). This can be done through awareness raising campaigns, industry training and education, support for new business models and modified regulations.
- Provide RD&D funding and support mechanisms to enable promising pre-commercial solar heating and cooling technologies to reach high volume commercial production within the next 10 years.

As far as the role of research institutes and universities is concerned, they have to:

- Develop integration of solar collectors in building surfaces.
- Research alternative materials, technologies and manufacturing techniques to reduce system cost and improve performance.
- Expand development of collectors that cover temperature gap between 100°C and 250°C.
- Adapt concentrating solar technology to different heat applications (smaller scale, adjustable temperature levels and building integrated solutions).
- Develop and standardise system integration for solar heat in industrial processes.
- Increase thermal COP and COP_{el} (electrical efficiency) of solar thermally driven cooling

systems, including developing new cycles and storage (with cooling industry).

- Address challenges in system design by developing standardized kit solutions and plug-and-function systems (with cooling industry).
- Develop small scale thermally driven solar cooling technology for single family and multi-family dwellings (with cooling industry).
- Develop integrated thermally driven solar cooling and heating technology, including compact storage (with cooling industry).
- Explore potential for retrofitting of existing vapor compression systems into solar thermal cooling (with cooling industry).
- Continue developing promising materials for compact thermal energy storage, particularly phase change materials, sorption and thermochemical materials.
- Validate stability of materials and performance characteristics for compact thermal energy storage; create linkages with other sectors (e.g. R&D into thermal storage for CSP and industrial processes.
- Develop and demonstrate heating and cooling systems with integrated, advanced compact thermal energy storage systems (based on PCMs, sorption or chemical reactions) to optimise performance and reduce costs.
- Research new materials for medium-temperature storage, between 100°C and 300°C, such as phase change, sorption and thermochemical materials.
- Demonstrate integrated systems.
- Develop PV-T into commercially viable technology.
- Introduce training and education in solar heating and cooling technology for architects, engineers, designers, owners, facility managers, consultants and installers.
- Expand international R&D collaboration, making best use of national competencies.
- Develop schemes to transfer knowledge from high solar utilisation regions to countries with good solar resource but less experience.

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