THE POTENTIAL OF SOLAR HEAT IN THE FUTURE ENERGY SYSTEM

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Abstract. There is no doubt that *Renewables* have to play an important role in the future energy system. And, Solar Heat has the potential for a high contribution to the future energy supply. Today, solar thermal systems are regarded as a well-established, low-tech technology with an enormous potential for energy production in the low- to medium temperature range, all over the world -- cold climates to hot climates. A large variety of solar-thermal components and systems, mostly for residential applications, are available on the market. The products are reliable and have a high technical standard. Key reasons for the utilisation of solar heat are: The energy need for heating and cooling, for crop drying and for process heating is large and growing; the solar resource is large and inexhaustible; the environmental benefits and the economic benefits are substantial. Therefore, solar thermal technologies are essential components of a sustainable energy future. Solar heat can cover a substantial part of the energy use (worldwide, OECD, Europe) in a cost effective and sustainable way. Any long-term vision for economic development must include solar thermal technologies, to save finite energy sources and to build up an industry of strategic importance. Necessary is the willingness for the transition from fossil fuels to renewable sources and therefore also to solar heat.

Keywords: The facts of our present energy supply and future options. The solar resource and solar thermal technologies. Market deployment, state of the art and actual contribution of solar heat to the worldwide heat supply. Main arguments for solar thermal applications.

1. Introduction – The Facts of our Present Energy Supply

Our present energy supply is characterized by limited fossil resources, instability by political influence on the oil and gas markets, greenhouse gas emission from fossil energy resources -- facts, which are serious arguments for creating a new energy system. Main resources for a *Future Sustainable Energy* System will be renewable sources. And, solar thermal technologies have the potential for a high contribution to the future energy supply.

Today, solar thermal systems are regarded as a well-established, low-tech technology with an enormous potential for energy production. *Solar thermal technologies* for low- to medium temperature applications can be used all over the world -- cold climates to hot climates. A large variety of solar-thermal components and systems, mostly for residential applications, are available on the market. The products are reliable and have a high technical standard in the low temperature regime (below 150 °C). The market introduction of solar thermal systems – from research and demonstration to market deployment – is illustrated in Figure 1.

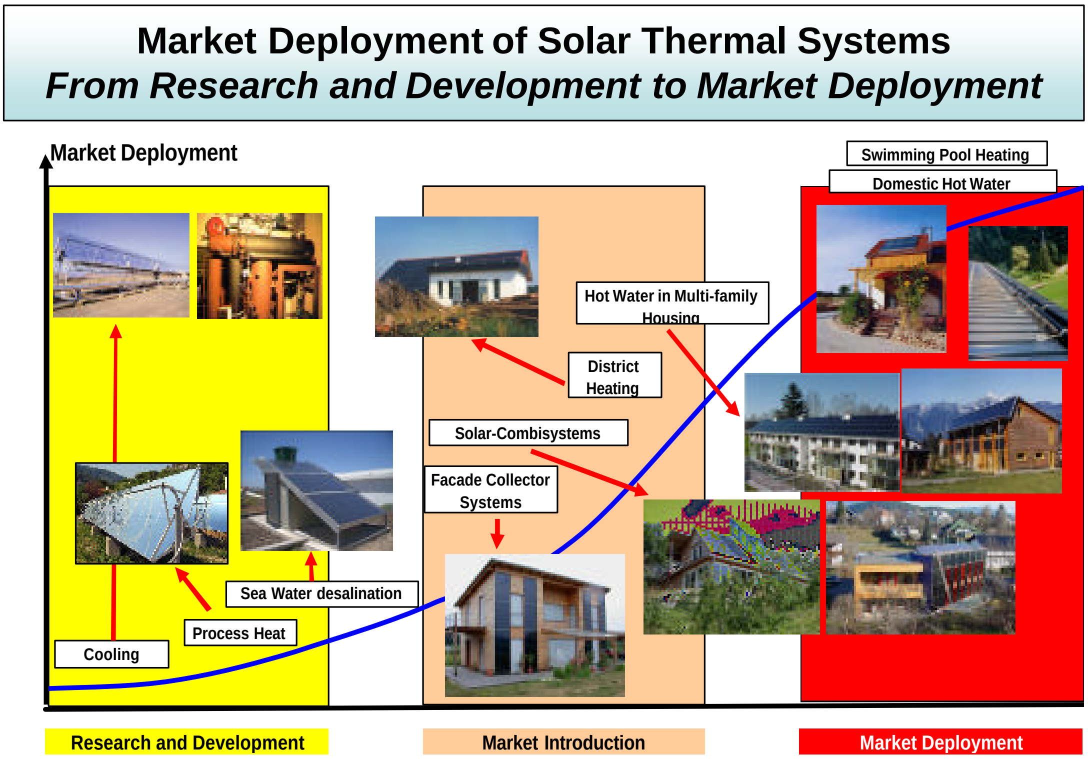


Figure 1: Solar thermal technologies on the market:
From research to demonstration and market deployment

There has been a rapid market growth in recent years for small solar hot water systems in countries moving towards partly automatic or semi-automatic fabrication of solar thermal components. Solar thermal systems in larger buildings – multi-family houses and apartment blocks – as well as in district heating plants are now emerging onto the market.

Up until now, solar thermal technology has not been a high priority in the OECD or in European and national R&D strategies, and therefore, only very limited financial resources have been allocated for R&D in this sector. However, the enormous potential for energy production, particularly in the heating and cooling sector, and the enormous potential for technical development of solar thermal technology illustrate that solar thermal technologies are dramatically underestimated.

The utilization of solar energy is considered to be promising in developing countries with suitable meteorological conditions. Also, the potential for decentralized (“stand-alone”) energy systems is in developing countries huge. Therefore, the use of solar energy for heat and electricity production is the first step for economic development. It appears essential to promote the development, testing, demonstration and market introduction of solar technologies in developing countries with the support of industrialized countries. Many joint projects were initiated since 1980, with the governmental support of OECD-Member States, the World Bank, UNIDO and other organisations; Figure 2.

Figure 2: Solar Heat for Developing Countries

2. The Solar Resource

The sun as the source of solar radiation is a continuous fusion reactor. Solar energy is essentially blackbody radiation corresponding to a temperature of about 6000 K and is therefore of high thermodynamic quality. For example, solar energy (direct radiation) can be concentrated by mirrors or lenses in order to achieve higher energy densities. Indeed, temperatures of about 3000 K have been reached in solar furnaces. By atmospheric scattering by air molecules, water and dust and atmospheric absorption by O_3, H_2O and CO_2 the on earth surface absorbed solar energy has a low density.

The *global (total) radiation* on the surface of the earth comprises the *direct (beam) radiation* from the sun's disk and the *diffuse radiation*, which is received from the sun after its direction has been changed by scattering in the atmosphere. The proportion of direct to diffuse radiation depends on cloud cover, moisture, and dust particle content in the atmosphere and on other environmental parameters.

Global, direct, and diffuse radiation is typically measured on a horizontal surface. In Central and Northern Europe, the diffuse radiation plays an important role for solar energy conversion. In these areas the diffuse part of the global radiation energy amounts to between 40% (summer) and 80% (winter). In Southern Countries direct radiation can be used to produce high-temperature heat by concentrating collectors.

The annual *available radiant energy* depends on the geographical location and meteorological conditions - values range between 2500 kWh/(m², a) in the Sahara to 775 kWh/(m², a) in Lerwick, UK. The solar radiation on the earth's surface has seasonal variations, which can be

1:2 in the tropic zones and up to 1:10 in the higher latitudes. The seasonal changes of solar radiation have a larger effect on the available radiation at higher latitudes.

The distribution of the *annual incident solar radiation* on a tilted surface as a function of slope and azimuth has to be considered within the installation as well as integration of solar thermal collectors in building envelope. The maximum intensity occurs when the flat surface is perpendicular to the sun's rays.

The *global radiation* for inclined surfaces can be calculated by the values of direct and diffuse radiation on the horizontal surface as a function of the time period considered as well as the inclination, orientation and sea level of the absorbing surface.

Conclusion: The *solar source* for solar thermal systems is immense and inexhaustible. The environmental and economic benefits are substantial.

3. Solar Thermal Technologies

Key applications for solar thermal technologies are those that require low temperature heat, such as for swimming pools, for domestic hot water and space heating, drying processes, and process heat in the low- to medium temperature range.

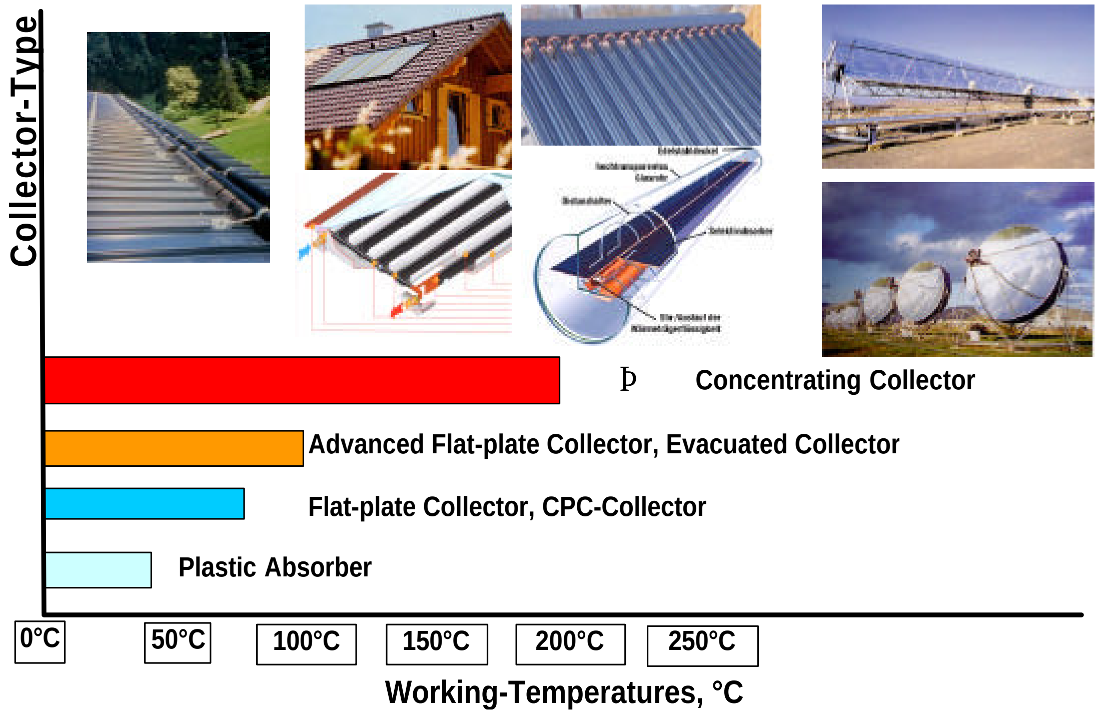
3.1 Solar Thermal Collectors

The component for the conversion of solar energy into heat is the collector – either non-concentrating or concentrating. Collector working temperatures of about 60°C to 80°C with a conversion-efficiency from 40 to 60 per cent can be achieved with flat-plate collectors. This type of collector is typically for hot water solar systems, the properties of this collector-type are well-known today and thus manufactured in many parts of the world. In countries with solar radiation = 1,800 kWh/ (m^2, a) it is advantageous to use solar systems for domestic hot water preparation as compact system with flat-plate collectors according to the thermosiphon principle. Synthetic absorbers are to be preferred to metal absorbers not only for cost reasons but also on account of missing corrosion.

Collectors are the component for the conversion of solar energy into low- and high-temperature heat. *Non-concentrating* collectors fully utilize the global radiation. *Concentrating collector*s use only the direct beam of the radiation by concentrating irradiation on the absorber thus increasing the intensity of radiation on the absorber. Concentrating collector systems are preferred technology in regions with more than 2500 annual sunshine hours; Figure 3.

The simplest design of a *non-concentrating collector* is the *flat-plate collector*. The properties of this collector are well known. As absorbers, black painted metal (copper, aluminium, steel) or plastic plates are used. In order to reduce the useful heat losses - which increase with rising temperatures - transparent covers are placed on the collectors and the heat losses at the back of the absorber are reduced by appropriate insulation. With these collector-type temperatures up to 80°C with conversion efficiency of about 40 to 60 per cent can be achieved. Applications are swimming pool heating, water heaters, agricultural drying, desalination, space heating.

Collector Types and Working Temperatures



Collector-Types for Solar Thermal Systems

Swimming Pool (Outdoor) *Temperature = 35°C*	*Non-covered plastic absorber*
Hot Water and Space Heating *Temperature = 80°C*	*Transparent covered flat-plate collectors, CPC- and evacuated tube-collectors*
Air-Conditioning and Cooling *Temperature = 120°C*	*Advanced flat-plate collectors and evacuated tube-collectors*
Process Heat *Temperature ³ 200°C*	*Advanced flat-plate collectors, evacuated tube-collectors, concentrating collectors*

Figure 3: Collector Types and Working Temperatures for Solar Thermal Systems

For temperatures above 100°C advanced designs, like some *evacuated tube collectors* has been developed. To obtain fluid temperatures above 150°C *concentrating solar collector* systems must be used. The concentrator (a mirror or lens) is normally equipped with a tracking device that follows the sun. The absorber in this system is located close to the geometric focus of the concentrator to intercept most of the incident direct radiation. In general, there are two types of concentrators - the linear focussing and the point focussing concentrator. In summary, the type of collector to use depends on the application and the desired temperature. For domestic hot water preparation, flat-plate collectors with selective coating are the most cost effective solution. For higher temperatures (above 80°C) and lower solar radiation, evacuated collectors would be the better choice.

A high-performance flat-plate collector is characterized by a superior absorber and glazing. The absorber should have a coating with a high solar abortively black painting (>95%) and low heat emissive selective coating (<5%). The glazing should be anti-reflection treated and consist of a low iron glass type to maximise solar radiation transmitted to the absorber. Such flat-plate collectors can easily achieve outlet temperatures of 80°C with a conversion efficiency of about 50 to 60 per cent.

Evacuated tube-collectors achieve superior performance because the vacuum surrounding the absorber drastically cuts heat losses to the ambient. Outlet temperatures above 100°C are easily achieved with a higher conversion efficiency compared with a flat-plate collector. The inside-facing underside of the glass pipe has a reflective coating to irradiate the absorber from beneath. Thus vacuum collectors have the further advantage of not having to have any given slope for optimal performance. The glass pipes can simply be rotated to the optimal incident angle for the application. For this reason, they can be mounted on a south-facade or roof.

It is beneficial to integrate solar collectors into the building envelope for aesthetic and economical reasons and when doing it is essential to take into consideration architectural rules and local building traditions. Façade collectors are used in urban buildings, where sufficient suitable and oriented roof for the installation of solar collectors is not available. A collector element directly integrated in the façade is understood by both solar collector and heat insulation of the building envelope. Advantages of façade integrated collectors are cost savings as a result of joint use of building components, replacement of the conventional façade, and the collectors suitable for both new buildings and existing buildings; Figure 4.

New Developments in the Collector sector

The objective of new developments in the collector sector is the cost-reduction as well as durability and reliability of novel design of solar thermal systems. Polymer engineering and science offers great potential for new products and applications, which simultaneously fulfil technological and environmental objectives as well as social needs. The full potential of polymeric materials can only be used when several product functions are integrated into a single component in a fundamentally new design. These goals will be achieved by either less expensive materials or less expensive manufacturing processes.

Most common is nowadays the use of copper absorbers for flat-plate solar collectors. The copper content in conventional flat plate collectors varies between 2 and 6 kg/m². Taking into account the copper used in piping and heat exchangers/heat stores, 5 kg/m² collector may be a good estimate. Each m² collector delivers about 300 kWh heat per year. Hence 1 MWh per year corresponds to 16.5 kg copper. Thus, to increase the annual world production of solar heat to 1% of the present human energy consumption an installation of 22 million tons of

Figure 4: Solar Thermal Systems in Operation
Hot Water and Space Heating, Thermosiphon Systems and District Heating

copper absorbers is required. The annual production of copper world-wide is approximately 15 million tons. The need for new materials is obvious. Aluminum, steel and other metallic materials will be used more. Polymeric materials have to be considered as an alternative.

The major advantages using polymeric materials are: low material cost in general (there also exist very expensive high performance polymers), low weight, and low manufacturing costs. The latter property is perhaps the most important factor when choosing polymeric materials for a specific application. Using polymers, at least in large scale production, complex integrated structures can be manufactured in a single step through e.g. injection molding or extrusion.
The objective of the Project "Polymeric Materials for Solar Thermal Applications" (Task 39) of the Solar Heating and Cooling Programme is the assessment of the applicability and the cost-reduction potential by using polymeric materials and polymer based novel designs of suitable solar thermal systems and to promote increased confidence in the use of these products by developing and applying appropriate methods for assessment of durability and reliability.

3.2 Solar Water Heating

Solar water heating, including pool heating, has been commercially available for over 30 years, and can be considered a mature technology. Today, domestic hot water preparation (DHW) with solar energy is standard in many countries. In the area of building renovation, solar hot water preparation is attractive to increase the efficiency of heating systems. Especially ineffective heating systems for hot water preparation outside the heating season have been replaced by solar hot water preparation. Thus pollutant emissions through heating (wood, coal, oil boilers) could be reduced and at the same time a high comfort in hot water preparation could be reached.

Solar hot water preparation in high-performance houses is sensible. In such houses the energy needed to heat domestic water can equal or even exceed the energy needed for space heating, since the latter has been so far reduced by insulation and heat recovery. In Europe, about 50 per cent of the new detached and row houses and about 15% of apartment houses are designed on this concept.

Further, demand for heating domestic water is a 12-month energy demand, including the high insulation during the summer months. Using a solar system is therefore an effective way to reduce the total primary energy demand.

For hot water heating in transition-countries, such as China and India, but also in countries without space heating systems (e.g. Greece, Cyprus, Malta….) direct-electricity is used. Large amount of electricity is necessary to meet the hot water requirements in domestic, institutional and commercial sectors resulting in peak load and load shedding to the shortage of power supply. With solar hot water systems, the electricity demand as well as the peak load can be reduced remarkable.

3.3 Solar Space Heating

Solar heating systems for combined domestic hot water preparation and space heating are similar to solar water heaters in that they use the same collectors and transport the produced heat to a storage device. There is, however, one major difference, the installed collector area is generally larger for *SolarCombisystems*, and in addition, this system has at least two energy sources to supply heat: The solar collectors and the auxiliary energy source. The auxiliary energy sources can be biomass, gas, oil or electricity. This dual system makes *SolarCombisystems* more complex than solar domestic hot water systems with the additional interactions of the extra subsystems. These interactions profoundly affect the overall performance of the solar part of the system.

Active solar space heating, while commercially available for almost as long, significantly lags behind solar water heating in the market due to its relatively higher costs as well as special requirements for utilisation (only low-energy buildings with low-temperature heat distribution). But in recent years, systems that combine water and space heating, called *SolarCombisystems*, have emerged on the market and show great promise for further market success.

3.4 Solar Cooling and Air-Refrigeration

While active *solar cooling* was developed in the 1980s, it was never able to compete economically with conventional air conditioning systems. In recent years, advanced solar cooling systems coupled with changed market conditions, suggests that active solar cooling will soon enter the market in a significant way. Solar assisted air-conditioning of commercial buildings is a promising concept. The advantage of solar is that the demand for cooling coincides with the availability of high solar radiation.

3.5 Passive Solar Heating

Passive solar heating, and to a lesser degree, *passive solar cooling* (or perhaps more accurately, passive cooling load reduction) has been commercially available for about 30 years. These systems can reduce the heating and cooling load by 50% with no additional cost and some systems can reach 75% heating and cooling load reduction with modest additional cost.

3.6 Day-lighting

Day-lighting designs have matured to the point where they can provide significant economic benefits and are expected to gain in use in new commercial buildings. In offices, day-lighting applications alone can reduce electricity demand for lighting: The day-lighting systems allow for significant dimming of the lights resulting in energy savings ranging from 50% to 70% for the south and west facing windows.

3.7 Solar Drying

One of the most promising agricultural applications for active solar heating worldwide is the *drying of agricultural products*. Wood and conventional fossil fuels are used extensively, and in many countries more expensive diesel and propane fuels are replacing wood. While solar crop drying is commercially available for specific crops in specific locations, its market share is insignificant at this time.

3.8 Solar Process Heat

In factories, solar collectors used in industrial and commercial processes, such as cleaning, drying, sterilization and pasteurization, heating of productions halls, can reach energy savings of 75 to 80% with payback periods under five years.

The energy needed by commercial and industrial companies in their *production processes* and to heat their factories can be covered by solar thermal collectors. The majority of the energy used by commercial and industrial companies is below 250°C, a temperature range perfect for solar technologies. Continued development of high performance collectors and system components will improve the cost effectiveness of higher temperature applications.

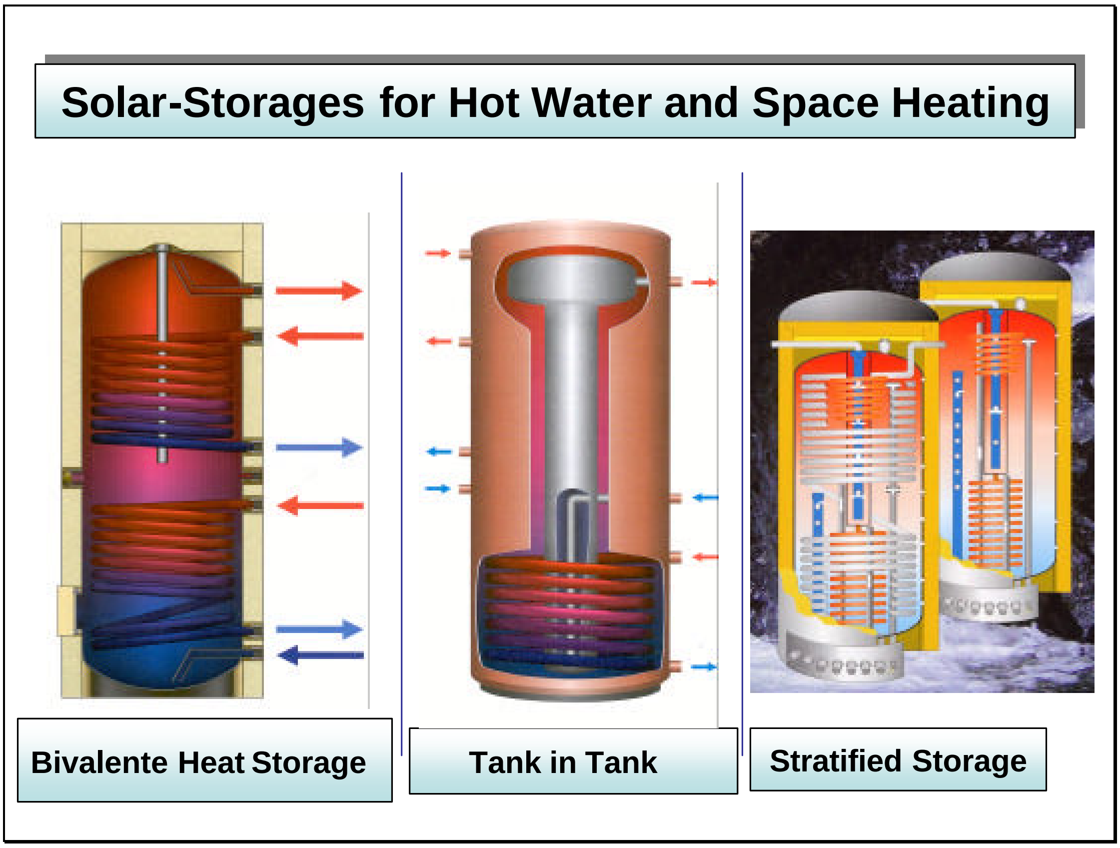
3.9 Thermal Storage

A heating system needs thermal storage when there is a mismatch between thermal energy supply and energy demand, e.g. when intermittent energy sources are utilized. The need for thermal storage in solar hot water systems is often short-term. In such instances, water is a very efficient storage medium. Water storages are sensible heat energy storage with the advantage of being relatively inexpensive but the energy density is low and decreases during the storage time.

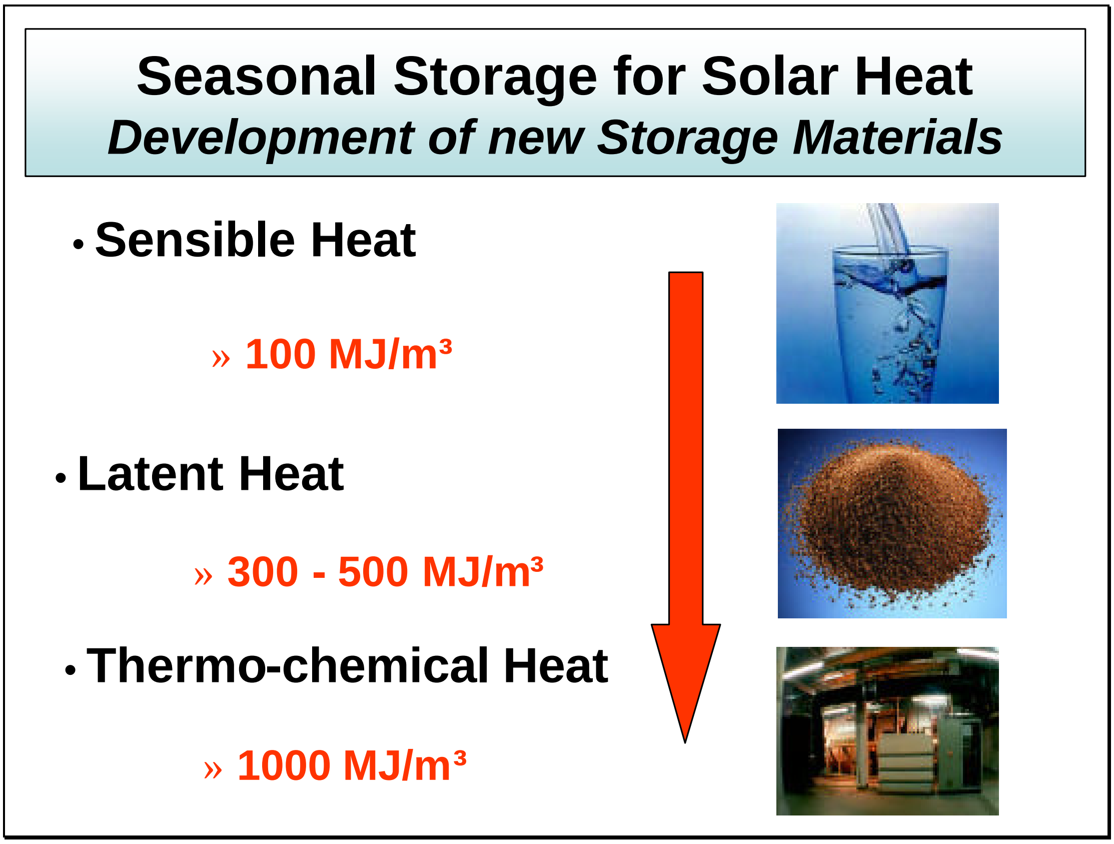
The *hot water tank* is one of the best known thermal energy storage technologies. The hot water tank serves to bridge sunless periods in the case of solar hot water and combined heating system, to increase the system efficiency in combination with cogeneration systems, and to shave the peak in electricity demand and improve the efficiency of electricity supply in the case of an electrically heated hot water tank. Water tank storage technology is mature and reliable. Sensible heat storage in water is still unbeaten regarding simplicity and cost. In refined systems the inlet/outlet heights in the tank can vary according to supply and storage temperatures. Three types of water storage concepts are on the market: Bivalent storage, tank in tank storage and stratified storage; Figure 5a.

For a wide spread market deployment of solar thermal systems, it is necessary to store heat efficiently for longer periods of time in order to reach high solar fractions, and therefore efficient and cost-effective compact storage technologies with high heat capacity are needed. Advanced storage technologies, such concepts with a phase change material (PCMs) or with thermo chemical materials (TCMs), are still in the research and development stage; Figure 5b.

Storage based on chemical reactions can achieve much higher energy density than storage based on sensible heat or even latent heat, but are not yet commercially viable. The storage systems based on chemical reactions have negligible losses whereas sensible heat storage dissipates the stored heat to the environment and need to be insulated and strongly if the storage period will be long.



a) Water Storage



b) Advanced heat storage technologies in development

Figure 5: Thermal Storage for Solar Heat

3.10 Decentralized and Centralized Solar Thermal Systems

Solar heating systems may distinguish between a *decentralized* and a *centralized* approach. In a decentralised approach, the storage and collectors are placed within the individual houses like in an ordinary active solar heating system but of a larger size. In the centralised concepts, these components are centrally situated, i.e. all solar heat is collected in one storage unit, from which the heat is distributed to the houses.

The major advantage of having a centralised system is the reduced unit costs and heat losses from the storage. In general, a centralised system may make better use of the economy of scale (unit prices drop with the size) than a decentralised one.

4. Market Introduction and Market Deployment of Solar Thermal Systems

The market introduction of solar hot water systems started in most of industrialised countries in 1976 caused by the (first) oil-price crises and with the aim of consumers to reduce the dependency from oil imports ("*First Solar-Boom*"). From 1980 until the middle of 1990s the solar market development was not stabile. First collectors and systems were offered by small companies, but missing guidance for design and construction and therefore not always satisfying the consumers. The market deployment decreased, but through new firms and better educated installers and available experiences on the market, the amount of installed collectors and systems increased again in late 1970s ("*Second Solar-Boom*"). The situation on the solar thermal market illustrates Figure 6 for Austria. Favourable applications were the separation of hot water preparation in households with firewood heating systems in small communities, especially outside the heating season. With the decrease of oil price at the beginning of 1980 also the solar market decreased again. In this period "self-built" solar heating systems were organised, primary for solar projects for personal use and later also offered on the market. Through these private activities, the interest for solar systems was pushed and industry was motivated for more attention and new activities. From early 1990s onwards, larger solar firms were founded and the industrial production was based on national standards, guidance for energy-efficient design, construction and operation. With the increase of industrial produced collectors, the production of "self-built" collectors and systems was focused to "social" projects - to involve unemployed young people as well as handicapped persons with the aim to open perspectives for the job market. The products are used in social projects.

More attention for "greenhouse-gases" and their potential for climate change were given - both in policy and by consumers – and this supported the solar market remarkable at the end of 1990s ("*Third Solar-Boom*"). Today, solar hot water systems are well designed, using materials with an expected lifetime of more than 25 years, the price for installed systems is acceptable and the results are satisfying the consumers. Also financial support by the governments has influenced the increase of annual growth rates.

5. Solar Heat Worldwide

Installed solar thermal capacity grew by 9% around the world in 2007. Solar thermal power output reached 88,845 GWh, resulting in the avoidance of 39.3 million tons of CO_2 emissions. At the end of 2007, the installed solar thermal capacity worldwide equalled 146.8 GW_{th} or 209.7 million square meters. The breakdown by collector type is: 120.5 GW_{th} - flat-plate and evacuated tube collectors, 25.1 GW_{th} - unglazed plastic collectors and 1.2 GW_{th} - air collectors; Figure 7.

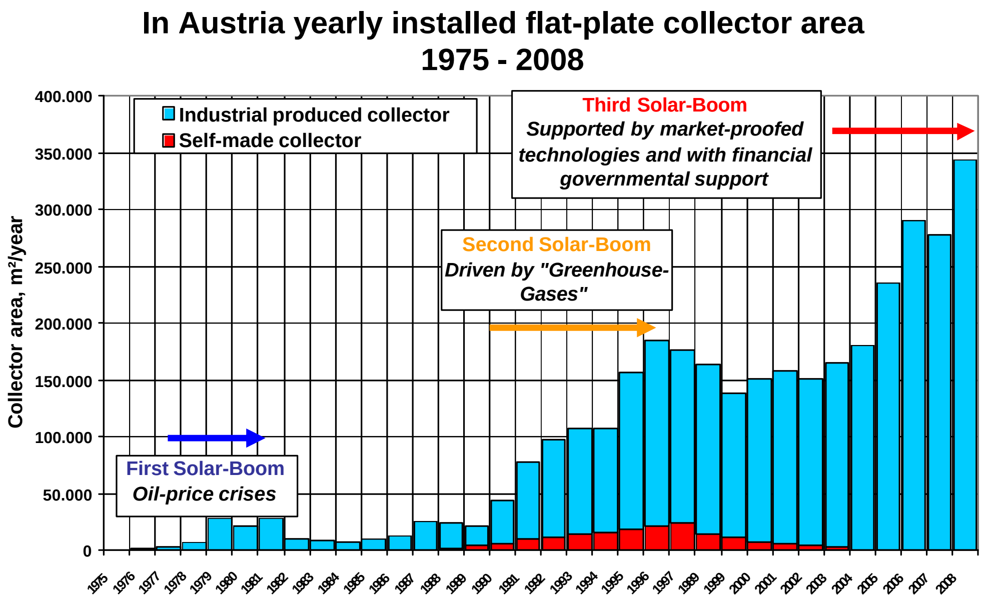


Figure 6: Market deployment of solar thermal collectors in Austria

The use of solar thermal energy varies greatly by country. In China and Taiwan (80.8 GW_{th}), Europe (15.9 GW_{th}) and Japan (4.9 GW_{th}), plants with flat-plate and evacuated tube collectors are mainly used to prepare hot water and to provide space heating while in North America (USA and Canada) swimming pool heating is still the dominant application with an installed capacity of 19.8 GW_{th} of unglazed plastic collectors. It should be noted that there is a growing unglazed solar air heating market in Canada and the USA aside from pool heating. Unglazed collectors are also used for commercial and industrial building ventilation, air heating and agricultural applications. Europe has the most sophisticated market for different solar thermal applications. It includes systems for hot water preparation, plants for space heating of single- and multi-family houses and hotels, large-scale plants for district heating as well as a growing number of systems for air conditioning, cooling and industrial applications.

From the worldwide collectors capacity in operation (2007) are 50% evacuated tube collectors, 32% flat-plate collectors, 17% unglazed collectors and 1% air collectors (mainly from the *Solarwall*-type). The main markets for evacuated tube collectors are in China, the most flat-plate collectors are found in Europe. In USA and Australia unglazed collectors are dominating. But in recent years, the worldwide market for new installed glazed collectors has been significantly growing, in Europe with growth rates near and above 100% compared to the capacity installed in 2006.

The already installed capacity of solar thermal heat is considerably higher than the installed capacity of the other renewable sources. The total energy yield of solar thermal heating systems comes in second place behind solid biomass, but it is higher than the energy yield of wind and PV power.

To find more detailed analysis on the market penetration of solar thermal technology in the 49 documented countries representing more than 85% of the solar thermal market, go to www.iea-shc.org.

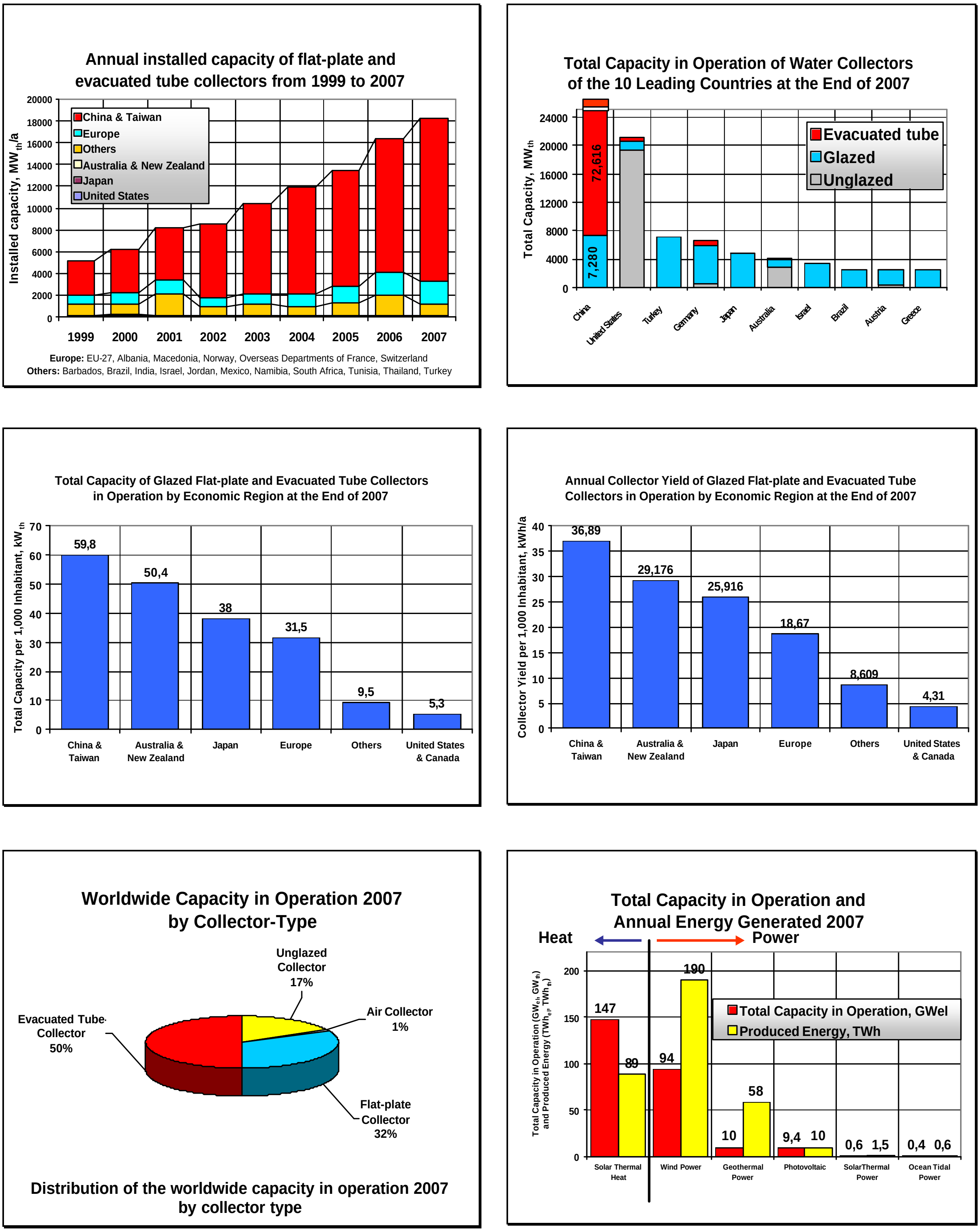


Figure 7: Worldwide solar thermal market 2007

Source: SOLAR HEAT WORLDWIDE. 2009 Edition.

6. The Potential of Solar Thermal Technologies

Solar heating and cooling

Solar thermal energy has the potential to meet the complete heating and cooling demand in the residential sector and to contribute significantly to the energy supply of the commercial and industrial sector.

The potential of solar thermal technologies for the heat supply (hot water and space heat) in housing is large. Passive solar heating in combination with energy-efficient building construction and practices can reduce the demand for space heating up to 30%. Active solar can reduce the fuel demand for hot water and space heating: 50% to 70% for hot water preparation and 40% to 60% for space heating in energy-efficient houses. Day-lighting can reduce the electricity demand for lighting up to 50%.

The potential for solar thermal applications in the housing sector will increase dramatically once suitable technical solutions are available to store the thermal heat for the medium to longer (seasonal) term. Such advanced storage systems could utilise chemical and physical processes to reduce the total storage volume and the related costs.

Solar assisted cooling is an extremely promising technology as peak cooling consumption coincides with peak solar radiation. A number of large-scale solar cooling systems have been successfully demonstrated, and it is now necessary to support wide market introduction. Small-scale solar cooling systems could be ready within a decade, if R&D support is provided.

With increasing demand for higher comfort levels in offices and houses, the market for cooling has been increasing steadily over the past years. Today, solar assisted cooling is most promising for large buildings with central air-conditioning systems. However, the growing demand for air-conditioned homes and small office buildings is opening new sectors for this technology.

In many regions of the world, air-conditioning represents the dominate share of electricity consumption in buildings, and will only continue to grow. The current technology, electrically driven chillers, unfortunately do not offer a solution as they create high electricity peak loads even if the system has a relatively high energy efficiency standard. In particular, in Mediterranean countries sales of air-conditioning equipment are dramatically increasing, and leading to electricity shortages in some areas during peak summer conditions. The obvious link, to provide the primary energy for these cooling applications using solar thermal energy, is still under development. Over the past ten years, the development of technical solutions has been strongly stimulated, mainly by small and medium-scale enterprises. In the range of small capacity water chillers using sorption technology very promising new products came up, which open a new market for use of solar thermal energy as a driving heat source for summer air conditioning. And, in the range of large capacity chillers many new solutions on the system level were developed and provide the opportunity for solar heat driven building air-conditioning.

Solar process heat

The consumption for process heat in the OECD is around 40% of the primary energy supply. The major share of the energy, which is needed in commercial and industrial companies for production, processes and for heating production halls, is below 250°C. The low temperature level complies with the temperature level, which can easily be reached with solar thermal collectors already on the market.

The most significant areas of use for solar heat plants are in the food and beverage industries, the textile and chemical industries, and for simple cleaning processes, such as car washes. The low temperatures required in these processes (30°C to 90°C) means that flat-plate collectors can be used as they are very efficient in this temperature range. Solar heat is used not only to provide process heat, but also to heat production halls.

Cleaning processes are mainly applied in the food industry, the textile industry and in the transport sector. For cleaning purposes, hot water is needed at a temperature level between 40°C and 90°C. Due to this temperature range flat-plate collectors are recommended for this application. The system design is quite similar to large-scale hot water systems for residential buildings, since they work in the same temperature range and the water is drained after usage. Concerning the hot water loop, it is an open system. Usually heat recovery is not feasible.

The increasing shortages in fresh water supplies provide a huge market for solar thermal seawater desalination. The temperature ranges at which desalination processes can be operated are below 120°C and are thus well suited for solar thermal collectors. R&D is needed to develop appropriate systems and technologies for wide spread application.

Summarising, about 30 to 40% of the process heat demand could be covered with low- to medium temperature solar collector systems.

7. Future options for solar thermal systems

Solar thermal systems are the logical successor of oil and gas heating - more than one third of our energy use is for heating. This is a cost effective investment as many applications are close to market entry.

The solar source for solar heating and cooling technologies is large and in reality “unlimited”, the contribution of solar produced heat depends from the possible installations. More than 70% of the worldwide energy supply could be covered by solar thermal systems - low and medium temperature applications.

It is estimated that about 30% to 40% of the worldwide heat demand could be covered by solar produced heat, and in Europe of about 20% of the demand for heat supply. With these assumption, the useful solar heat will be in the long-term (2050) of about 60 to 100 EJ/year worldwide and 10 to 20 EJ/year in OECD Member States.

Scenario for the market deployment of solar thermal collectors

The solar thermal market scenario is continuing the solar thermal market deployment in the last five years, starting with 2006 and the assumption of an average growth of the 2006 installed collector area by 15% per year from 2006 to 2010 (“*business as usual*”), and followed by an advanced market deployment of 20% per year - driven by national and international policies and measures. From 2021 until 2030, the annual growth rate of the installed collector area will be reduced to about 10% per year and then will remain constant until 2050. These calculations take into consideration the need to replace/renovate the solar thermal systems as a 25 year lifetime is assumed.

SOLAR THERMAL COLLECTOR MARKET			
WORLDWIDE			
Collector, installed 2006		**Collector, in operation 2006**	
million m²	Capacity, GW*(thermal)*	million m²	Capacity, GW*(thermal)*
26.1	18.3	182.5	127.8
Average annual growth rate: 1999 - 2006		15% - 20%/year	
OECD			
Collector, installed 2006		**Collector, in operation 2006**	
million m²	Capacity, GW*(thermal)*	million m²	Capacity, GW*(thermal)*
6.1	4.3	65.2	45.6
Average annual growth rate: 1999 - 2006		15% - 20%/year	
EUROPE			
Collector, installed 2006		**Collector, in operation 2006**	
million m²	Capacity, GW*(thermal)*	million m²	Capacity, GW*(thermal)*
3.5	2.4	22.4	15.7
Average annual growth rate: 1999 - 2006		15% - 20%/year	

Scenario for Solar Thermal Collector Market Deployment						
WORLD						
Year	Yearly installed	In operation			Population	Collector/Inhabitant
	million m²/year	million m²	$GW_{thermal}$	EJ	million	m²/inhabitant
2006	26	183	128	0,304	6400	0,029
2010	46	332	232	0,552	6660	0,050
2020	283	1756	1229	2,921	7357	0,239
2030	1145	8364	5855	13,911	8126	1,029
2040	2970	28437	19906	47,296	8977	3,168
2050	2070	58153	40707	96,720	9916	5,865
OECD						
Year	Yearly installed	In operation			Population	Collector/Inhabitant
	million m²/year	million m²	$GW_{thermal}$	EJ	million	m²/inhabitant
2006	6	65	46	0,108	1150	0,057
2010	11	100	70	0,166	1169	0,086
2020	66	434	304	0,722	1216	0,357
2030	268	1982	1387	3,296	1266	1,566
2040	696	6684	4679	11,117	1317	5,075
2050	696	13643	9550	22,691	1371	9,951
EUROPE						
Year	Yearly installed	In operation			Population	Collector/Inhabitant
	million m²/year	million m²	$GW_{thermal}$	EJ	million	m²/inhabitant
2006	3,5	22,4	16	0,037	508	0,044
2010	6,1	42,5	30	0,071	516	0,082
2020	37,8	232,5	163	0,387	537	0,433
2030	153	1115	781	1,854	559	1,995
2040	397	3796	2657	6,314	582	6,522
2050	397	7764	5435	12,913	606	12,812

Table 1: Results of scenario for the worldwide market deployment of solar thermal collectors

Source: Gerhard Faninger, IEA SHC 2009

The results of the calculation are summarized in Table 1. Table 1 illustrates the annual installed collector area, the number of collectors in operation, and the expected primary energy demand and population data. These calculations are based on data from the *IEA World Energy Outlook*. In the *IEA World Energy Outlook*, the world's population is projected to grow by 1% per year, from 6.4 billion in 2005 to almost 8.2 billion in 2030. For OECD countries the prospected growth rate is 0.4% per year until 2030.

The worldwide contribution of solar heat to the energy supply in 2030 may reach about 14 EJ and in 2050 about 97 EJ. The results for OECD Member States are 3,3 EJ in 2030 and 22,7 EJ in 2050, for Europe 1,9 EJ in 2030 and 12,9 EJ in 2050.

The world primary energy demand in the *IEA Reference Scenario*, in which government policies are assumed to remain unchanged from mid-2007, is projected to grow by 55% between 2005 and 2030, which relates to an average annual rate of 1.8%. The *IEA Alternative Policy Scenario* analyses the impact of the adoption of a set of policies and measures that governments around the world are currently considering to address energy security and climate change concerns. In this scenario, global primary energy demand will grow at a rate of 1.3% per year between 2005 and 2030 and will account for 11% less compared with the results of the *Reference Scenario*.

Based on this data, the installed collector area per inhabitant worldwide is about 1 m² in 2030 and 6 m² in 2050, in OECD Member States it is about 2 m² in 2030 and 10 m² in 2050 and in Europe about 2 m² in 2030 and 13 m² in 2050. The technical limit for building integrated collectors (roof and façade) may 10 m² collector areas per inhabitant when space for the installation of photovoltaic systems is taken into consideration.

The vision of the European Solar thermal Technology Platform (ESTTP) is to cover about 50% of the total heat demand in EU-25 in the long term (2050) using solar thermal, if the heat demand is first reduced by energy saving measures; Figure 8.

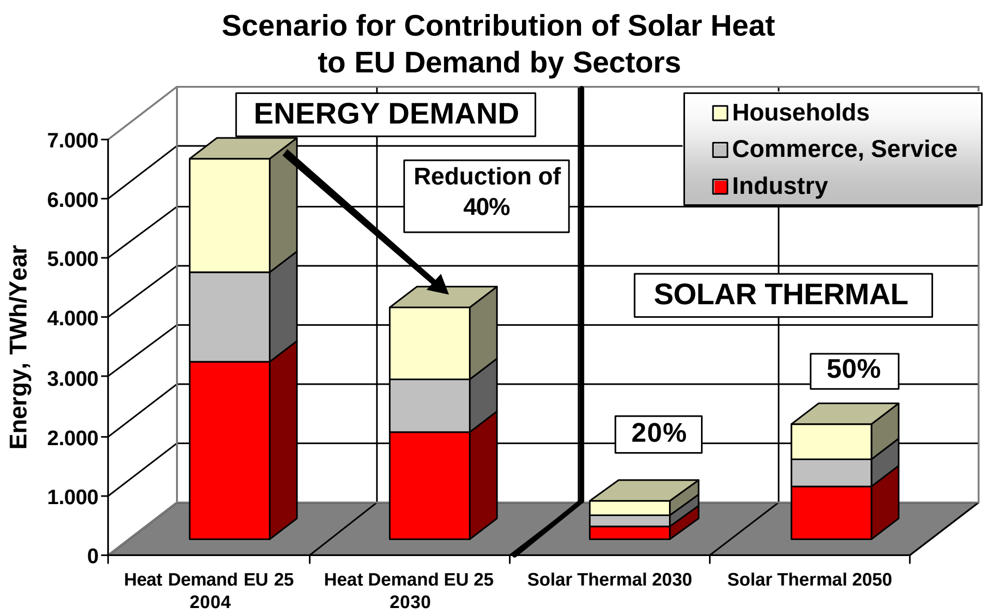


Figure 8: Contribution of solar thermal to EU heat demand by sector, assuming that the total heat demand can be reduced by energy conservation and a 40% increase in efficiency by 2030. *Source: AEE INTEC, 2008.*

8. Summary and Conclusion

Almost 50% of the final energy consumption in industrialized countries (OECD) is used for the heating needs of buildings, for domestic hot water production and for heating in industrial processes. Heat is the largest consumer of energy, being greater than electricity or transport. Renewable heating sources (solar thermal, biomass, geothermal) have a huge potential for growth and can replace substantial amounts of fossil fuels and electricity currently used for heating purposes.

Highly efficient, innovative and intelligent solar thermal energy systems providing hot water, space heating and cooling will be available, and will offer a high level of reliability and comfort. It may be estimated, that Active Solar Building - which is 100% heated and cooled by solar thermal energy - will be the building standard for new buildings, Active Solar Renovated Buildings will be heated and cooled by at least 50% with solar thermal energy. And Active Solar Renovation will be the most cost-efficient way to renovate buildings. The vision for the "Building of Tomorrow" is the "*Zero-Energy Building*", with the building envelope as solar collector and seasonal thermal heat storage.

Important limitations to expanding the use of technical potentials of solar resources for heat production are economics as well as the geographic distribution of the resource.

For a wide spread market deployment of solar thermal systems, it is necessary to store heat (or cold) efficiently for longer periods of time in order to reach high solar fractions, and therefore efficient and cost-effective compact storage technologies have to be developed. Alternative storage technologies, such as phase change materials (PCMs) and thermo chemical materials (TCMs), are still in the research and development stage.

Main reasons/arguments for solar thermal utilisation are:

- The energy need is large and growing.
- The solar resource is large and inexhaustible.
- The environmental and economic benefits are substantial.
- The potential of solar thermal systems in buildings is enormous:
  - 50% to 70% solar share for hot water preparation;
  - 40% to 60% of the heat supply (hot water and space heat) in low-energy houses.

Solar thermal systems - as with other renewable energy sources - provide significant local and global environmental benefits:

- Contribute to energy security and energy services at point of end use.
- Promote employment, and therefore contribute to sustainable economic development of nations.

The potential for solar thermal applications in the housing sector and industry will increase dramatically once suitable technical solutions are available to store the heat for the medium (daily) to longer (seasonal) term.

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