The Potential of Solar Thermal Technologies in a Sustainable Energy Future

Results from 32 Years of International R&D Co-operation

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IEA Solar Heating & Cooling Programme
www.iea-shc.org

The **Solar Heating and Cooling Programme** was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. A total of 49 Tasks have been initiated, 34 of which have been completed. Each Task is managed by an Operating Agent from one of the Member countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities – Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops – have been undertaken.

Current Members are Australia, Austria, Belgium, Canada, Denmark, European Commission, Germany, Finland, France, Italy, Mexico, Netherlands, Norway, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland and United States.

The Solar Heating and Cooling Programme, also known as the Programme to Develop and Test Solar Heating and Cooling Systems, functions within a framework created by the International Energy Agency (IEA).

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Key Points

- At the end of 2007, global capacity of solar thermal systems stood at 147 GWth [1], with an estimated output of 320 PJ of heat. Solar thermal is therefore the fourth largest renewable source of energy after biomass, hydro and wind.

- There is large potential for increasing the use of solar thermal for heating and cooling needs. Solar thermal provides only around 0.5% of estimated global water and space heating demand in the buildings sector, whereas the potential in the EU-27 in 2050 is around 47% of the overall low-temperature heat demand [2].

- Solar thermal technologies are mature and commercially available today. In areas with good solar insolation levels and competing fuel prices, these technologies can be very cost effective. However, further improvements in the technologies are possible and costs are projected to come down as the technology moves from niche to mass market deployment. Integration of solar thermal systems into building designs before construction starts offers the best opportunity to take advantage of solar thermal at low costs. Retrofitting is common, but is a more costly option and makes design and optimization of the system more challenging.

- New applications for process heat, cooling, district heating and desalination are entering the market. Solar thermal technologies for commercial and industrial processes have remarkable potential because the majority of the energy used in these processes is below 250°C, a temperature range well suited for solar thermal technologies. Application areas include food processing, textile cleaning and drying, pharmaceutical and biochemical processes, desalination, and the heating and cooling of factories.

- The key to boosting the contribution of solar thermal will be continuing to develop low-cost, highly efficient compact thermal storage technologies. This will allow more solar energy (simply by increasing collector area) to be captured in summer and stored for use in the winter. These technologies are not commercially available today, but are expected to be commercially available between 2020 and 2030.

- The current barriers to the uptake of solar thermal systems include misconceptions about performance and costs, a generally inadequate supply of qualified and experienced technicians/installers, poor economics in some regions, significant upfront costs, principal-agent problems, and lack of compact thermal storage.

- Addressing these barriers will require a wide range of policies. A key pre-requisite is an overall policy framework that provides an incentive to reduce CO2 emissions and create an environmentally sustainable resource thus ensuring that the least-cost options from different sectors and sub-sectors can compete. This will not be enough in itself, deployment policies (such as solar obligations) and additional R&D effort will also be required.

- R&D priorities are low-cost materials and components, improved building integration and optimization, and affordable compact storage technologies [3].

The Potential of Solar Thermal Technologies

The solar resource for solar heating and cooling technologies is large and "unlimited," therefore solar thermal systems for heating and cooling can be used in cold, temperate and mild climates. Solar energy is a local resource, reducing the external energy dependency for many countries.

Passive solar design of buildings is the simplest way to collect solar thermal energy. By using the position of the sun when designing a building, sunlight can be used for heating during the day and the mass of the building can radiate heat after the sun has set. To reduce cooling needs, buildings can be shaded (designed either to minimise direct sunshine in summer or all year round in hot climates) while employing natural ventilation and daylighting.

Active solar thermal systems use solar collectors. The heated fluid in the collectors is used either directly (e.g., to heat swimming pools) or indirectly with the use of a heat exchanger to transfer the heat to its final destination (e.g., space heating). Key applications for active solar thermal technologies are those that require low temperature heat. In the building sector, this means domestic hot water heating, space heating, swimming pool heating, and space cooling with heat driven cooling technologies. The amount of heat energy produced per square metre of collector surface area varies with design and location, but typically ranges from 300 to 900 $kWh/m^2/yr$.

Active solar thermal systems have numerous benefits that make them attractive solutions for meeting heating and cooling needs, including:

- The energy provided for heating or cooling is CO2 free and the life-cycle environmental impact of active solar thermal systems is extremely low.
- Solar energy is available in useful quantities nearly everywhere. Current limitations, for instance at high latitudes or in the case of limited space for heat storage, can largely be overcome through research and development.
- Active solar thermal systems lead to a reduction of primary energy consumption when replacing conventional technologies and can be combined with nearly all types of back-up heat sources.
- Predictable energy costs – the upfront capital costs represent the majority of delivered energy costs, removing uncertainty about the impact the evolution of energy prices have on the cost of hot water, space heating or cooling provision. Solar thermal systems therefore act as a hedge against future price increases.

The annual collector yield of all solar thermal systems in operation by the end of 2008 in the IEA SHC recorded countries is about 395 PJ. This corresponds to an oil equivalent of 12.4 million tons and an annual avoidance of 39.4 million tons of CO2.

Until now, solar thermal technology has not been a high priority, therefore only very limited financial resources have been allocated for R&D in this sector. The primary reason for this is that in many circles, solar thermal systems are regarded as a well-established, low-tech technology with little potential for development. 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 demonstrate that solar thermal technologies are dramatically underestimated.

Already impressive technological developments by industry, with support of the IEA Solar Heating and Cooling Programme, have been made. All components of solar thermal systems have been improved, new concepts have been introduced, and materials and new types of production have been developed. All these developments were carried out to increase efficiency, quality and life of the systems, and to reduce costs. An example of this is the *SolarCombisystem* (a solar thermal system for combined domestic hot water and space heating), this technology has been significantly improved for efficiency and reliability, for integration of the collectors into roofs and façades, and for system integration into conventional heating technology.

New applications also are entering the market for process heating, cooling, district heating and desalination. Solar thermal technologies for commercial and industrial processes have remarkable potential to support the contribution of solar thermal to energy consumption because the majority of the energy used in these processes is below 250°C, a temperature range well suited for solar thermal technologies. Application areas are food processing, textile cleaning and drying, pharmaceutical and biochemical processes, desalination, and heating and cooling of factories.

In summary, solar thermal energy can cover a substantial part of the world's energy use in a cost effective and sustainable way. Any long-term vision for economic development must include solar thermal technologies to save finite energy sources. Key to solar's growth is the willingness by governments, industry and all of us for the transition from fossil fuels to renewables.

By collaborating with others, the IEA SHC Programme is working to increase awareness of solar thermal energy's potential to contribute significantly to the future supply of energy worldwide.

This report supports the awareness to create a *Future Sustainable Energy System*, based on R&D results from more than 30 years of international co-operation in the IEA Solar Heating Programme.

The facts of our present energy supply – limited fossil resources, instability by political influence on the oil and gas market, greenhouse gas emission from fossil energy resources, environmental degradation – are serious arguments for creating a new energy system. *The main resources for a Future Sustainable Energy System will be renewables with solar thermal as a key contributor to the future energy supply*.

What is needed *now* is commitment by governments and industry to stimulate demand and significantly increase the use of emerging solar thermal technologies.

Annex 1

The Solar Resource

A1.1 Sun as an Energy Source

The sun as the source of solar radiation is a continuous fusion reactor. Several fusion reactions supply solar radiation as a form of energy conversion. The most important fusion reaction is a process in which hydrogen (protons) are fused into helium. The mass of the helium nucleus is less than that of the four protons of the hydrogen nucleus, mass having been lost in the reaction and converted into energy in the form of electromagnetic waves.

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 to achieve higher energy densities. By atmospheric scattering by air molecules, water and dust and atmospheric absorption by O3, H2O and CO2 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.

Solar radiation, absorbed on the earth's surface, is the source for the main energy resources including fossil energy sources (coal, oil and gas) in the form of "stored" solar energy in million of years, but limited in supply and therefore non-renewable.

Renewable energy sources (*Renewables*) are derived from natural processes that are replenished constantly at a rate equal to or greater then the rate of consumption. In its various forms, Renewables are derived directly or indirectly from the sun. Renewables come in many forms – electricity generated from solar, wind, biomass, geothermal, hydropower, and ocean sources; heat generated from solar thermal, geothermal and biomass sources; bio-fuels and hydrogen obtained from renewable sources. And, they are capable of supplying most of the world's energy needs and have the potential to support global economic development.

The solar resource for solar heating and cooling technologies is truly "unlimited". The contribution of solar produced heat depends on the number of possible installations.

A1.2 Solar Radiation on the Earth's Surface

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 using 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 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.

A1.3 Meteorological Data and Simulation Tool

Meteorological data from all parts of the world are used to simulate solar energy systems. For many regions, the measured data may only be applied within a 50 km radius of the collection station. This makes it necessary to interpolate parameters between stations.

Through existing data sets (e.g., METEONORM) it is possible to simulate solar energy systems in all parts of the world on a consistent basis. The interpolation errors are within the variations of climate from one year to the next.

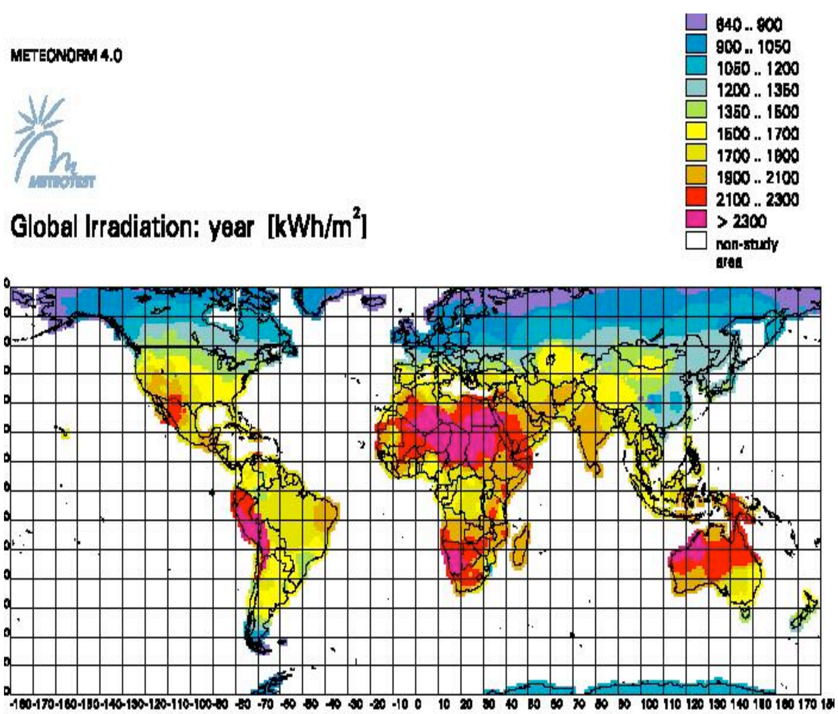


Figure 1.1 Annual global solar radiation. *Source: Richard Perez of the University of Albany, NY, USA, perez@asrc.cestm.albany.edu and Marc Perez of AltPOWER Inc., NY, USA, marc@altpower.com*

When designing solar thermal systems the knowledge of the solar energy resources in a geographical area is critical. However, good quality measurements of the solar resource are often expensive and scarce, and are time-consuming and costly to acquire so scientists from around the world are devising ways to assess the solar energy resource by using other data sources, such as weather satellite data.

The influence of available solar radiation in different climates on the heat output of solar thermal systems for hot water preparation in housing calculated with METEONORM is illustrated in Figure 1.2.

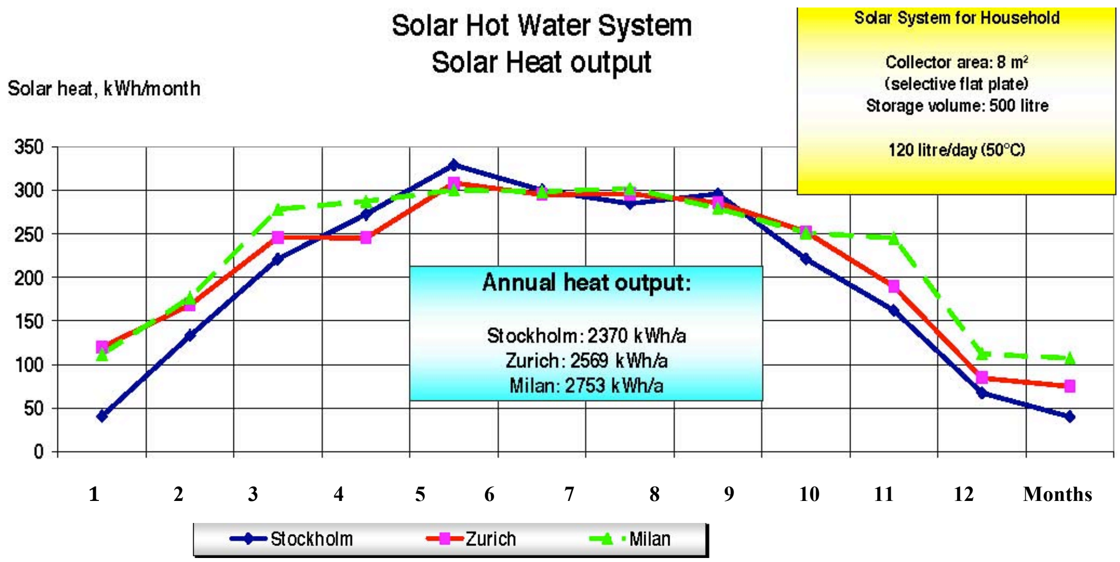


Figure 1.2 Heat output of solar thermal system for hot water preparation in cold (Stockholm), temperate (Zurich) and mild (Milan) climates.
Source: Gerhard Faninger: IEA SHC Task 28, Solar Sustainable Housing

A1.4 Solar Radiation and Energy Sources

Solar radiation, absorbed on the earth's surface, is the source for the main energy resources. Fossil energy sources (coal, oil and gas) are "stored" solar energy in million of years, but limited in resources and therefore non-renewable. Renewable energy sources (*Renewables*) are derived from natural processes that are replenished constantly at a rate equal to or greater then the rate of consumption. In its various forms, *Renewables* derives directly or indirectly from the sun. Renewables come in many forms: electricity generated from solar, wind, biomass, geothermal, hydropower, and ocean sources; heat generated from solar thermal, geothermal and biomass sources; bio-fuels and hydrogen obtained from renewable sources. Therefore, renewables are capable supplying most of world's energy needs and have the potential to support global economic development.

The three-dimensional rendering in Figure 1.3 compares the current annual energy consumption of the world to (1) the known reserves of the finite fossil and nuclear resources and (2) the yearly potential of the renewable alternatives. The volume of each sphere represents the total amount of energy recoverable from the finite reserves and the energy recoverable per year from renewable sources.

This direct side-by-side view shows that the renewable sources are not all equivalent. The solar resource is orders of magnitude larger than all the others combined. Wind energy could probably supply all of the planet's energy requirements if pushed to a considerable portion of its exploitable potential. However, none of the others – most of which are first and second order by-products of the solar resource – could, alone, meet the demand. Biomass in particular could not replace the current fossil base – the rise in food cost paralleling the recent rise in oil prices and the resulting increase in the demand for biofuels is symptomatic of this underlying reality. On the other hand, exploiting only a very small fraction of the earth's solar potential could meet the demand with considerable room for growth.

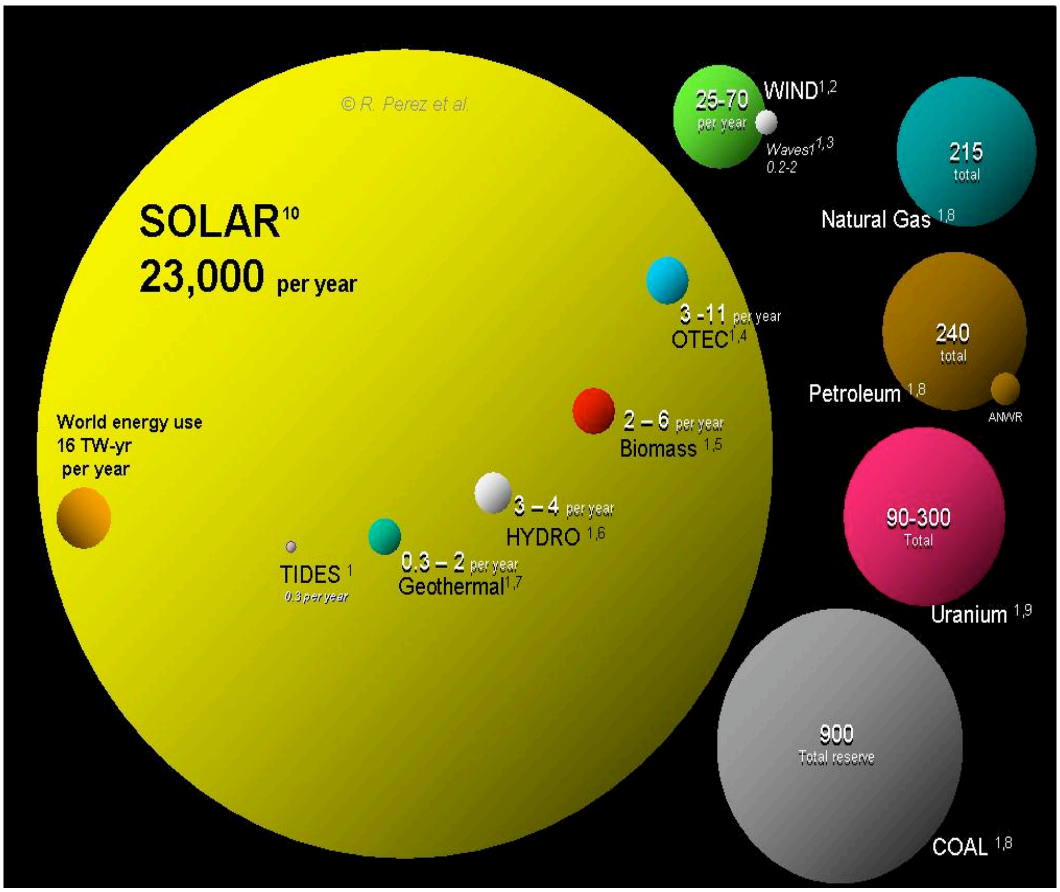


Figure 1.3 The power of solar energy comparing finite and renewable planetary energy reserves (in TWh/year). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables. *Source: Richard Perez of the University of Albany, NY, USA; Marc Perez of AltPOWER Inc., NY, USA*

While coal reserves are vast, they are finite and will last at most a few generations if this became the predominant fuel, notwithstanding the environmental impact that would result from such exploitation if now elusive clean coal technologies do not fully materialize. Nuclear energy is not the global warming silver bullet. Reserves of uranium are large, but they are far from limitless. Putting aside the environmental and proliferation unknowns associated with this resource, there would simply not be enough nuclear fuel to take over the role of fossil fuels – the rise in the cost of uranium that paralleled and even exceeded that of oil from 1997 to 2007 is symptomatic of this reality. Of course this statement would have to be revisited if an acceptable breeder technology or nuclear fusion became deployable. Nevertheless, short of fusion itself, even with the most speculative uranium reserves scenario and assuming deployment of advanced fast reactors and fuel recycling, the total finite nuclear potential would remain well below the one-year solar energy potential.

In conclusion, logic alone indicates that the energy future will be solar-based. There will of course be challenges managing this local, but globally stable and predictable resource. In particular, developing the necessary storage technologies and infrastructures. Solar energy – as embodied by dispersed PV and Concentrated Solar Power (CSP) – is the only quasi-ready-to-deploy resource that is both large enough and acceptable enough to carry the planet for the long haul.

Annex 2

Solar Thermal Technologies: Applications and Attractiveness

A2.1 Solar Thermal Collectors

Collectors are the most important 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 mainly 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 2,500 annual sunshine hours.

The simplest design of a *non-concentrating collector* is the *flat plate collector*. The properties of this collector are well known and they are manufactured in many parts of the world. As absorbers, black painted metal (copper, aluminum, 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 temperatures up to 80°C with conversion efficiency of about 50-60% can be achieved. Applications are swimming pool heating, water heaters, agricultural drying, desalination, space heating. For temperatures above 100°C advanced designs, like some *evacuated tube* and *CPC collectors* have been developed.

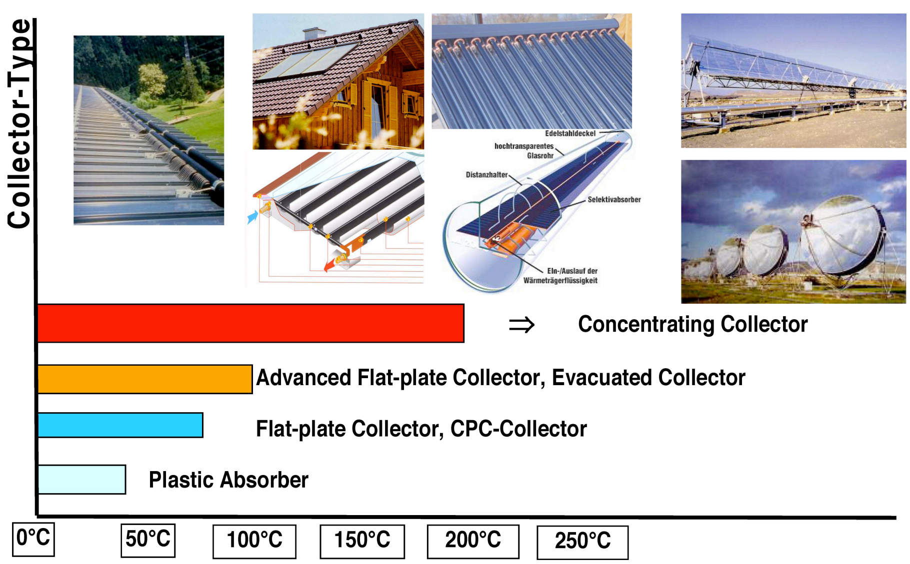


Figure 2.1 Collector Types and Working Temperatures for Solar Thermal Systems.

Solar collectors should be integrated in the building envelope (roof, façade) and when doing so it is essential to take into consideration architectural rules and local building traditions. Building integrated collectors are illustrated in Figure 2.2. façade collectors are used in urban buildings, where sufficient, suitable and oriented roofs for the installation of solar collectors is not available. A collector element directly integrated in the façade acts as both a solar collector and a heat insulation of the

Figure 2.2. Solar thermal systems for low to medium heat production.

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. There are two types of concentrators, the linear focusing and the point focusing concentrator.

A2.2 Applications for Solar Thermal Systems

Solar thermal technologies can be used almost anywhere in the world. A large variety of solar thermal components and systems, mostly for residential applications, are commercially available. These products are reliable and show a high technical standard for low temperature demand.

Key applications for solar thermal technologies are those that require low temperature heat, such as for domestic hot water heating, space heating, drying processes, water processes for industrial heating and swimming pools. Solar energy also can meet

Solar thermal technologies are appropriate for all building types – single-family homes, multifamily residences, office and industrial buildings, schools, hospitals, and other public buildings.

Solar heating and cooling (SHC) includes technologies and designs that use active and passive technologies and designs for solar water heating, solar space heating, cooling, daylighting, and agricultural and industrial process heating. *Solar water heating*, including pool heating, has been commercially available for over 30 years, and can be considered a mature technology. 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 cost as well as special requirements for its application (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.

Under typical meteorological conditions in temperate climates, the annual solar share for hot water preparation – considering also economical aspects and dependence on the daily hot water demand – should be in the range of about 60-70% for single-family houses, and during the summer about 60-90% (see Figure 2.3a). In multifamily houses and apartment buildings, the solar share for hot water preparation will generally be below 50% due to limited space for the collectors.

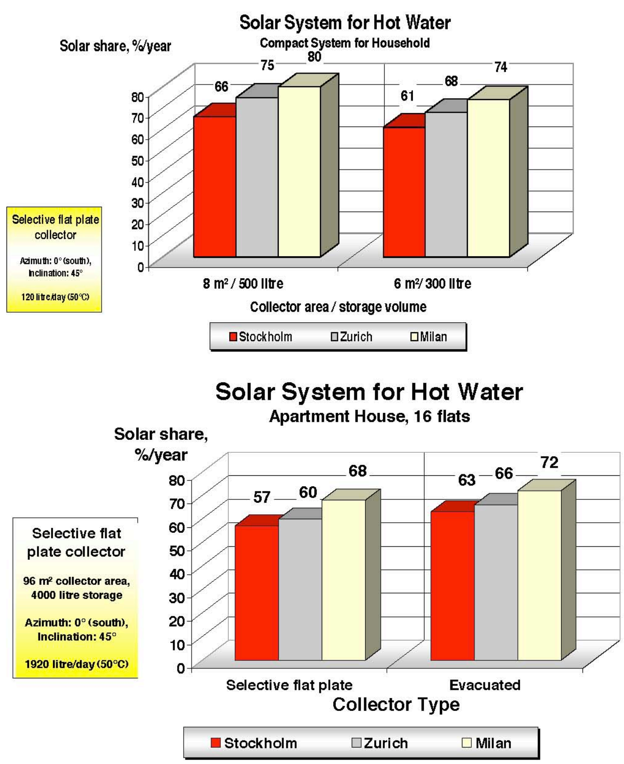


Figure 2.3a Solar thermal systems for hot water preparation in cold (Stockholm), temperate (Zurich), and mild (Milan) climates. *Source: Gerhard Faninger: IEA-SHC Task 28 "Sustainable Solar Housing*

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. However, there are two major difference, the installed collector area is generally larger for *SolarCombisystems* and the 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 and profoundly affects the overall performance of the solar part of the system.

In high latitudes, the solar energy available in summer is more than twice that available in winter. Virtually the opposite applies to the energy demand for space heating. In comparison to hot water supply, the heating load is dependent on the outside temperature. Measurements of solar irradiation and temperature in the transitional periods (September to October and March to May) clearly show that solar irradiation availability is relatively high at the beginning and end of the space heating season. Even on winter days, energy demand and solar irradiation are partially related. To make efficient use of the available solar energy supply, it is necessary to use storage systems to even out the fluctuations in the solar radiation and provide a continuous supply of hot water and a constant room temperature. Currently, installed systems clearly show that solar space heating is possible even under temperate (Middle Europe) and northern climatic conditions (see example in Figure 2.3b).

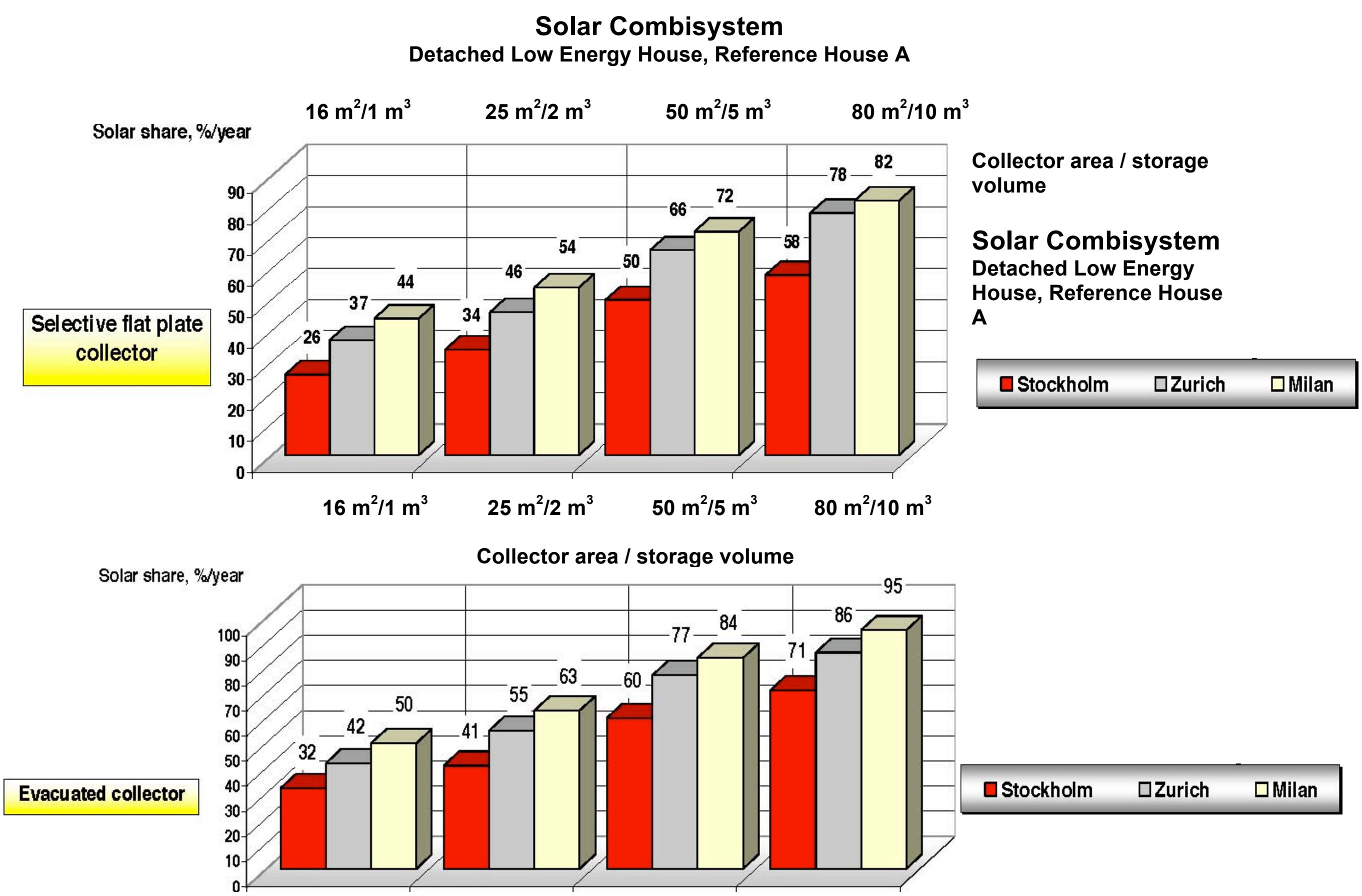


Figure 2.3b Solar thermal systems for hot water preparation and space heating in cold (Stockholm), temperate (Zurich), and mild (Milan) climates.
Source: Gerhard Faninger: IEA-SHC Task 28, Sustainable Solar Housing

The solar contribution, that is the part of the heating demand met by solar energy, varies from 10% for some systems up to 100% for others depending on the size of the solar collector field, the storage volume, the hot water consumption, the heat load of the building and the climate.

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.

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.

Daylighting designs have matured to the point where they can provide significant economic benefits through reduction of electricity demand – especially in offices -and are expected to gain in use in new commercial buildings. The daylighting systems allow for significant dimming of the lights resulting in energy savings ranging from 50% to 70% for the south and west facing windows. Examples are Illustrated In Figure 2.4.

Figure 2.4: Daylighting Systems for commercial Buildings

The majority of the energy used by commercial and industrial companies is below 250°C, a temperature range perfect for solar technologies. 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.

Continued development of high performance collectors and system components will improve the cost effectiveness of higher temperature applications.

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.

A2.3 Market Situation for Solar Thermal Applications

The market for low-to medium-temperature solar applications is well established, and applications for industrial process heat and cooling are entering markets today as a result of international R&D by the IEA and EU Member States.

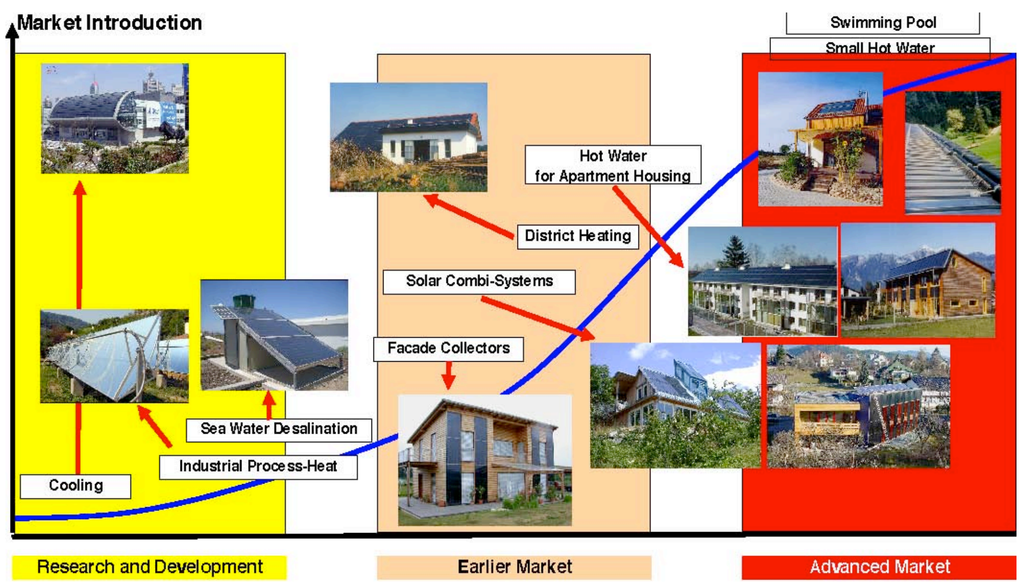


Figure 2.5: Market development of solar thermal systems *From Research and Development to Earlier and Advanced Market*

Solar thermal systems with concentrating collectors to produce high-temperature heat will be used in the near term for niche industrial applications, such as detoxification of hazardous wastes and the testing and treatment of materials.

A2.4 The Attractiveness of Solar Thermal Systems

Solar energy is the most abundant and widely distributed renewable energy resource in the world, and can be used everywhere. Solar energy provides a non-polluting energy source for heating, cooling, and hot water in building and displaces environment unfriendly sources. Solar thermal technologies are essential components of a sustainable energy future.

Over 75% of the energy used in single and multi-family homes is for space heating and hot water preparation. Solar energy can meet, with existing technologies, up to 70-80% of this heating demand depending on the climate.

Office building energy bills are the highest of any commercial building type. The energy demand for heating, ventilation, air conditioning, and lighting account for approximately 70% of a building's energy use.

Buildings using solar energy have remarkable advantages – require less energy, cause less adverse environmental impacts, provide open sunlight and high quality space, improve building aesthetics, and provide new medium for architectural expression.
Reliable, low cost technologies combined with strong marketing strategies will push solar further into the main building market. Sustainable, solar assisted low-energy solar houses are a growing part of the housing industry. Their technical performance is no longer in question so how they are marketed is critical.

There is not only great potential to substitute fossil fuels with solar heat in buildings, but also in the industrial sector including agriculture (e.g., crop drying in developing countries).

Annex 3

Solar Heat Worldwide [1]

A3.1 Solar Thermal Capacity in Operation 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 CO2 emissions. At the end of 2007, the installed solar thermal capacity worldwide equaled 146.8 GWth or 209.7 million square meters. The breakdown by collector type is: 120.5 GWth flat-plate and evacuated tube collectors, 25.1 GWth unglazed plastic collectors and 1.2 GWth air collectors.

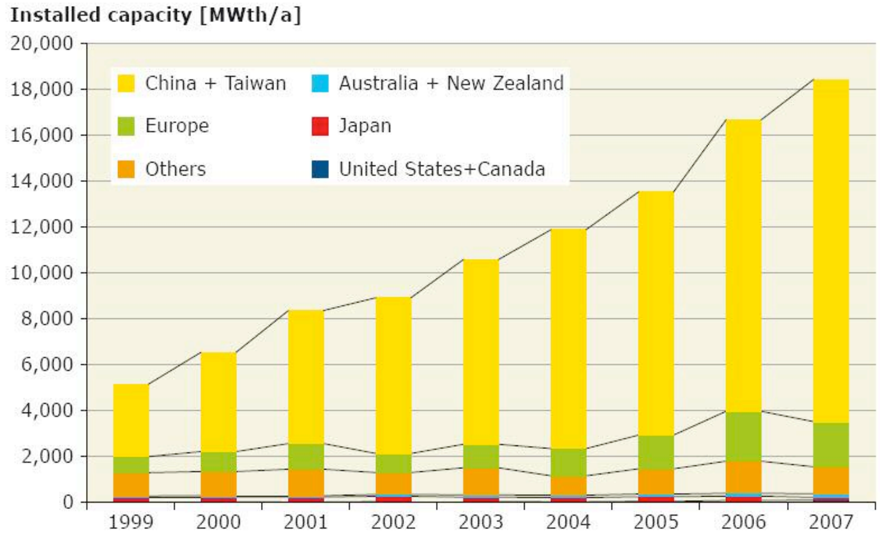
A3.2 Distribution by Application

The use of solar thermal energy varies greatly by country. In China and Taiwan (80.8 GWth), Europe (15.9 GWth) and Japan (4.9 GWth), 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 GWth 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.

In Austria, Germany, Switzerland and the Netherlands the share of applications other than hot water preparation in single-family houses is 20% and higher than in other European countries. There are about 130 large-scale plants (500m^2; 350 kWth) in operation in Europe with a total installed capacity of 140 MWth. The biggest plants for solar assisted district heating are located in Denmark with 13 MWth (18,300 m^2) and Sweden with 7 MWth (10,000 m^2). The biggest reported solar thermal system for providing industrial process heat was installed in 2007 in China. This 9 MWth (13,000 m^2) plant produces heat for a textile company.

A3.3 Leading Countries

Flat-plate and evacuated tube collectors
Based on the total capacity of flat-plate and evacuated tube collectors in operation at the end of the year 2007, the leading countries are: China (79.9 GWth), Turkey (7.1 GWth), Germany (6.1 GWth), Japan (4.9 GWth) and Israel (3.5 GWth). Followed by: Brazil (2.51 GWth), Greece (2.50 GWth), Austria (2.1 GWth), the USA (1.7 GWth) and India (1.5 GWth). As can be seen China is by far the largest market, representing 66% of the world market of flat-plate and evacuated tube collectors. Here it should also be mentioned that China again increased its market share by 2% in 2007. Based on the market penetration – total capacity in operation per 1,000 inhabitants – the leading countries are Cyprus (651 kWth), Israel (499 kWth), Austria (252 kWth), Greece (224 kWth) and Barbados (197 kWth). Followed by: Jordan (100 kWth), Turkey (95 kWth), Germany (73 kWth), China (60 kWth) and Australia (57 kWth).



Europe: EU-27, Albania, Macedonia, Norway, Overseas Departments of France, Switzerland;
Others: Barbados, Brazil, India, Israel, Jordan, Mexico, Namibia, South Africa, Thailand, Tunisia and Turkey

Figure 3.1 Annual installed capacity of flat-plate and evacuated tube collectors from 1999 to 2007.

Unglazed plastic collectors
For the heating of swimming pools using unglazed plastic collectors, the USA leads with a total capacity of 19.3 GWth in operation ahead of Australia with 2.8 GWth, Germany and Canada with 0.5 GWth each, and Austria and South Africa with 0.4 GWth. The market penetration – total capacity in operation per 1,000 inhabitants – gives a slightly different picture. The lead countries are: Australia leads with 137 kWth ahead of the USA with 63 kWth and Austria with 51 kWth per 1,000 inhabitants. Followed by: Switzerland, the Netherlands and Canada with an installed capacity between 20 and 14 kWth per 1,000 inhabitants.

A3.4 Installed Capacity in 2007

In the year 2007, a new capacity of 19.9 GWth corresponding to 28.4 million square meters of solar collectors was installed worldwide. The number of new installations increased 8.7% compared to 2006. This represents a decrease of the growth rate compared to 2005/2006 when the market grew 22%. The main reasons for this were the market slumps of unglazed plastic collectors in the USA and of flat plate and evacuated tube collectors in Germany.

It is remarkable that the global market of evacuated tube collectors grew 23.4% compared to the year 2006, whereas the markets of flat plate collectors and unglazed collectors decreased 18.3% and 7.2% respectively.

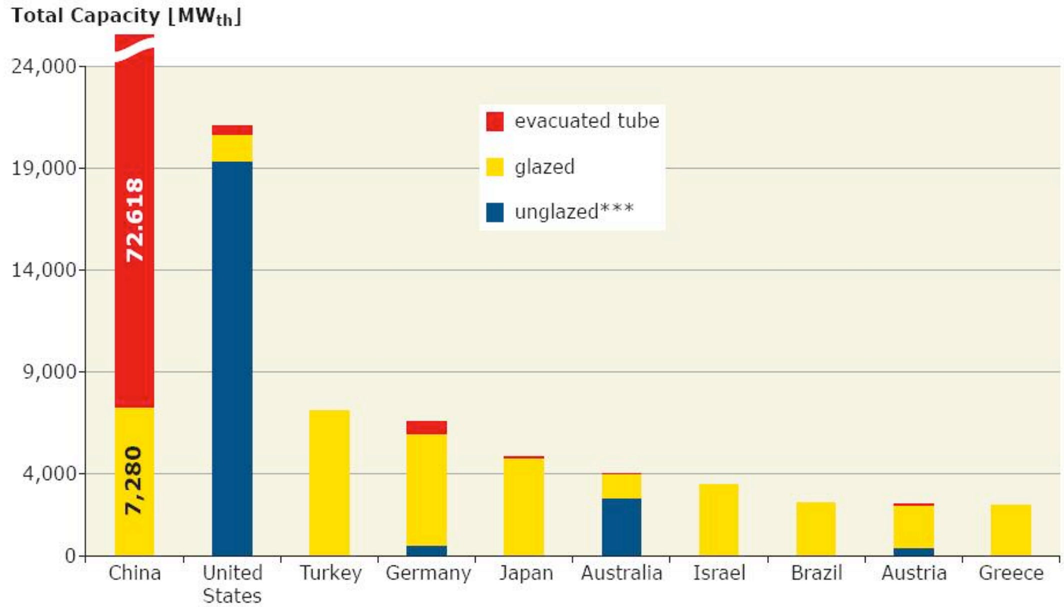
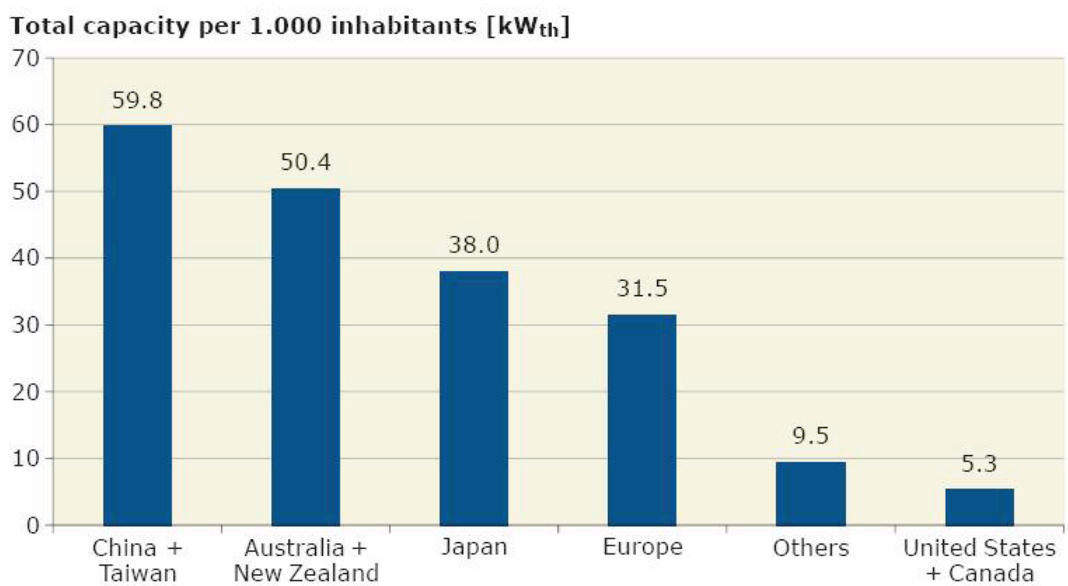


Figure 3.2: Total capacity in operation of water collectors of the 10 leading countries at the end of 2007.



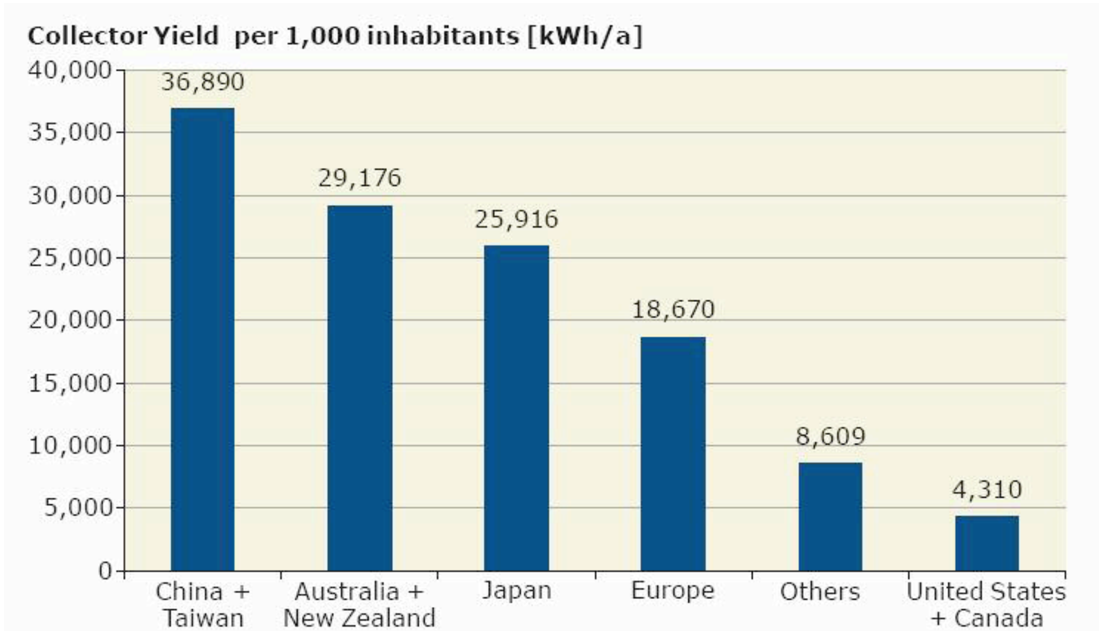


Figure 3.3: Total capacity and collector yield of glazed flat-plate and evacuated tube collectors in operation by economic region at the end of 2007 in kWth and kWha per 1,000 inhabitants.

A3.5 Market Development

The most dynamic markets for water collectors (unglazed, flat-plate and evacuated tube collectors) in Europe with growth rates near and above 100% compared to the capacity installed in 2006 were: Hungary 700%, Ireland 293%, Slovak Republic 200%, UK 93% and Portugal 80%. Outside of Europe, large market growth rates were seen in: Namibia 74.5%, Mexico 60% and Brazil 32%. In China, the world's largest market, the number of new installations increased in 2007 by 17.4% compared to 2006.

The main markets for flat-plate and evacuated tube collectors worldwide are in China and Europe as well as in Australia and New Zealand. The average annual growth rate between 1999 and 2007 was 23.6% in China, 20% in Europe, 26% in Canada and the USA and 16% in Australia and New Zealand. Although the installed capacity of flat-plate and evacuated tube collectors in the USA is very low compared to other countries, especially with regard to USA's large population, the market for new installed glazed collectors has been growing significantly in the recent years. The worldwide market of unglazed collectors for swimming pool heating recorded an increase between 1999 and 2002 and a slight decrease in 2003. After a slight increase from 2004 to 2006, the installed capacity rate declined again in 2007. The main markets for unglazed collectors can mainly be found in the USA (0.79 GWth) and Australia (0.4 GWth). South Africa, Canada, Germany, Mexico, The Netherlands, Sweden, Switzerland, Belgium and Austria also have notable markets, but all with values below 0.1 GWth of new installed unglazed collectors in 2007.

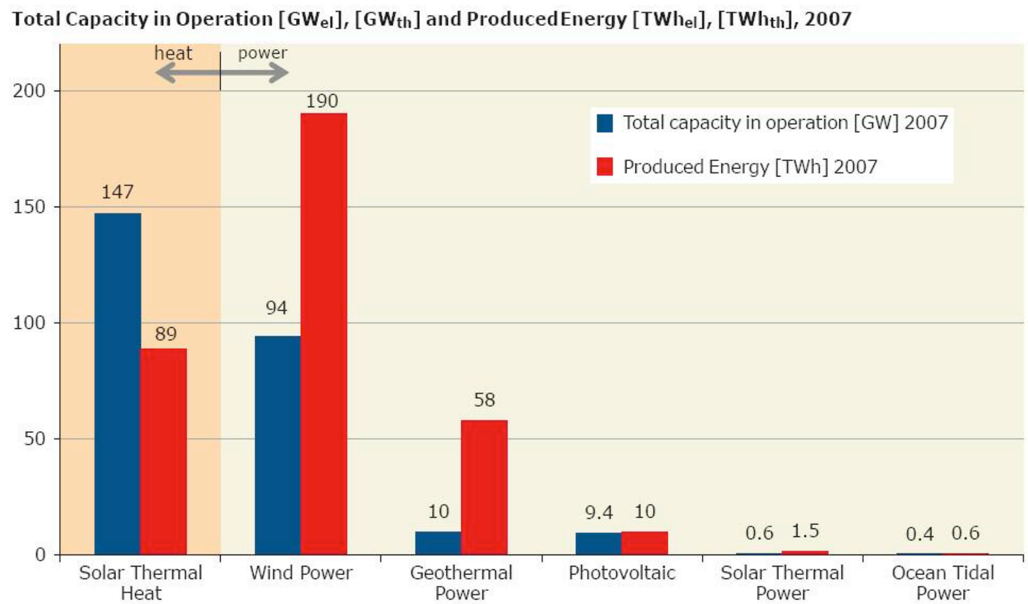


Figure 3.4: Total capacity in operation (GWel and GWth) 2007 and annually energy generated (TWhel and TWhth)
Sources: EPIA, GEWC, EWEA, EGEC, REN21 and IEA SHC 2

Annex 4

The Potential of Solar Thermal Technologies

A4.1 Primary Energy for Heat Supply

More than half of the worldwide primary energy is used for low-to medium-temperature heat, and about one third of the OECD primary energy is needed for heat devices in buildings. And, housing accounts for the greatest part of this energy use. Renovating existing housing offers an enormous energy saving potential, and it is the only strategy that can achieve a substantial reduction in energy use in the housing sector in the short-term. This figure reflects the potential for solar thermal technologies as the main technology to replace traditional fuels used for heating and cooling.

A wide range of low-temperature solar-heat collectors and systems, mostly for residential applications, have been available on the market for decades. These products are now fairly reliable, usually built to a high technical standard.

A4.2 Solar Heating

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 from 50% to 70% for hot water preparation and 40% to 60% for space heating. *Daylighting* 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 long (seasonal) term. Such advanced storage systems could utilize chemical and physical processes to reduce the total storage volume and the related costs.

A4.3 Solar Cooling

Solar assisted cooling is an extremely promising technology as peak cooling consumption coincides with peak solar radiation. Now it is necessary to support its commercialization and continued R&D.

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 dominant 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 five years, the development of technical solutions has been initiated primarily by small and medium-scale enterprises. Very promising small capacity water chillers using sorption technology have opened a new market for use of solar thermal energy as a driving heat source for summer air conditioning. And, many new system solutions for large capacity chillers have been developed providing solar heat driven building air-conditioning.

A4.4 Solar Process Heat

Process heat accounts for about 40% of the primary energy supply in the OECD. The major share of the energy needed by commercial and industrial companies for production and processing and for the heating of production halls is below 250°C. This low temperature level can easily be reached using solar thermal collectors already on the market.

Typical applications 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 efficiently in this temperature range.

Cleaning processes are mainly applied in the food and textile industries 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. 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. Summarizing, about 30% to 40% of the process heat demand could be covered with low to medium temperature solar collector systems.

A4.5 Future Options for Solar Thermal Systems

Solar thermal systems have the potential to substitute oil and gas for heating and cooling - 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 “unlimited”. Being not very optimistic, it is estimated that about 30% to 40% of the worldwide heat demand could be covered by solar produced heat, and in Europe about 20% of the demand for heat supply (ESTIF estimated that this percentage may reach up to 50%). With these assumptions, the useful in the long-term (2050) about 60 EJ to 100 EJ/year worldwide and 10 EJ to 20 EJ/year in OECD Member States.

A4.6 Scenario for the Market Deployment of Solar Thermal Collectors

The solar thermal market scenario illustrated in Table 4.1 starts with 2006 and the assumption of an average growth of the 2006 installed collector area by 15% per year from 2006 to 2010, 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 assume a 25-year lifetime for the thermal systems.

SOLAR THERMAL COLLECTOR MARKET			
WORLDWIDE			
Collector, installed 2006		**Collector, in operation 2006**	
million m•	**Capacity, GW*(thermal)***	**million m•**	**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 m•	**Capacity, GW*(thermal)***	**million m•**	**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 m•	**Capacity, GW*(thermal)***	**million m•**	**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 m•/year	**million m•**	**GW$_{thermal}$**	**EJ**	**million**	**m•/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	2970	58153	40707	96,720	9916	5,865
OECD						
Year	**Yearly installed**	**In operation**			**Population**	**Collector/Inhabitant**
	million m•/year	**million m•**	**GW$_{thermal}$**	**EJ**	**million**	**m•/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 m•/year	**million m•**	**GW$_{thermal}$**	**EJ**	**million**	**m•/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 4.1. Results of scenario for the worldwide market deployment of solar thermal collectors
Source: Gerhard Faninger, IEA SHC 2009.

The worldwide contribution of solar heat to the energy supply in 2030 will 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. Table 4.1 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.*

POPULATION: 2006 and Estimates for 2030 and 2050				
REGION	2006 million	Annual Average Growth Rate %/year	2030 million	2050 million
WORLDWIDE	6400	1,0%/year	8126	9916
OECD	1150	0,4%/year	1266	1371

WORLD PRIMARY ENERGY DEMAND, TPES						
2005 and Estimates for 2030 and 2050						
		IEA Reference Scenario				
		Average Annual Growth rate	2030		2050	
		%/year	Mtoe	EJ	Mtoe	EJ
2005		1.8%	17721	741,766	25056	1048,794
Mtoe	EJ	IEA Alternative Policy Scenario				
11429	478,395	Average Annual Growth rate	2030		2050	
		%/year	Mtoe	EJ	Mtoe	EJ
		1.3%	15783	660,645	20176	844,527

SOLAR YIELDS: Conversion Factors
WORLDWIDE
1 m• collector = 0,7 kW (thermal), 1 m• collector area = 462 kWh/year
1 million m• collector = 0,7 GW (thermal), 1 million m• collector area = 462 GWh/year, 1 GWh = 3,6 TJ
1 GWh (thermal) = 0,162 billion liter oil-equivalent, 1 GWh (thermal) = 0,443 million tons CO_2
OECD/EUROPE
1 m• collector = 0,7 kW (thermal), 1 m• collector area = 350 kWh/year
1 million m• collector = 0,7 GW (thermal), 1 million m• collector area = 350 GWh/year, 1 GWh = 3,6 TJ
1 GWh (thermal) = 0,162 billion liter oil-equivalent, 1 GWh (thermal) = 0,443 million tons CO_2
1 Mtoe = $4.1858*10^{-2}$ EJ = $4.1858*10^{4}$ TJ = $1.163*10^{4}$ GWh

Table 4.2. Estimates for population and energy demand. Conversion factors for solar yields

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, see Table 4.2.

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*.

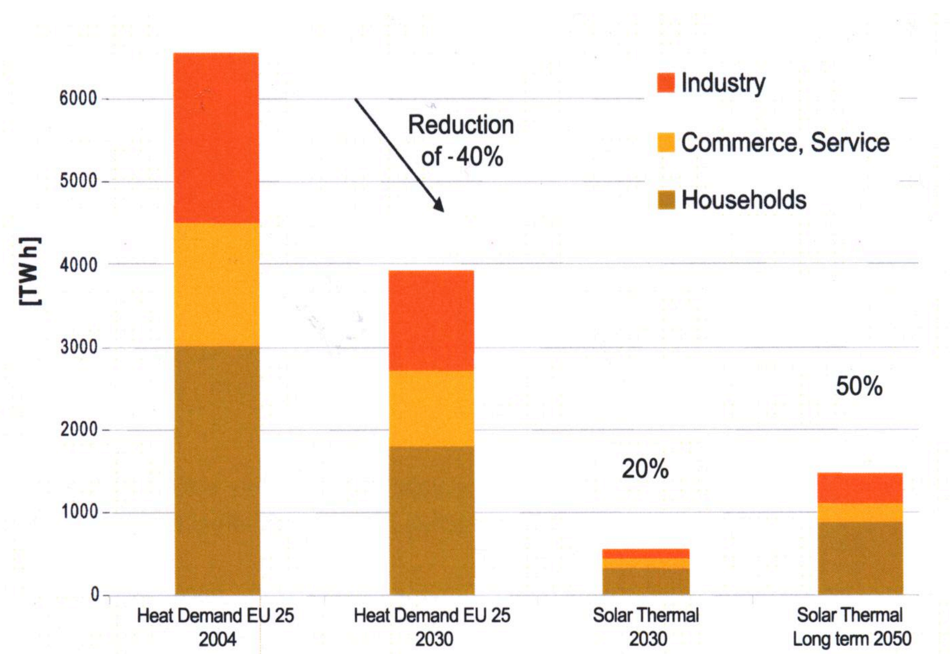
Based on this data, the installed collector area per inhabitant worldwide is about 1 m² in 2030 and 6 m² in 2050, in OECD Member States it is about 2 m² in 2030 and 10 m² in 2050 and in Europe about 2 m² in 2030 and 13 m² in 2050. The technical limit for building integrated collectors (roof and façade) is 10 m² collector area 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, see Figure 4.1 and Figure 4.2. The assumption in the *"Full R&D and Policy Scenario (RDP)"* are 1) significant reduction of the heat demand, compared to 2006 (-10% by 2020, -20% by 2030 and -30% by 2050), 2) full political support mechanisms -solar obligations for all new and existing residential, service and commercial buildings as well as for low temperature industrial applications, 3) high energy prices of fossil energy carriers, 4) high R&D rate and therefore solutions for cost efficient high energy density heat stores and new collector materials, 5) sufficient and cost competitive solutions for solar thermal cooling available by 2020, 6) main focus on *SolarCombisystems* for combined hot water preparation and space heating in the residential sector, 7) *SolarCombisystems* with low solar fraction (10% to 20%) until 2020 and high solar fraction (50% to 100%) from 2020, 8) substantial market diffusion in all other sectors, and 9) high growth rate of installed capacity (~25% per annum until 2020).

The scenarios start with the heat demand for heating in cooling in EU 27 in the year 2006 with 6,629 TWh/year (23.96 EJ/year), from which about 70% amount to low-temperature heat demand: 4,640 TWh/year (16.7 EJ/year).

In the *"Full R&D and Policy Scenario (RDP)"* the low-temperature heat demand will be 4,297 TWh (15.47 EJ) in 2020, 3,787 TWh (13.63 EJ) in 2030 and 3,271 TWh (11.78 EJ) in 2050. With the expected installed collector area of 3,880 million m2 (2,700 GWth installed capacity) solar heat of about 1,552 TWh (5.59 EJ) will be produced in 2050. The solar share to the low-temperature heat demand in 2050 will amount to about 48%. The results of the calculations are illustrated in Figure 4.2.

For the full report, go to www.estif.org.



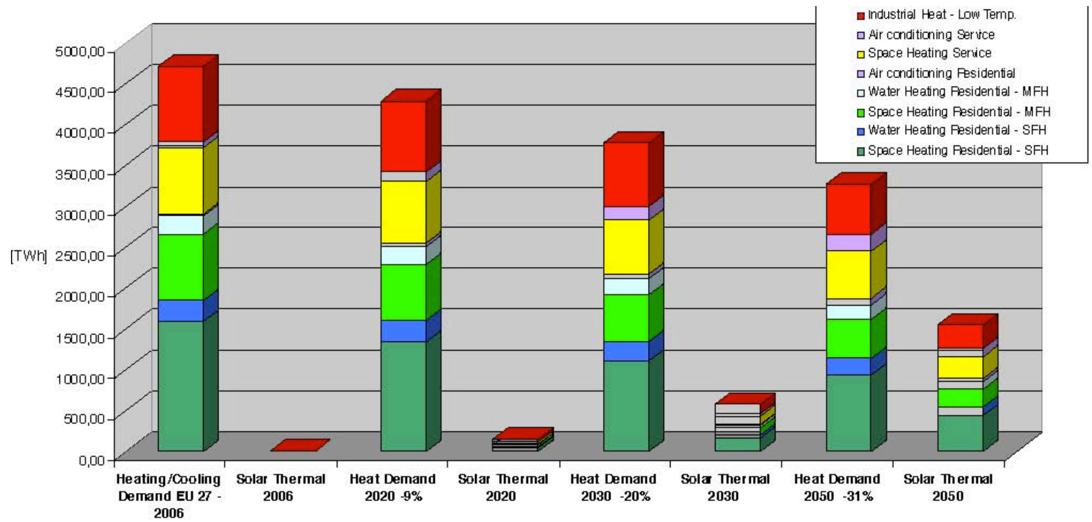


Figure 4.2: Total heating and cooling demand of EU 27 and contribution of solar thermal by sector according to the Full R&D and Policy Scenario (RDP) assuming the heat demand can be reduced by 31% by 2050 *Source: Weiss, W., Biermayr, P.: Potential of Solar Thermal in Europe, ESTIF 2009*

Annex 5

The Role of Solar Thermal Technologies to Create a Sustainable Energy Future

Almost 50% of the final energy consumption in OECD countries 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, 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. The 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. Solar Renovation will be the most cost-efficient way to renovate buildings. The vision for the "Building of Tomorrow" the "*Zero Energy Building*" with the building envelope as solar collector and seasonal thermal heat storage (see Figure 5.1).

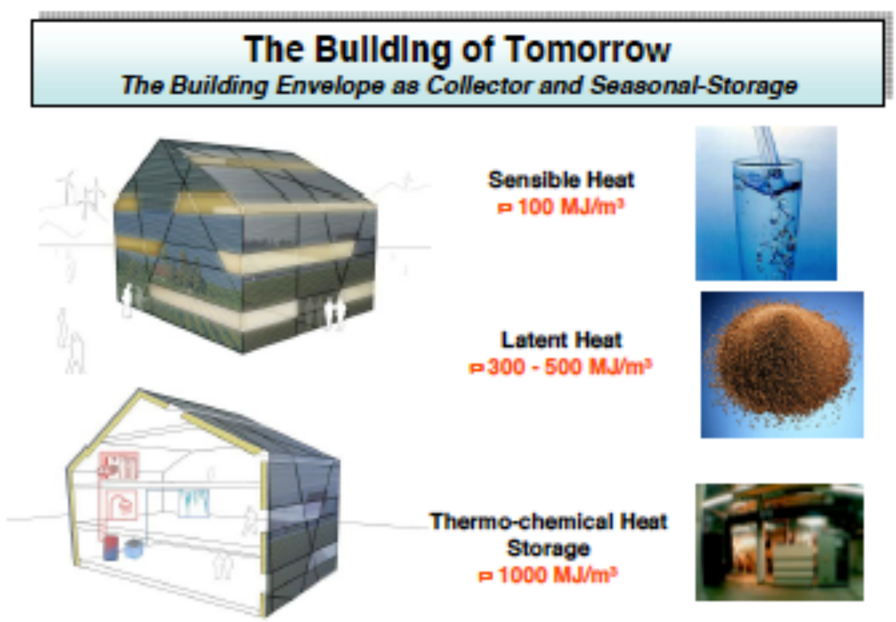


Figure 5.1. The Vision for the „Building of Tomorrow".

About 30% of the end energy demand in OECD countries originates in the industrial sector. Many industrial processes require heat on a temperature level below 250°C.

Solar thermal energy will play an important role in all segments where heat of up to 250 °C is used.

It is expected by the IEA SHC Programme and the SHC community that in the coming years solar thermal will become the most important source of energy for heating and cooling buildings and will play an important role in providing (industrial) process heat.

Solar thermal energy offers the availability to cover a substantial part of the OECD energy use in a cost effective and sustainable way. Based on the present state of the technology, the perspectives for further technological developments and the combination with price developments for traditional fuels as a result of scarcity and environmental cost, a plausible assumption can be made that over the next 25 years energy needed for heating and cooling in the OECD could be reduced around 50% through a mix of energy savings, energy efficiency and solar thermal.

It may be estimated that about 30% to 40% of the worldwide heat demand could be covered by solar produced heat, and in the OECD about 20% of the demand for heat supply.

For 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.

Annex 6

SHC Projects &Lead Countries

Task 1	Performance of Solar Heating and Cooling Systems, 1977-83 (Denmark)
Task 2	National Solar R & D Programs & Projects, 1977-84 (Japan)
Task 3	Solar Collector and System Testing, 1977-87 (Germany and United Kingdom)
Task 4	Insolation Handbook and Instrumentation Package, 1977-80 (United States)
Task 5	Existing Meteorological Information for Solar Applications, 1977-82 (Sweden)
Task 6	Evacuated Tubular Collector Performance, 1979-87 (United States)
Task 7	Central Solar Heating Plants with Seasonal Storage, 1979-89 (Sweden)
Task 8	Passive Solar Low Energy Homes, 1982-89 (United States)
Task 9	Solar Radiation and Pyranometry, 1982-91 (Canada and Germany)
Task 10	Solar Materials R & D, 1985-91 (Japan)
Task 11	Passive Solar Commercial Buildings, 1986-91 (Switzerland)
Task 12	Solar Building Analysis Tools, 1989-94 (United States)
Task 13	Advanced Solar Low Energy Buildings, 1989-94 (Norway)
Task 14	Advanced Active Solar Systems, 1990-94 (Canada)
Task 15	Advanced Central Solar Heating Plants, not initiated
Task 16	Photovoltaics for Buildings, 1990-95 (Germany)
Task 17	Measuring and Modeling Spectral Radiation, 1991-94 (Germany)
Task 18	Advanced Glazing Materials, 1991-97 (United Kingdom)
Task 19	Solar Air Systems, 1993-99 (Switzerland)
Task 20	Solar Energy in Building Renovation, 1993-98 (Sweden)
Task 21	Daylight in Buildings, 1995-99 (Denmark)
Task 22	Building Energy Analysis Tools, 1996-03 (United States)
Task 23	Optimization of Solar Energy Use in Large Buildings, 1997-02 (Norway)
Task 24	Solar Procurement, 1998-03 (Sweden)
Task 25	Solar Assisted Air Conditioning of Buildings, 1999-04 (Germany)
Task 26	Solar Combisystems, 1998-02 (Austria)
Task 27	Performance of Solar Facade Components, 2000-05 (Germany)
Task 28	Solar Sustainable Housing, 2000-05 (Switzerland)
Task 29	Solar Crop Drying, 2000-06 (Canada)
Task 30	Solar Cities, not initiated
Task 31	Daylighting Buildings in the 21st Century, 2001-05 (Australia)
Task 32	Advanced Storage Concepts for Solar and Low Energy Buildings, 2003-07 (Switzerland)
Task 33	Solar Heat for Industrial Processes, 2003-07 (Austria)
Task 34	Testing and Validation of Building Energy Simulation Tools, 2003-07 (United States)
Task 35	PV/Thermal Systems, 2005-07 (Denmark)
Task 36	Solar Resource Knowledge Management, 2005-11 (United States)
Task 37	Advanced Housing Renovation with Solar & Conservation, 2006-09 (Norway)

Task 38	Solar Air Conditioning and Refrigeration, 2006-10 (Germany)
Task 39	Polymeric Materials for Solar Thermal Applications, 2006-10 (Germany)
Task 40:	Net Zero Energy Solar Buildings, 2008-13 (Canada)
Task 41	Solar Energy and Architecture, 2009-12 (Denmark, Norway, Sweden)
Task 42	Compact Thermal Energy Storage: Material Development for System Integration, 2009-12 (Netherlands)
Task 43	Rating and Certification Procedures – Advanced Solar Thermal Testing and Characterization for Certification of Collectors and Systems, 2009-12 (United States and Denmark)
Task 44	Solar and Heat Pump Systems, 2010-13 (Switzerland)
Task 45	Large Systems: Large Solar Heating/Cooling Systems, Seasonal Storages, Heat Pumps, 2011-13 (Denmark)
Task 46	Solar Resource Assessment and Forecasting, TBD
Task 47	Solar Renovation of Non-Residential Buildings, 2011-14 (Norway)
Task 48	Quality Assurance and Support Measures for Solar Cooling, 2011- 15 (France)

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[5] IEA "World Energy Outlook" IEA, Edition 2007