IEA SHC Task 49

SolarPACES Annex IV

Solar Process Heat for Production and Advanced Applications

Process Heat Collectors:
State of the Art and available medium temperature collectors

Technical Report A.1.3

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With contributions by:
STAGE-STE: European Excellence in Concentrating STE (WP 11)

Contents

1 IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The members of the IEA SHC collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 57 such projects have been initiated, 47 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding – working agreement with solar thermal trade organizations
- Workshops and seminars

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2 Introduction

Worldwide 66% of heat is generated by fossil fuels and 45% of it is used in Industry as Process Heat. At a regional level, the share of Process Heat in the total final energy consumption stands for values around 30% in Asia and Latin America, around 20% in Non-OECD Europe and Eurasia and Australia or around 15% in OECD Europe, Africa and OECD Americas [1]. Despite process heat is recognized as the application with highest potential among solar heating and cooling applications[2], Solar Heat for Industrial Processes (SHIP) still presents a modest share of about 88 MWth installed capacity (0.3% of total installed solar thermal capacity) [3].

Process temperatures found in industrial processes are manifold, ranging from low (T<100ºC), medium (100ºC < T < 250ºC) to high (T > 250ºC) operating temperatures: low and medium temperature processes presenting a high share of heat demands on the mining, food & beverage, tobacco, pulp & paper, machinery and transport equipment manufacturing sectors; high temperatures presenting a high share of heat demand on the chemical, non-metallic minerals and basic metals production sectors [4].

In the present SHIP applications are suited by well-established technologies tackling low temperature applications (T < 100ºC) and by a growing range of technologies, all of them presenting products already in pre-commercial or commercial stage suitable for medium temperature applications (100ºC < T < 250ºC).

Built upon the "Process Heat Collectors State of The Art" report developed within IEA/SHC Task 33 [5] and complementing the information on technologies and available products therein presented, the current report presents a basic description of thermal enhancement strategies adopted in different collector technologies and an updated list of available collectors.

Low temperature collectors have already reached a high stage of development, being regarded today as commercially available technologies. The report focuses on solar collector technologies suitable for operation in the medium temperature range, considering their paramount role in widening the scope of SHIP applications and that less information on such technologies is available.

As thermal losses (thus efficiency) in a solar collector are directly related to the operating temperature and different solar collector technological concepts are based on different strategies aiming the minimization of heat losses at increasingly higher operating temperatures, the range of solar collector technologies suiting process heat applications is also wide: stationary, tracking, air-filled, evacuated – all of them presenting optical and thermal specificities and falling into different technology cost ranges, determining their technical and economic performance under prescribed operating conditions.

As the first SHIP applications derived from the use of stationary solar thermal technologies, traditionally used for hot water or space heating purposes in the residential sector, in low temperature industrial processes standing today for more than 90% of the installed capacity in SHIP applications [6], production of process heat in the medium and high temperature ranges is foreseen as an important potential application of solar concentrating technologies, whose development has been driven from the early 1980's by Concentrated Solar Power (CSP) purposes.

In view of assuring the means of comparing different technological possibilities, technology independent yield assessment methodologies are required. The available solar collector standard ISO 9806 (2013) [7] provides already a solar collector model enabling such a common framework for technology inter-comparison. Setting the backbone for such a technology independent approach, such model is able to deliver detailed simulation results in the framework of detailed system design.

3 Solar collector technologies

In the present SHIP applications are suited by well-established technologies covering the range of process temperatures found in different industrial sectors: low (T < 100ºC), medium (100ºC < T < 250ºC) or high temperature (250ºC < T < 400ºC).

Considering that solar collectors suiting industrial processes might also suit non-industrial applications (e.g. hot water production on the Residential sector or high pressure steam for power generation purposes) it is important to establish the scope of a Solar Process Heat Collector definition in terms of:

- their modularity: such collectors must be prone to medium (10^2 m^2) or large (10^3 m^2) solar fields and present easy/fast collector installation and repair/replacement procedures as well as the potential for hydraulic field layouts with low costs for connecting parts and low pressure drop;
- their robustness and safety: such collectors must present material properties and design features suitable for a reliable and safe operation under the conditions of an industrial environment, including special regard to overheating and stagnation conditions [8];
- their operation and maintenance requirements: the operation and maintenance procedures (basic, excluding repair/replacement) must be accessible to end-user technical personnel without special training in solar technologies (besides the basic training required for the use and operation of any new equipment);
- their integration into running processes: at either heat supply (e.g. steam network) or heat demand (industrial process) levels, by their compatibility with pre-existing (hydraulic) circuits, interference with production processes and by the use of common and standard components or heat transfer fluids (HTFs), not requiring additional efforts on safety or procurement procedures to the end-user.

The latter links directly to the operating temperatures of such collectors. Even if present line-focus concentrator technologies enable heat delivery at temperatures up to 400ºC (and the current developments related to thermal power generation drive maximum temperatures to the range of 550ºC, with molten salt HTFs), such temperatures stand for stepping up in costs, complexity and safety parameters which might not be common to a wide range of industrial processes and sectors.

Thus, considering the requirements of ease-of-use, no added efforts and technical resources to a wide range of end-users, process heat applications here considered are those suitable to provide heat, at a reasonable efficiency, in the low and medium temperature ranges, i.e., T < 250ºC.

This chapter presents the most prominent technological concepts underlying market available collector technologies, their relation to operating temperature and operation requirements, as well as the background for their performance assessment under prescribed operating conditions.

3.1 Introduction

A solar collector converts solar irradiation hitting a surface into heat by heating a suitable heat transport media. This surface is called absorber and is physically attached to a hydraulic circuit containing the heat transport media, the Heat Transport Fluid (HTF). As both the absorber and HTF in the collector present a temperature higher than the surrounding air temperature, thermal losses occur to the surroundings.

In solar collectors, efficiency is thus directly related to the operating temperature and determines, upon a collector cost, the final cost of heat being produced at a given temperature.

To prevent or reduce such losses, occurring either by means of conduction, convection and radiation, solar collectors might also dispose of thermal insulation and glazing materials encasing this basic tandem absorber-HTF. Considering that thermal losses are proportional to the “hot surface” area, such losses can be also reduced by means of optical concentration of the irradiative flux in a smaller absorber area.

In brief, the thermal conversion of solar radiation on a solar collector is affected, thermally, by heat losses occurring by means of conduction, convection and radiation, and optically by the geometry and optical properties of the materials used on its construction, namely those on the path of the radiative flux reaching the aperture of the collector: glass or other dielectric materials used in covers; the absorber surface; mirrors used for optical concentration purposes.

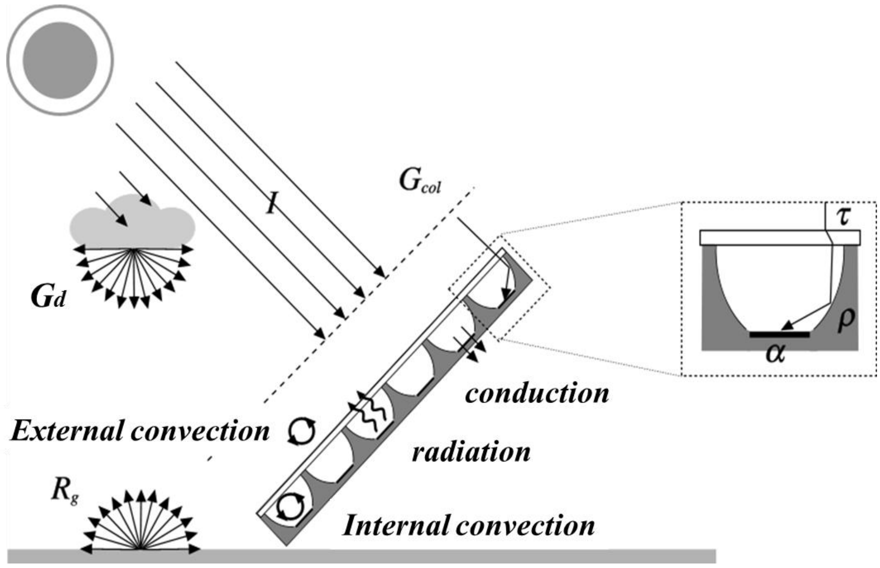


Fig.2.1 – Basic scheme of a low concentration collector

The first solar thermal collector developments where based on the flat plate collector concept, consisting of a flat absorber surface comprising an hydraulic circuit for HTF circulation, thermally insulated on the back and side faces, reducing losses by conduction, and using front glazing reducing losses by external convection and radiation. While attaining suitable conversion efficiency at low temperature operation, higher efficiencies at increasingly higher operation temperatures depend on the isolated or combined use of different thermal performance enhancement strategies.

Spectrally selective absorber surfaces

The use of spectrally selective absorber surfaces is today a common strategy as such materials became available as mass production components from the late 1990's, early 2000's. Shifting absorptivity and emissivity spectral distributions, such materials present high absorptivity values along the solar spectrum and low emissivity values along the emission spectrum (defined by the absorber temperature, always significantly lower than the source temperature and thus shifted towards higher wavelengths, on the infrared).

Different spectrally selective coatings are available on the market. Typical selective surface present absorptivity values in the range of 0.9 to 0.95 and emissivity values in the range of 0.05 to 0.15 (depending on the operating temperature).

Vacuum

A notable enhancement of the thermal performance of solar collectors is achieved by creating vacuum between the absorber and glazing surfaces, thus eliminating losses by means of internal convection.

Not disregarding the most recent flat plate manufacturing processes, with flat glazing collectors withstanding the pressure differential thus created between the outer and the inner surface of the glazing material, such strategy has been traditionally used in tubular glazing (and absorber) configurations, the so called Evacuated Tubes.

Relying on different manufacturing processes and configurations (e.g. single-pass, Dewar or Sydney, heat pipes), when compared to flat non-evacuated collectors stand for poorer optical efficiencies which are compensated by lower thermal losses, which become predominant at increasingly higher operation temperatures.

Optical Concentration

Considering the distributed nature of solar irradiation, amounting roughly to 1 kW/m2 at Earth's surface (on a clear sky day), the maximum temperature achievable at the absorber surface is limited by its thermal balance with the surroundings.
Given the dependence of thermal losses on surface area, a strategy commonly used to increase thermal conversion temperatures is to increase the irradiative flux at the absorber by means of optical concentrating systems relying on dully designed mirrors and/or lenses. Their concentration factor is the ratio between aperture (unobstructed collector area being irradiated, A_a) and absorber areas, A_A:

$$C = A_a / A_A \qquad \text{(Eq.1)}$$

Taking only the radiative balance between absorption and emission of an ideal absorber surface (black body, non-spectrally selective), i.e., neglecting convection and conduction thermal losses to the surroundings, when irradiated at 1 kW/m^2 its equilibrium temperature would not rise to more than 91.3 ºC[1], a suitable temperature only for low temperature applications. The graphic in fig. 2.2 presents the increase in equilibrium temperature with increased fluxes (or concentration factors), illustrating the effect of solar concentration on the maximum achievable operating temperature of the solar collector.

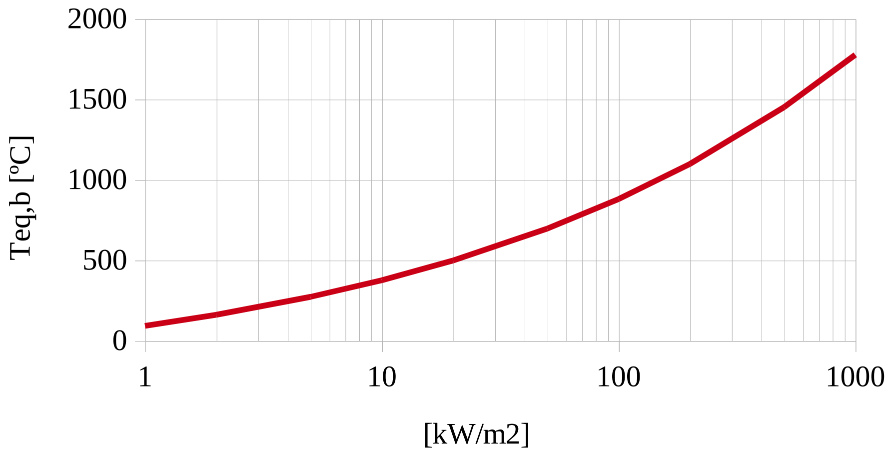


Fig.2.2. – Equilibrium temperature of a blackbody exposed to increasing radiative fluxes, neglecting convection and conduction losses to the surroundings

1 With a spectrally selective surface with α = 0.9 (solar spectrum) and ε = 0.1 (emission spectrum) the equilibrium temperature would raise to 358ºC, again neglecting convection and conduction thermal losses to the surroundings.

Yet, optical concentration comes with a price: the reduction of the acceptance angle, θ_a. Being a measure of the hemispherical region from which radiation reaching the aperture of the collector is directed to the absorber surface, the acceptance angle decreases with increased concentration factors. For an ideal concentrator this relation is given by[2]:

$$C = 1 / \sin(\theta_a) \tag{Eq.2}$$

This fact explains the need of tracking systems with solar concentrators: the collector aperture area must be pointed to the Sun, following its trajectory along the day. This establishes also a possible classification of solar collector technologies: stationary (with a fixed positioning) or tracking collectors (following permanently the sun path).

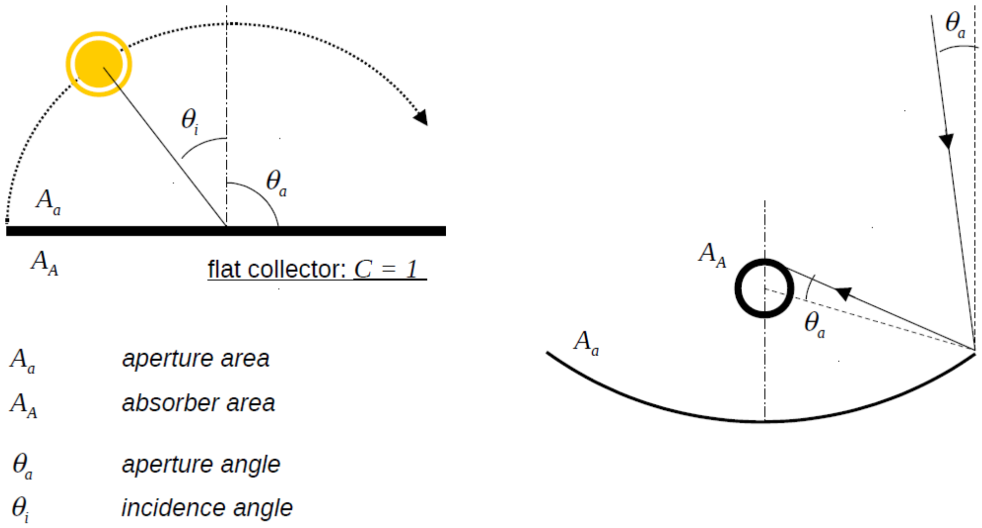


Fig.2.3 - Acceptance angle and concentration factor

The reduction of the hemispherical view of the collector aperture impacts also the acceptance of diffuse radiation, G_d. Such reduction is (approximately) related to the concentration factor by:

$$G_{d,accept} = (1 / C) \, G_{d,aper} \tag{Eq.3}$$

3.2 *Collector technologies*

The installed capacity of solar thermal collectors has been driven by well-established solar collector technologies suitable to low temperature applications, such as glazed or unglazed flat plate or evacuated tube collectors.

Following the physical principles aforementioned, different solar collector technologies emerge from adoption of different thermal performance strategies and optical designs, suiting improved performances in different temperature ranges. Availability of new materials and adoption of new optical designs lead to a flourishing landscape of technologies.

Regardless of the performance enhancement strategies adopted, collector technologies might be

2 Considering a line-focus concentrator with absorber immersed in air or vacuum. For non-ideal concentrators this relation is even more restrictive in terms of acceptance reduction.

divided into two different categories, related to the use of concentration and thus to the use of tracking systems:

- stationary collectors: technologies without concentration or with very moderate concentration factor (typically C < 2) suitable for a fixed positioning;
- tracking collectors: solar concentrators (typically C > 10) requiring the use of tracking systems enabling incidence conditions within the collector acceptance (see 3.1.3), thus following the Sun along its trajectory throughout the day.

3.2.1 Stationary collectors

Not neglecting concepts such as evacuated flat-plate collectors, the most common technologies currently available as marketed products are:

- flat-plate collectors (FPC): (selective) flat absorber with back and side thermal insulation and with/without single or multiple flat glazing cover; hydraulic circuit attached to the back of the absorber surface; stationary collector suitable to the low temperature range (T < 100ºC);
- evacuated tube collectors (ETC): selective absorber layer coating the outer surface of the inner glass wall of a Dewar evacuated tube; hydraulic circuit based on a U-pipe or on heat pipes, mounted inside the evacuated tube sleeve; stationary collector suitable to the low and lower boundary of medium temperature ranges (T < 120ºC);
- Compound Parabolic Concentrator (CPC) collectors: stationary line-focus concentrator (with low concentration factor) designed after non-imaging optics concepts for ideal concentrators; might be combined with evacuated tubes (with external concentrator reflectors) or with flat (or flat-type) absorbers with external glazing; depending on the absorber and on the effective concentration factor is suitable to the low and medium temperature ranges (T < 100ºC – 150ºC).

3.2.2 Tracking collectors

The development of solar concentration technologies, driven from the early 1980's by Solar Thermal Electricity (STE) established the technological ground for R&D and product development activities. Such developments were led by Parabolic Trough Collector (PTC) technology and more recently by derivate line-focus concepts, such as the Linear Fresnel Reflector (LFR) technology, to mention the most prominent.

- Parabolic Trough Concentrator (PTC): tracking line-focus concentrator designed after the parabola geometrical feature of reflecting any ray incident on its aperture parallel to its axis to the parabola focus; one-axis tracking around the longitudinal (absorber) axis; coupled with evacuated or non-evacuated (single-pass) absorber tubes; depending on the absorber and on the effective concentration factor is suitable to the medium temperature ranges (100ºC < T < 250ºC);
- Linear Fresnel Reflector (LFR) Concentrator: tracking line-focus concentrator designed after the Fresnel principle of dividing a parabola into segments displaced in (or close to) a horizontal plane; individual mirror one-axis tracking around the longitudinal axis; coupled with evacuated or non-evacuated (single-pass) absorber tubes located at a vertical displacement related to its focal length; used with a secondary concentrator located around the absorber to enhance its optical behavior; depending on the absorber and on the effective concentration factor is suitable to the medium temperature ranges (100ºC < T < 250ºC).

3.2.3 Temperature levels

In view of the operating temperature dependence of solar collector thermal losses, the selection of the most suitable solar collector technology is directly related to the heat demand temperature (in turn related with the solar integration strategy adopted in the definition of the system layout: process or supply level [9].

Considering both the range of process temperature in different industrial sectors [10] and the most suitable range of operating temperatures of the different collector technologies, the scheme presented in fig.2.4 summarizes this information and can be regarded as a preliminary step into defining the most suitable technologies for the operating conditions found on a prescribed project.

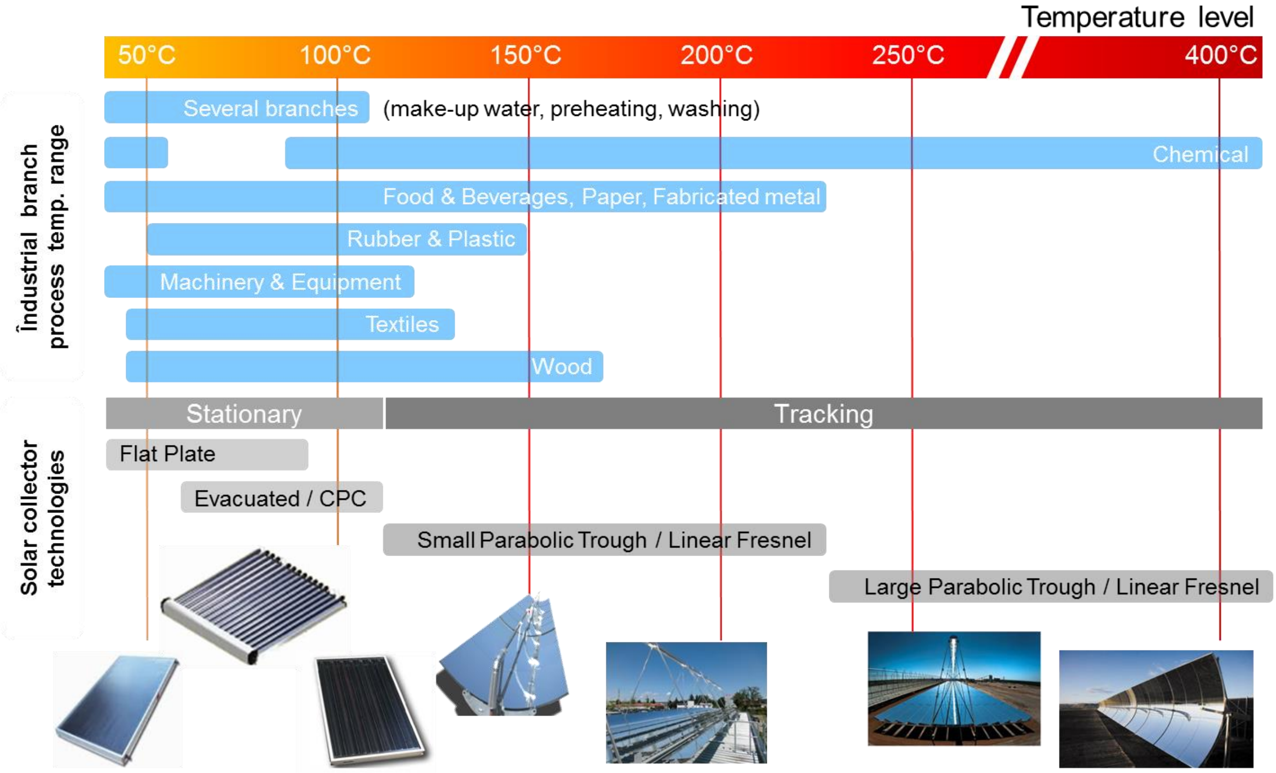


Fig.2.4 – Stationary and tracking solar collector technologies related to operation temperature and process temperature range in different industrial branches

3.3 Collector characterization

The performance of a solar collector depends not only on its thermal behavior, determining how much heat is lost to the surroundings when its temperature raises, but also on its optical behavior, determining the amount of irradiation which effectively hits the absorber and its transformed in heat on the HTF. As so, solar collector efficiency is not a fixed value, as it depends on the collector operating temperature, but is rather represented by a curve - the efficiency curve.

Solar collector models are built upon the separation of optical and thermal losses, following inherently the different dependencies of both phenomena. As so, it may be stated that from a threshold (maximum) temperature independent efficiency (accounting only for optical losses), collector instantaneous efficiency is decreased with increased operating temperature levels due to the temperature dependence of thermal losses.

The efficiency curve is thus a representation of collector instantaneous efficiency with increasing temperature differential between collector (or mean heat transfer fluid) and ambient temperatures.

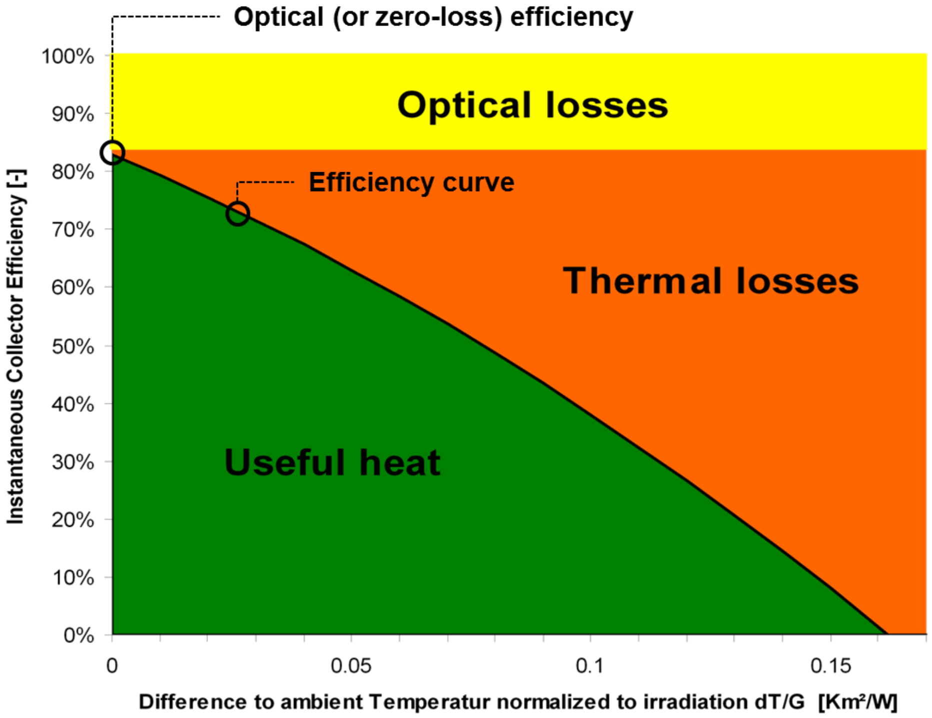


Fig.2.5 – Solar collector efficiency curve

As represented in fig.2.5, the efficiency curve starts with the optical (or zero-loss) efficiency value and presents a downward evolution with increasing temperature differential (to ambient temperature), standing for increasing thermal losses and thus reduced instantaneous efficiency values. The slope of the efficiency curve is directly related to the thermal loss coefficients obtained as thermal characterization parameters as result of the solar collector testing procedures.

The collector efficiency curve, relating the performance of the collector with the operating temperature, is thus one (not the only [12]) of the available tools enabling an early assessment of the suitability of a specific collector or collector technology for a specific application.

Optical and thermal characterization parameters obtained after one (or both) of the solar collector models presented in ISO 9806:2013 [7] are available, for certified solar collectors, at the Solar Keymark database [13]. Promoted by ESTIF – European Solar Thermal Industry Federation, Solar Keymark is a voluntary third-party certification mark for solar thermal products, demonstrating to end-users that a product conforms to the relevant European standards and fulfils additional requirements. The Solar Keymark is used in Europe and increasingly recognized worldwide.

Besides ISO 9806:2013, directly linked to the Solar Keymark database, other solar collector standards are available (e.g. ASHRAE 93-2003 applicable to non-tracking collectors or ASTM E 905-87 applicable to tracking collectors, [14]).

4 Available Medium Temperature Collectors

Built upon the “Process Heat Collectors State of The Art” report developed within IEA/SHC Task 33 [5] and complementing the information on technologies and available products therein presented, an updated list of available collectors is presented in the current section.

Low temperature collectors have already reached a high stage of development, being regarded today as commercially available technologies. The report focuses on solar collector technologies suitable for operation in the medium temperature range, considering their paramount role in widening the scope of SHIP applications and that less information on such technologies is available.

The information herein presented derives from a detailed database of existing collectors for medium temperature applications [15], recently developed in the framework of within the framework of the European project STAGE-STE (Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy) [16].

Aiming the availability of a comprehensive overview of the existing technologies to system designers and end-users, the database has been fed through an online form, enabling a permanent update by technology suppliers, to achieve a live database gathering the most updated and relevant technical information on solar concentrating collectors for medium temperature applications. The online form for addition of new collectors, the existing information in the collectors’ database, and database statistics are available online [17].

The database contains information on medium temperature collectors in different stages of availability/development. The information herein presented refers only to collectors for which efficiency parameter results are available. A list of companies with collectors under development or with incomplete information is also included.

4.1 Stationary collectors

SRB energy UHV (Ultra High Vacuum) Flat Plate

Manufacturer	
Name:	SRB energy
Location:	Almussafes (Spain) and Geneve (Switzerland)
Website:	http://www.srbenergy.com/

Collector main features	
Technology:	Flat Plate
Tracking type:	Stationary
Receiver atmosphere:	Evacuated

Geometrical features	
Aperture width [m]:	1,4
Aperture length [m]:	3,41
Collector height [m]:	-
Concentration factor:	-

Certification	
Applied standard:	ISO9806
Testing lab.:	-
Certification Scheme:	Solar Keymark
Status:	Pending

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,55
heat loss coefficient, a1 [W/(m2.K)]:	0,67
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0

Operating conditions	
Max. Operating Temp. [°C]:	200
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	Domestic hot water, industrial processes, solar cooling, electricity generation

Picture reference: http://www.srbenergy.com/pages/caracteristicas-del-colector

TVP solar Thermal Vacuum Power Charged™ Flat Plate

Manufacturer	
Name:	TVP solar
Location:	Geneve (Switzerland)
Website:	http://www.tvpsolar.com/index.php?context=about-us

Collector main features	
Technology:	Flat Plate
Tracking type:	Stationary
Receiver atmosphere:	-

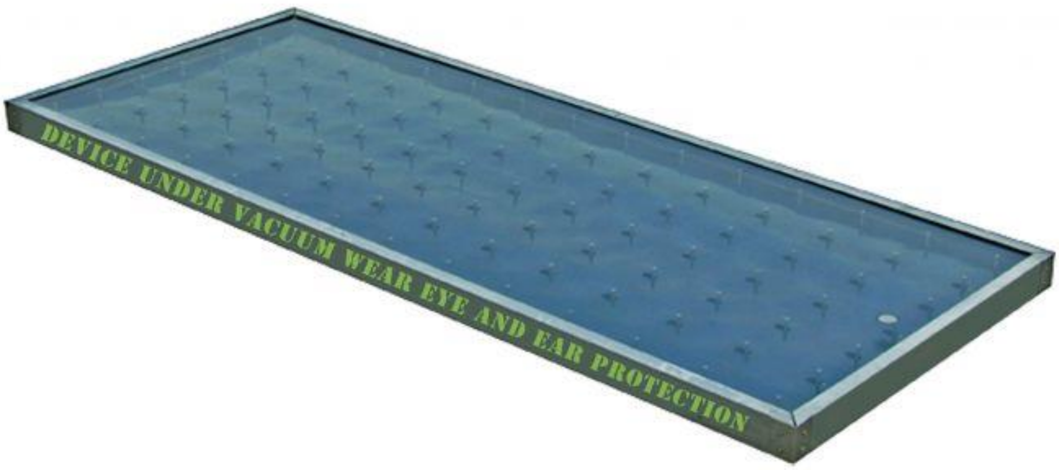
Geometrical features	
Aperture width [m]:	0,691
Aperture length [m]:	1,691
Collector height [m]:	0,062
Concentration factor:	-

Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	Solar Keymark
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,759
heat loss coefficient, a1 [W/(m2.K)]:	0,508
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,007

Operating conditions	
Max. Operating Temp. [°C]:	200
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	water heating, pool and ambient heating, Enhanced oil recovery, Desalination

Picture reference: http://www.tvpsolar.com/index.php?context=product&liv2=MT



4.2 Tracking collectors

4.2.1 Parabolic Trough Concentrator

Solitem PTC1100 Parabolic Trough

Manufacturer	
Name:	Solitem
Location:	Aachen (Germany)
Website:	http://www.solitem.de/

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	1,1
Aperture length [m]:	2,5
Collector height [m]:	-
Concentration factor:	-

Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,75
heat loss coefficient, a1 [W/(m2.K)]:	0,1123
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00128

Operating conditions	
Max. Operating Temp. [°C]:	200
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Water / steam (DSG), Thermal oil
Suitable applications:	ıg, Steam production, Heating systems, Cooling systems, Electric production,

Picture reference: http://www.solitem.de/

Solitem PTC1800 Parabolic Trough

Manufacturer	
Name:	Solitem
Location:	Aachen (Germany)
Website:	http://www.solitem.de/

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	1,8
Aperture length [m]:	5,09
Collector height [m]:	-
Concentration factor:	15,08

Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,75
heat loss coefficient, a1 [W/(m2.K)]:	0,1123
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00128

Operating conditions	
Max. Operating Temp. [°C]:	250
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Water / steam (DSG), Thermal oil
Suitable applications:	-

Picture reference: http://www.solitem.de/

Solitem PTC3000 Parabolic Trough

Manufacturer	
Name:	Solitem
Location:	Aachen (Germany)
Website:	http://www.solitem.de/

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	3
Aperture length [m]:	5
Collector height [m]:	-
Concentration factor:	-

Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,75
heat loss coefficient, a1 [W/(m2.K)]:	0,1123
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00128

Operating conditions	
Max. Operating Temp. [°C]:	250
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Water / steam (DSG), Thermal oil
Suitable applications:	-

Picture reference: http://www.solitem.de/

Solitem PTC4000 Parabolic Trough

Manufacturer	
Name:	Solitem
Location:	Aachen (Germany)
Website:	http://www.solitem.de/
Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air
Geometrical features	
Aperture width [m]:	4
Aperture length [m]:	5
Collector height [m]:	-
Concentration factor:	-
Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	-
Status:	-
Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,75
heat loss coefficient, a1 [W/(m2.K)]:	0,1123
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00128
Operating conditions	
Max. Operating Temp. [°C]:	250
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Water / steam (DSG), Thermal oil
Suitable applications:	-

Picture reference:

Inventive Power Power Trough 110 Parabolic Trough

Manufacturer	
Name:	Inventive Power
Location:	Zapopan (Jalisco, Mexico)
Website:	http://www.inventivepower.com.mx/

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	1,1
Aperture length [m]:	3
Collector height [m]:	-
Concentration factor:	33,33

Certification	
Applied standard:	SRCC
Testing lab.:	-
Certification Scheme:	-
Status:	Pending

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,6
heat loss coefficient, a1 [W/(m2.K)]:	2,756
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,07

Operating conditions	
Max. Operating Temp. [°C]:	200
Max. Operating Press. [bar]:	15
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Water / steam (DSG)
Suitable applications:	Industrial processes, Commercial sector, Solar refrigeration

Picture reference: http://inventivepower.com.mx/tecnologia-power-trough-110/

Trivelli energy SRL SolarWing EVO Parabolic Trough

Manufacturer	
Name:	Trivelli energy SRL
Location:	Bressana Bottarone (Pavia, Italy)
Website:	http://www.seagroupe.com/
Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	-
Geometrical features	
Aperture width [m]:	1,25
Aperture length [m]:	8,2
Collector height [m]:	-
Concentration factor:	-
Certification	
Applied standard:	EN 12975
Testing lab.:	-
Certification Scheme:	-
Status:	Pending
Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,7
heat loss coefficient, a1 [W/(m2.K)]:	0,7
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	-
Operating conditions	
Max. Operating Temp. [°C]:	250
Max. Operating Press. [bar]:	16
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	Process heat, solar cooling

Picture reference:

Abengoa solar (developed and previously manufactured by IST, USA) PT-1 (ground-mounted version) Parabolic Trough

Manufacturer	
Name:	Abengoa solar (developed and previously manufactured by IST, USA)
Location:	Sevilla (Spain) and Denver (CO, USA)
Website:	http://www.abengoasolar.com

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	2,3
Aperture length [m]:	6,1
Collector height [m]:	-
Concentration factor:	50,00

Certification	
Applied standard:	SRCC
Testing lab.:	-
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,71
heat loss coefficient, a1 [W/(m2.K)]:	0,437
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,0029

Operating conditions	
Max. Operating Temp. [°C]:	288
Max. Operating Press. [bar]:	40
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	ı as: Mining, Food, Beverages, Paper, Chemicals, Enhanced oil recovery, etc

Picture reference: ngoasolar.com/web/en/Productos_y_Servicios/Aplicaciones_industriales/Aplicaciones/

Abengoa solar (developed and previously manufactured by IST, USA) RMT (roof mounted- version) Parabolic Trough

Manufacturer	
Name:	Abengoa solar (developed and previously manufactured by IST, USA)
Location:	Sevilla (Spain) and Denver (CO, USA)
Website:	http://www.abengoasolar.com

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	1,148
Aperture length [m]:	3,677
Collector height [m]:	-
Concentration factor:	50,00

Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,65
heat loss coefficient, a1 [W/(m2.K)]:	0,404
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,0027

Operating conditions	
Max. Operating Temp. [°C]:	205
Max. Operating Press. [bar]:	30
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	ı as: Mining, Food, Beverages, Paper, Chemicals, Enhanced oil recovery, etc

Picture reference: ngoasolar.com/web/en/Productos_y_Servicios/Aplicaciones_industriales/Aplicaciones/

Solarlite CSP Technology SL2300 Parabolic Trough

Manufacturer	
Name:	Solarlite CSP Technology
Location:	Duckwitz (Germany)
Website:	www.solarlite-csp.com

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air

Geometrical features	
Aperture width [m]:	2,3
Aperture length [m]:	6
Collector height [m]:	-
Concentration factor:	57,50

Certification	
Applied standard:	-
Testing lab.:	SERT - Naresuan University, Thailand
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,641
heat loss coefficient, a1 [W/(m2.K)]:	0,4201
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00119

Operating conditions	
Max. Operating Temp. [°C]:	250
Max. Operating Press. [bar]:	20
Heat transfer media:	Pressurized Water (w/ or w/out glycol)
Suitable applications:	y, Chemical, Paper & pulp, hotels, District heating and cooling networks etc…

Picture reference:

Solarlite CSP Technology SL4600 Parabolic Trough

Manufacturer	
Name:	Solarlite CSP Technology
Location:	Duckwitz (Germany)
Website:	www.solarlite-csp.com

Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Evacuated

Geometrical features	
Aperture width [m]:	2,3
Aperture length [m]:	6
Collector height [m]:	-
Concentration factor:	66,00

Certification	
Applied standard:	-
Testing lab.:	German Aerospace Center, DLR
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,757
heat loss coefficient, a1 [W/(m2.K)]:	0,0191
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00006

Operating conditions	
Max. Operating Temp. [°C]:	400
Max. Operating Press. [bar]:	55
Heat transfer media:	Pressurized Water (w/ or w/out glycol)
Suitable applications:	ıtralised as well as utility scale, Cogeneration for industries and communities,

Picture reference: http://solarlite-csp.com/en/reference/tse-1-kanchanaburi-provinz-thailand/

NEP Solar Polythrough 1800 Parabolic Trough

Manufacturer	
Name:	NEP Solar
Location:	Zürich (Switzerland)
Website:	http://www.nep-solar.com/
Collector main features	
Technology:	Parabolic Trough
Tracking type:	1-axis tracking
Receiver atmosphere:	Air
Geometrical features	
Aperture width [m]:	1,845
Aperture length [m]:	20.9 m gross length, 20.0 m net length (reflector)length
Collector height [m]:	0
Concentration factor:	17,27
Certification	
Applied standard:	EN 12975
Testing lab.:	-
Certification Scheme:	-
Status:	-
Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,689
heat loss coefficient, a1 [W/(m2.K)]:	0,3600
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00110
Operating conditions	
Max. Operating Temp. [°C]:	230
Max. Operating Press. [bar]:	-
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	Process heat, solar cooling, polygeneration

Picture reference: http://www.nep-solar.com/products/polytrough-1800/

4.2.2 Linear Fresnel Reflector

INERSUR LINEAR FRESNEL Linear Fresnel	
Manufacturer	
Name:	INERSUR
Location:	Córdoba (Spain)
Website:	http://www.inersur.com/new_design/index.html
Collector main features	
Technology:	Linear Fresnel
Tracking type:	1-axis tracking
Receiver atmosphere:	-
Geometrical features	
Aperture width [m]:	0,4
Aperture length [m]:	0,8
Collector height [m]:	-
Concentration factor:	12,00
Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	-
Status:	-
Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,76
heat loss coefficient, a1 [W/(m2.K)]:	1,9
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	-
Operating conditions	
Max. Operating Temp. [°C]:	150
Max. Operating Press. [bar]:	8
Heat transfer media:	Pressurized Water (w/ or w/out glycol)
Suitable applications:	Food industry, air conditioning
Picture reference:	http://www.inersur.com/new_design/html/productos.html

Industrial Solar LF-11 Linear Fresnel

Manufacturer	
Name:	Industrial Solar
Location:	Freiburg (Germany)
Website:	http://www.industrial-solar.de/CMS/en/angebot/fresnel-kollektor/
Collector main features	
Technology:	Linear Fresnel
Tracking type:	1-axis tracking
Receiver atmosphere:	Evacuated
Geometrical features	
Aperture width [m]:	7,5
Aperture length [m]:	4,06
Collector height [m]:	4,5
Concentration factor:	25
Certification	
Applied standard:	-
Testing lab.:	-
Certification Scheme:	Solar Keymark
Status:	Pending
Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,635
heat loss coefficient, a1 [W/(m2.K)]:	0,0265
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,00043
Operating conditions	
Max. Operating Temp. [°C]:	400
Max. Operating Press. [bar]:	16 bar (up to 120 bar
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Water / steam (DSG), Thermal oil
Suitable applications:	Process heat, solar cooling, polygeneration
Picture reference:	http://www.industrial-solar.de/content/referenzen/fresnel/

4.2.3 Other line-focus technologies

Tecnología solar concentrada (TSC) CCStaR FMSC type with curved mirror

Manufacturer	
Name:	Tecnología solar concentrada (TSC)
Location:	Palma de Mallorca (Spain)
Website:	http://www.tsc-concentra.com/wp-content/uploads/2013/07/TSC-CCStaR-

Collector main features	
Technology:	FMSC type with curved mirror
Tracking type:	fixed mirrors, tracking receiver
Receiver atmosphere:	Evacuated

Geometrical features	
Aperture width [m]:	5,2
Aperture length [m]:	8
Collector height [m]:	-
Concentration factor:	14,40

Certification	
Applied standard:	None
Testing lab.:	-
Certification Scheme:	-
Status:	-

Optical and thermal characterization parameters	
zero loss coefficient (Optical efficiency):	0,687
heat loss coefficient, a1 [W/(m2.K)]:	0
temp.dep.heat loss coeff., a2 [W/(m2.K2)]:	0,004

Operating conditions	
Max. Operating Temp. [°C]:	200
Max. Operating Press. [bar]:	10
Heat transfer media:	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications:	Industrial processes, solar cooling, district heat

Picture reference: http://task39.iea-shc.org/Data/Sites/12/documents/newsletters/2013-03/index.html

4.3 Manufacturers with collectors under development

4.3.1 Parabolic Trough Concentrator

Manufacturer	
Name:	Absolicon Solar Concentrator
Location:	Härnösand (Suecia)
Website:	www.absolicon.com

Manufacturer	
Name:	Airier Natura
Location:	Karnataka (India)
Website:	http://airier.com/product.html

Manufacturer	
Name:	Dezhou Mingnuo
Location:	Dezhou (China)
Website:	http://dzmn.cclycs.com/

Manufacturer	
Name:	Dr. Vetter
Location:	Baden-Baden (Germany)
Website:	http://www.itcollect.dr-vetter.de/

Manufacturer	
Name:	FEROtec s.r.l
Location:	Prato (Italy)
Website:	http://www.ferotech.it/index.html

Manufacturer	
Name:	Global CSP
Location:	Manchester (UK)
Website:	http://www.global-csp.com/

Manufacturer	
Name:	Huayuan New Energy Project
Location:	Dezhou (China)
Website:	http://www.hyne.cn

Manufacturer	
Name:	Industrie-Montagen-Kornmüller GmbH
Location:	Seitenstetten (Austria)
Website:	http://www.imkgmbh.at/

Manufacturer	
Name:	Koluacik
Location:	Antalya (Turkey)
Website:	http://www.koluacik.com/

Manufacturer	
Name:	Millionsun Energy Co., Ltd
Location:	Hyderabad (India)
Website:	www.millionsun.com

Manufacturer	
Name:	Rackam
Location:	Sherbrooke (Quebec, Canada)
Website:	http://rackam.com

Manufacturer	
Name:	SLT Energy LTD.
Location:	Gujarat (India)
Website:	http://www.sltenergy.com/

Manufacturer	
Name:	Solar mirrortec
Location:	Seitenstetten (Austria)
Website:	http://www.solarmirrortec.com/de/kollektor_smt8.html

Manufacturer	
Name:	SolarX Energy
Location:	New York (USA)
Website:	http://www.solarxenergy.com/

Manufacturer	
Name:	Solera Sun Power / Smirro GmbH
Location:	Geislingen (Germany)
Website:	http://www.smirro.de/

Manufacturer	
Name:	Soltigua
Location:	Gambettola (Italy)
Website:	http://www.soltigua.com/

Manufacturer	
Name:	Sopogy
Location:	Honolulu (Hawaii, USA)
Website:	http://sopogy.org

Manufacturer	
Name:	Thermax
Location:	Pune (India)
Website:	http://www.thermaxindia.com

Manufacturer	
Name:	Ultra Conserve Pvt. Ltd
Location:	Maharashtra (India)
Website:	http://www.conserve.co.in/

Manufacturer	
Name:	Vicot
Location:	Dezhou City (Shandong Province, China)
Website:	http://www.vicothvac.com/6-2-vicot-solar-collector.html

4.3.2 Linear Fresnel Reflector

Manufacturer	
Name:	Alsolen-Alcen
Location:	Versailles (France)
Website:	http://www.alsolen-alcen.com/fr

Manufacturer	
Name:	Feranova
Location:	Westerkappeln (Germany)
Website:	http://feranova.com/

Manufacturer	
Name:	Millenium Energy Systems
Location:	Barcelona (Spain)
Website:	http://www.millenniumenergies.com/es/nuestra-tecnologia/fresnel/

Manufacturer	
Name:	NOVATEC SOLAR
Location:	Karlsruhe (Germany)
Website:	http://www.novatecsolar.com/

Manufacturer	
Name:	Solar Euromed
Location:	Dijon (France)
Website:	http://www.solareuromed.com/

Manufacturer	
Name:	Solar Power Group
Location:	Ratingen (Germany)
Website:	http://www.solarpowergroup.com/

Manufacturer	
Name:	Soltigua
Location:	Gambettola (Italy)
Website:	http://www.soltigua.com/

4.3.3 Other line-focus technologies

Manufacturer	
Name:	Chromasun
Location:	San Jose (USA)
Website:	http://chromasun.com/MCT.html

5 References

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IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is

*To enhance **collective knowledge** and **application** of solar heating and cooling through **international collaboration.***

The members of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 53 such projects have been initiated to-date, 39 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are a number of special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding with solar thermal trade organizations

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