

Chapter 2

Solar Thermal Collectors

Abstract Solar thermal collectors are used to heat up a fluid, generally water or a mixture of glycol and water depending of the configuration of the solar thermal system. They are adopted for many applications in both industrial and residential sectors. Many typologies exist in order to comply with heterogeneous needs. All have a common operating principle: to capture solar radiation, converting it to useful heat and transferring it to a working fluid. In this chapter the main solar thermal collector typologies are described giving also information about the application field, system configuration and performances.

Keywords Solar thermal collector typologies • Operating principles • Efficiency and energy performance

2.1 Typologies and Working Principle

2.1.1 *Unglazed Collectors*

Unglazed solar collectors are the simplest solar thermal collectors. It consists of an absorber with embedded channels where the fluid circulates. Insulation is not used. Generally, the absorber and the pipes are made in plastic materials. The working principle is very simple. Basically, solar radiation impacts on the absorber heating it up. Since the absorber is treated with special paints only a very small solar radiation portion is reflected back to the environment. The produced heat is then transferred to the fluid which circulates in the pipes. The efficiency is strongly affected by the external conditions, particularly by external air temperature and wind. Indeed, at low air temperatures, although the solar irradiance is strong, unglazed collectors are not available to heat up the fluid. Despite they are not able to increase the temperature of the fluid up to 50 °C (OECD/IEA 2013), unglazed collectors are widely used for pool heating applications (IEA SHC).

2.1.2 Flat Plate Glazed Collectors

Different from the unglazed collectors, flat plate Glazed collectors have a glass cover above the absorber, creating a cavity filled with gas (usually air), which generates the greenhouse effect. The cover acts also as a barrier against the wind. Advanced glasses, specifically treated, are used as covering material in order to reduce optical losses. It has to be mentioned that increasing the number of glass coverings is not productive due to optical losses increment. Both absorber and pipes are made of metals with enhanced absorbing properties. All these components are encapsulated in a frame as shown in Fig. 2.1. Insulation is used on the back and sides surfaces of flat plate glazed collectors to reduce heat losses.

Thus, solar radiation is absorbed through the glass by the metal absorber, heating up the fluid which circulates within the pipes,

2.1.3 Evacuated Tubes Collectors

This solar collector typology consists of two main parts: vacuum pipes and the manifold (Fig. 2.2). Along the manifold a set of vacuum pipes are installed. Particularly, each vacuum pipe consists of an inner tube and an outer tube; between them the vacuum is created to enhance the thermal features of the collector, decreasing thermal losses.

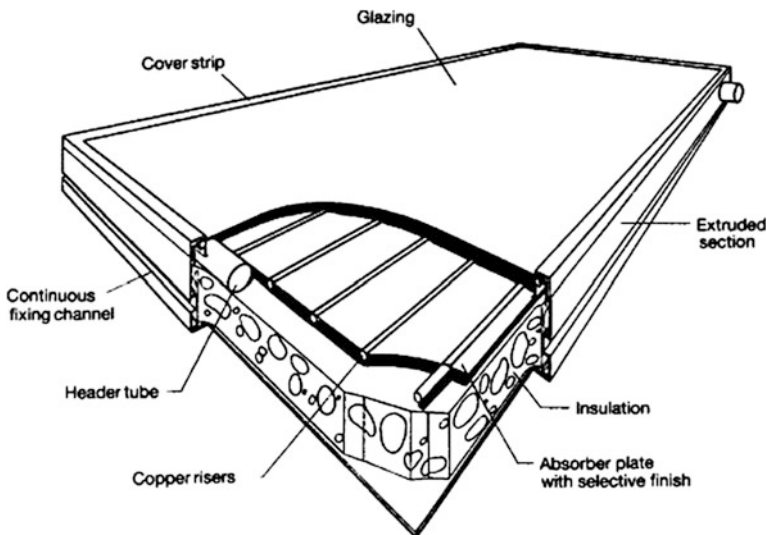


Fig. 2.1 Solar flat plate glazed collector (Kalogirou 2004)

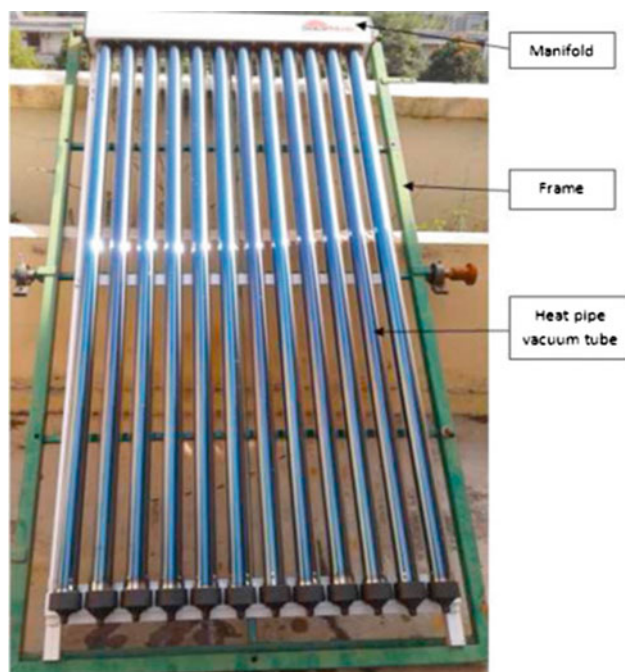


Fig. 2.2 Heat pipe evacuated tube collector representation (Sabiha et al. 2015)

There are two typologies of pipes: direct flow or heat pipe (Nkwetta et al. 2013). The first has similar working principles to the collectors described before. Indeed, within the vacuum pipe there is an absorber sheet with tubes embedded, where the working fluid circulates. Instead, the second has a different operating principle: each vacuum pipe contains a fluid which evaporates, when heated up by solar radiation. Then, the vapour goes up in the manifold, where, condensing, it releases latent heat to the system working fluid.

2.2 System Configuration

Solar thermal collectors can be arranged in series or in parallel. Solar collector fields with same amount of collectors disposed in a number of series connected panels, which can be then arranged in parallel (Fig. 2.3a) or cascade (Fig. 2.3b). Fluid flow rate, along the solar thermal system, does not change when panels are connected in series, while fluid temperature increases from previous panel to next panel. Instead, fluid flow rate changes along the solar thermal system when panels are connected in parallel and fluid temperature is the same at the end of each branch. Therefore, in the configuration shown in Fig. 2.3a, fluid temperature is the same at the end of each

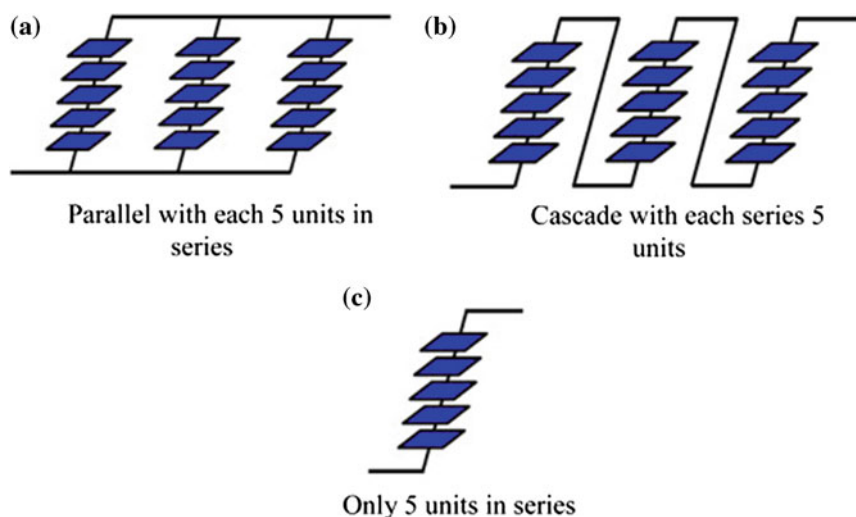


Fig. 2.3 Solar collectors parallel and series arrangement (Niu et al. 2013)

branch of panels connected in series, while system flow rate increases from branch to branch. For the same flow rate and number of collectors, pressure drop, which the circulation pump has to exceed, decreases with the number of branches in parallel and increases with the number of collectors in series (Picón-Núñez et al. 2014).

Ideally, panels should be connected all in parallel to minimize the pressure drop. However, ensuring same flow rate distribution among each panel complicates the system control and design; the investment may not compensate the benefits. Thus, solar thermal collectors are arranged in series when the design system flow rate is low, while when the design flow rate is high collectors are arranged in parallel branches of series collectors.

Solar thermal systems are often equipped with storage tank in order to store energy produced in a certain moment of the day and not utilised. Collectors can be connected only to the tank or to both tank and indoor heating distribution system as shown in Fig. 2.4. The last configuration, which is capable to increase the solar thermal energy yield compared to a solar thermal buffer system with small storage tank, is recommended only if the indoor distribution system requires low temperature such as radiant floor systems (Glembin et al. 2016).

Usually solar collectors are filled with brine; a mixture of water and glycol. Indeed, solar collectors loop is generally connected to the rest of the system through a heat exchanger. Nowadays, for residential applications solar collectors with drain back systems, syphon effect based, are becoming popular. These systems are able to increase the efficiency and the design of the system, reducing the necessary components, such as expansion vessel, air vents and heat exchanger (Botpaev et al. 2014). In such system the heat carrier is water, which makes them more eco-friendly than conventional solar thermal systems.

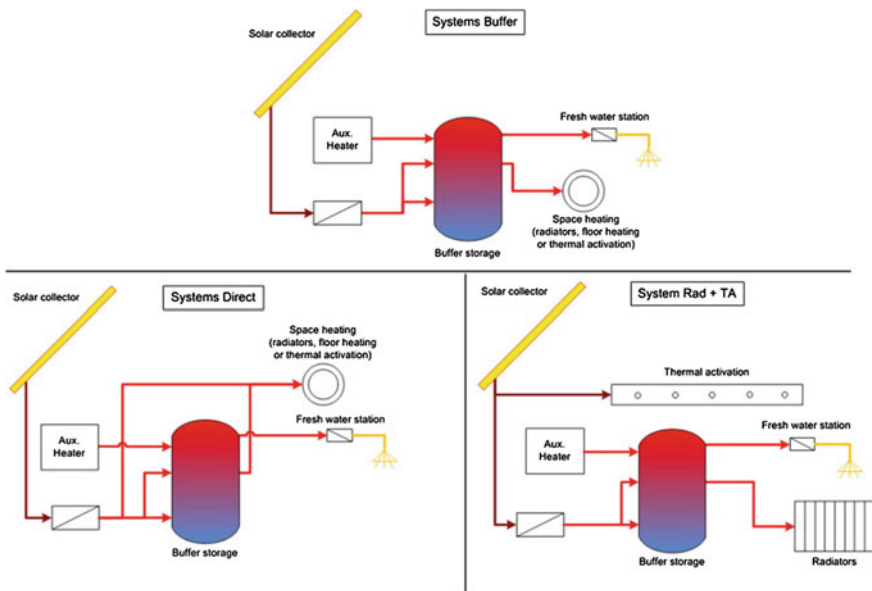


Fig. 2.4 Solar thermal system configuration: direct or buffer (Glembin et al. 2016)

2.3 Performance

The described solar collectors show different performances as a function of the external conditions. Generally solar collector efficiency can be calculated as the ratio between the useful thermal energy generated by the collector and the incident solar irradiance. Usually collector efficiency is expressed as a function of the inlet and ambient temperature and the total incident solar irradiance (Kalogirou 2014):

$$\eta_{coll} = F_R \left[(\tau\alpha) - U_L \frac{(T_i - T_a)}{G_t} \right] \quad (2.1)$$

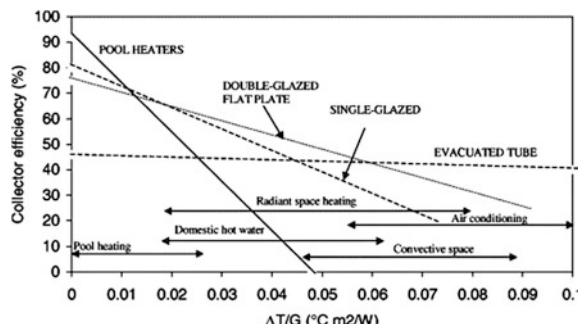
where, $\tau\alpha$ is the transmittance absorptance product of the glass cover, G_t is the total solar irradiance incident on the solar collector surface, T_i and T_a are respectively solar collector inlet and ambient temperatures, U_L is the solar collectors overall heat loss coefficient and F_R is the heat removal factor of a specific typology of solar collectors. This is defined as the ratio of the actual useful energy gain (solar collector energy output) and the useful energy gain of the very same collector considering the absorbing surface at the same temperature of the fluid inlet temperature. It is not within the scope of this book to investigate in detail solar collectors working principle; therefore solar collector efficiency will not be addressed in details. The main aim is to give comprehensive notions for understanding what the

variables that affect solar collector efficiency are. Accordingly with the European standard EN12975, solar collector efficiency is expressed as (Kalogirou 2009):

$$\eta_{coll} = \eta_0 - a_1 \frac{(T_m - T_a)}{G_t} - a_2 \frac{(T_m - T_a)^2}{G_t} \quad (2.2)$$

where, T_m is the mean collector fluid temperature, a_1 the first order coefficient, a_2 the second order coefficient and η_0 is the zero loss collector efficiency. The latter three parameters are given by the solar collector manufacturer. Obviously, they differ quite a lot from solar collector to solar collector. Figure 2.5 shows solar collector efficiency of the main solar collector typologies. The figure shows also the end use of solar collector typologies, going from pool heating to air condition. It appears that the use of unglazed panels (Pool heaters within Fig. 2.5) is suggested for pool heating application, while glazed collectors for domestic hot water and radiant space heating. Thus, glazed collectors use for space heating set one constrain to the indoor heating distribution system. Particularly, radiant systems, such as floor heating or radiant panels, have to be used. Actually, this is true for mild climate. Instead for warm climate, since the efficiency is higher, glazed collectors can be used also in combination with convective indoor distribution system, like radiator. Indeed, solar collector efficiency varies also with the external temperature (Fig. 2.5). Basically, solar collector efficiency depends on solar irradiance, external air temperature and on its final application, which set somehow the solar mean temperature (T_m), influencing the inlet temperature. Generally, the term on the y axis has lower value for warm climates than for mild climates. However, the end application has also strong influence. Indeed, the temperature difference, $T_m - T_a$, is affected by external temperature values and solar collector end applications. Summarizing, if the purpose of solar collectors is to heat up a pool in summer in Italy, the use of unglazed collectors is suggested, but if the purpose is to heat up a pool in winter in Finland the use of evacuated tube is suggested. This example, even though it is far from rationality, wants only to stress what affects the solar collector efficiency.

Fig. 2.5 Collector efficiencies of various liquid collectors (Kalogirou 2004).
Note $\Delta T = T_m - T_a$



Beside the efficiency, another parameter often used for measuring collector performances is the solar fraction (SF). This states the share of solar thermal energy of the total energy required by the application/process; it can be formulated as:

$$SF = \frac{Q_{sol}}{Q_{tot}} \quad (3.3)$$

where, Q_{sol} is the useful solar thermal energy yielded by solar collectors and Q_{tot} is the total energy required by the process/application.

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