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"Solar Thermal Conversion"

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WORKSHOP ON "PHYSICS OF RENEWABLE ENERGY"

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SOLAR THERMAL CONVERSION

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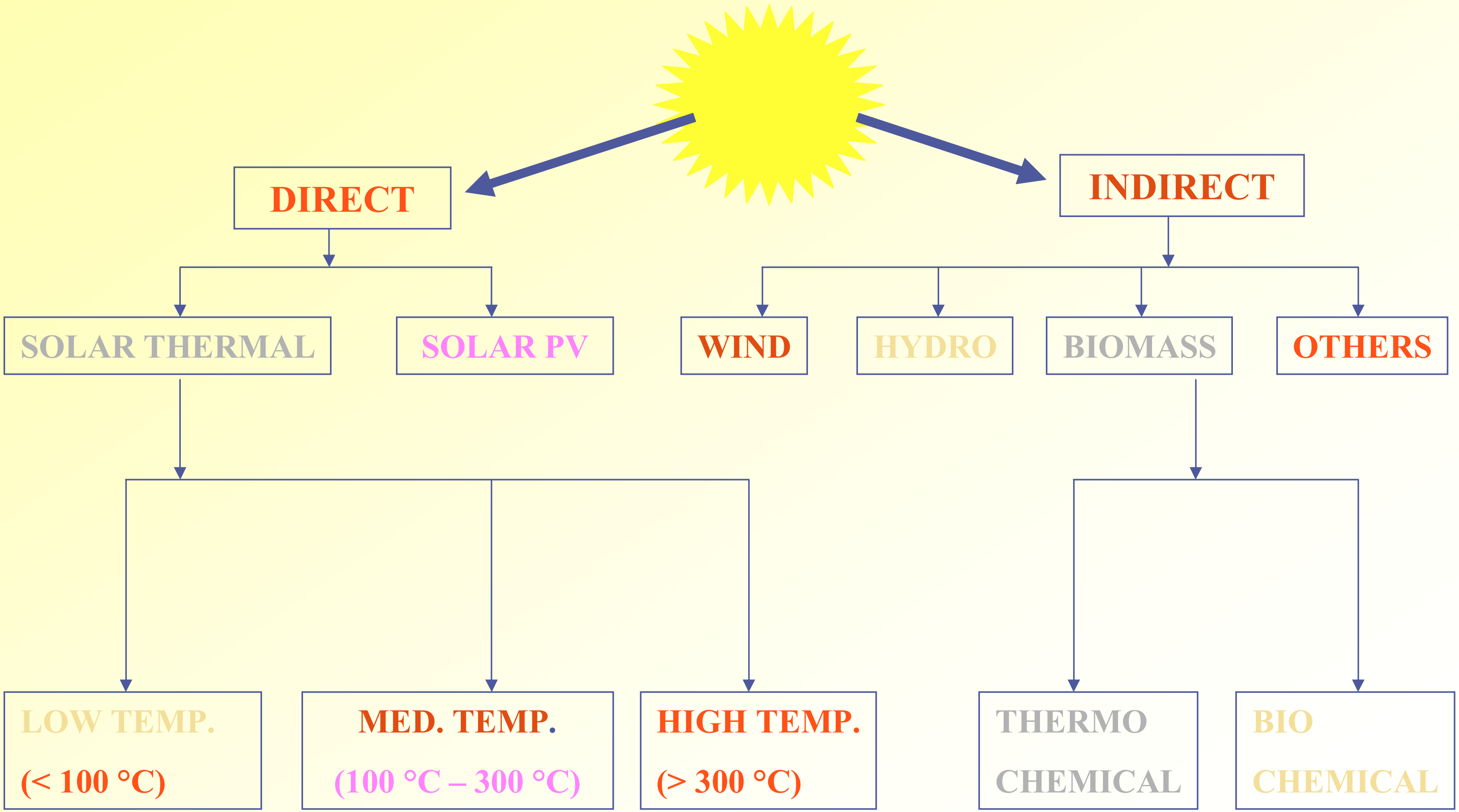
TRADITIONAL CLASSIFICATION OF RENEWABLES



With the exception of nuclear, geothermal and tidal energy, all forms of of energy used on earth originate from the sun’s energy. The flow of renewable solar energies on earth is essentially equal to the flow of energy due to solar radiation. Every year, the sun irradiates the earth's land masses with the equivalent of 19 trillion toe. A fraction of this energy could satisfy the world's energy requirements, around 9 billion toe per year.

The use of energy in the form of heat is one of the largest items in the energy budget.In Europe, for instance, it accounts for around 50% of total energy consumption: around 630 million toe, of which 383 in low-temperature heat and 247 in medium- and high-temperature heat.

Today, low-temperature (<100^{o}C) thermal solar technologies are reliable and mature for the market. World-wide, they help to meet heating needs with the installation of several million square metres of solar collectors per year. These technologies can play a very important role in advanced energy-saving projects, especially in new buildings and structures.

SOLAR THERMAL

- The thermal conversion of solar energy is usually classified according to the temperatures required (low, medium and high temperature ranges) but it can also be classified according to the specific use of the collected energy (water heating, space heating, process heat, etc.).

The modern Active Solar Systems market began as a consequence of the oil crisis in the 1970's.

Many companies were created World-wide to manufacture, sell and install a series of new products, principally for heating water in private houses, public buildings and swimming pools.

This enthusiastic and dynamic commercial activity was backed up by government sponsored research and development projects.

Great hopes were built on a steadily growing market. However, by the mid-1980s the situation changed, oil prices started to fall and the public fear of a conventional energy shortage slowly died out.

The solar industry suffered badly and the majority of the newly formed companies disappeared. Those that manage to survive improved their products, re-organised production methods and introduced quality controls in order to satisfy more exacting customer demands.

The market has stabilised, but in most European countries the stabilisation is at a rather low level.

Solar thermal heating is a proven technology for domestic water heating (household and large scale), and for swimming pool heating. Total installed capacity in 2003 estimated at 94 million m^2 .

Solar Hot Water Installations by Country, 2003* (million m^2)

China	**:52.0**
European Union	**:12.0**
Turkey	**:9.3**
Israel	**:4.5**
USA	**:2.1**
Australia	**:1.3**
India	**:0.6**
Egypt	**:0.5**

***Figures exclude unglazed water collectors and all air collectors.**

China alone accounts for more than half of the global total of 94 million m^2 in 2003.

EU hold a fifth of the world installed capacity. Within the European Union, Germany has the largest share, with 4.9 million m^2, and Greece second with 2.8 million.

Other countries outside of the EU with installed capacities larger than that of Greece are Israel and Australia in descending order.

Other countries with some installations include Botswana, Canada, Kenya, Korea, Mauritius, Mexico, Nepal, Thailand, and Tunisia.

The range of solar heating applications varies between the different countries of the EU, but domestic water heating for households is the main application in all countries.

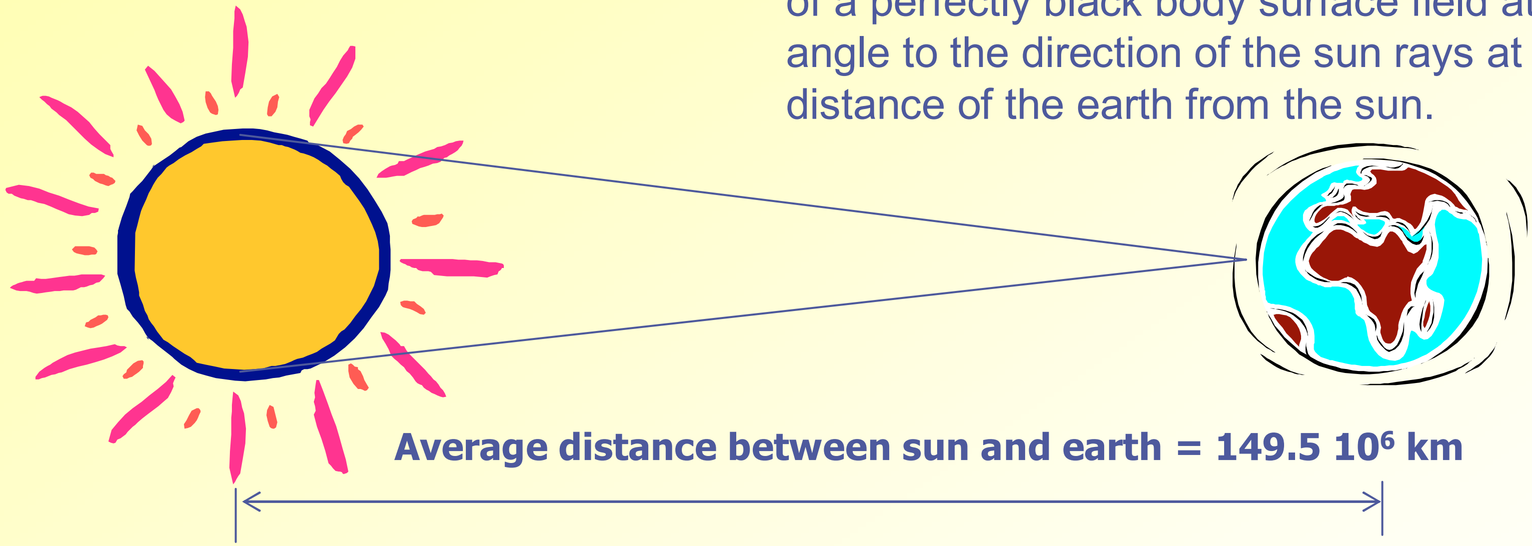
Space heating applications have particular relevance to Austria and to a lesser extent France and Germany, but are not widespread in other countries.

Solar radiation: Some data

Surafce temperaure = 5780°C
Expression for surface temperature
$T = (r^2 S / R^2 \sigma)^{1/4}$

Solar constant: 1367 W/m²

Solar constant : is defined as the amount of radiant energy received per second by a unit area of a perfectly black body surface field at right angle to the direction of the sun rays at the mean distance of the earth from the sun.



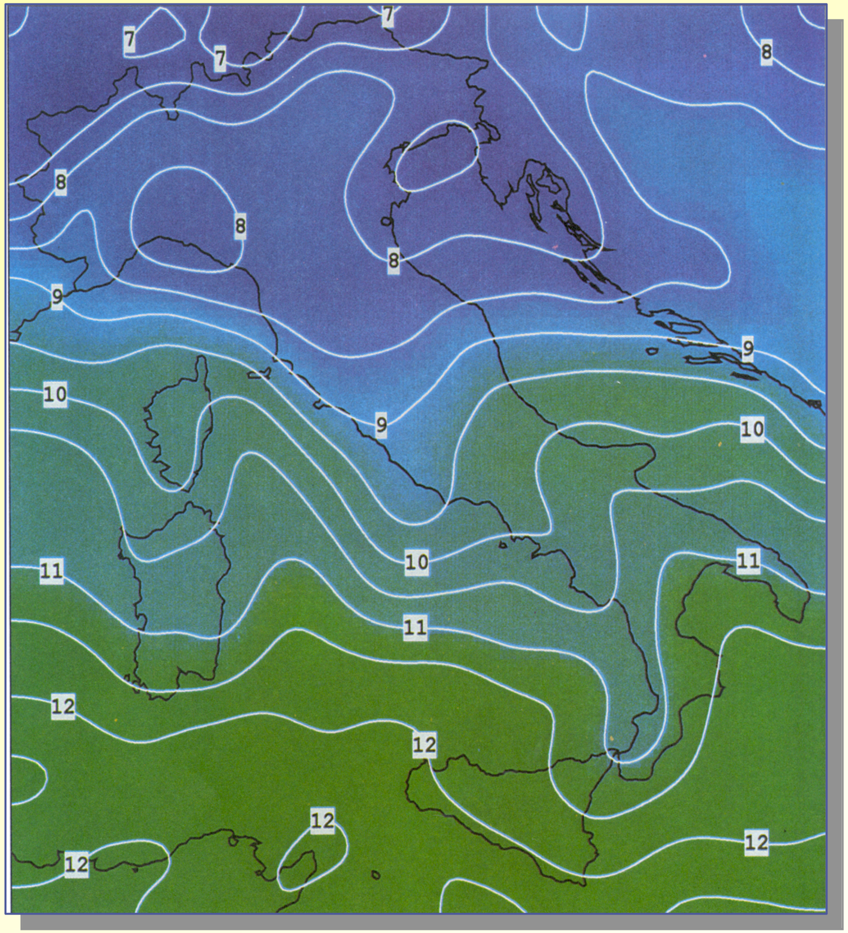
Solar radiation on the surface comprises of :

- **Direct radiation: The solar radiation that reaches the surface of the earth without being diffused is called direct beam solar radiation.**
- **Diffused radiation: As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by air molecules, water vapour, clouds, dust, and pollutants from power plants, forest fires, and volcanoes. This is called diffuse solar radiation.**
- **Global solar radiation: The sum of the diffuse and direct solar radiation is called global solar radiation.**

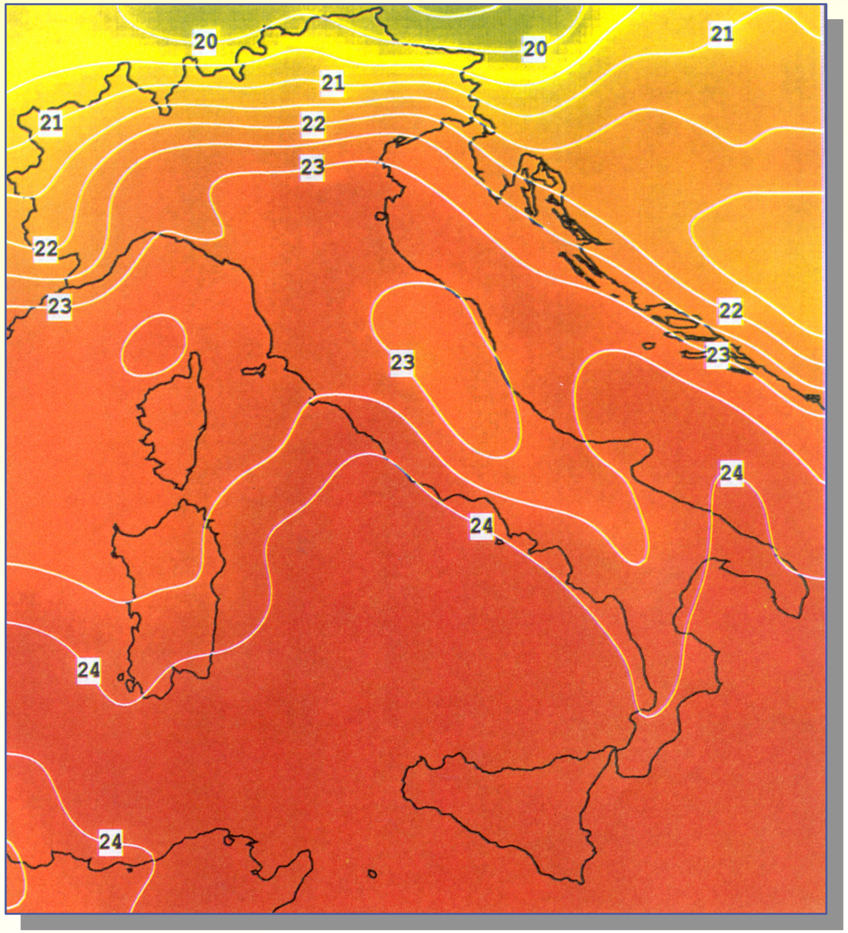
Distribution of solar radiation, in Italy

Daily solar radiation monthly average (MJ/m²)

February



July



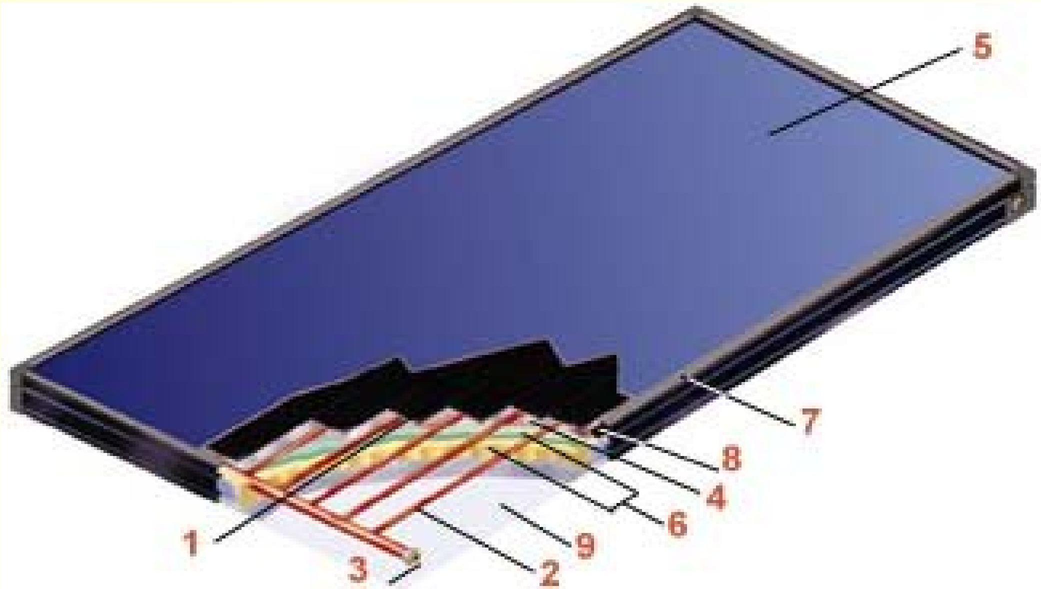
Components of a glazed collector

ABSORBER PLATE (1)
- copper and fins enhance heat transfer
- high absorptance and low emissivity thanks to a selective paint
- includes the TUBING GRID (2) and the PIPING CONNECTION (3)

TRANSPARENT COVERING (5)
- typically a relatively thick glass with high solar transmittance
- designed to reduce reflection
- tempered to maximise strength and durability

THERMAL INSULATION (6)
- polyurethane foam or mineral wool
- surrounding the absorber heat losses from the carrier fluid
- an attached ALUMINUM FOIL (4) acts as a barrier against out-gassing

CASING (7)
- plastic or aluminium
- ensures strength and resistance to the atmospheric agents
- equipped for roof integration or anchorage to the roof or stand
- differential expansion of frame and glazing is absorbed by GASKETS (8)
- the whole is closed by a BACK PLATE (9) usually made of PVC



Solar collectors

- ⇒ The conventional collector is the core element of a solar system for DHW or space heating
- ⇒ Low temperature panels supply the carrier fluid at a temperature usually lesser than 80 °C
- ⇒ Differently from concentrating collectors, conventional solar panels work with both direct and diffused irradiation, thus producing hot water in cloudy days also

Two large families:

- **Unglazed collectors**
- **Glazed collectors**

Unglazed collectors

Working principle: the water, flowing into the panels tubes, is instantly heated by the sunbeams and then sent to a storage tank or even directly to the final user

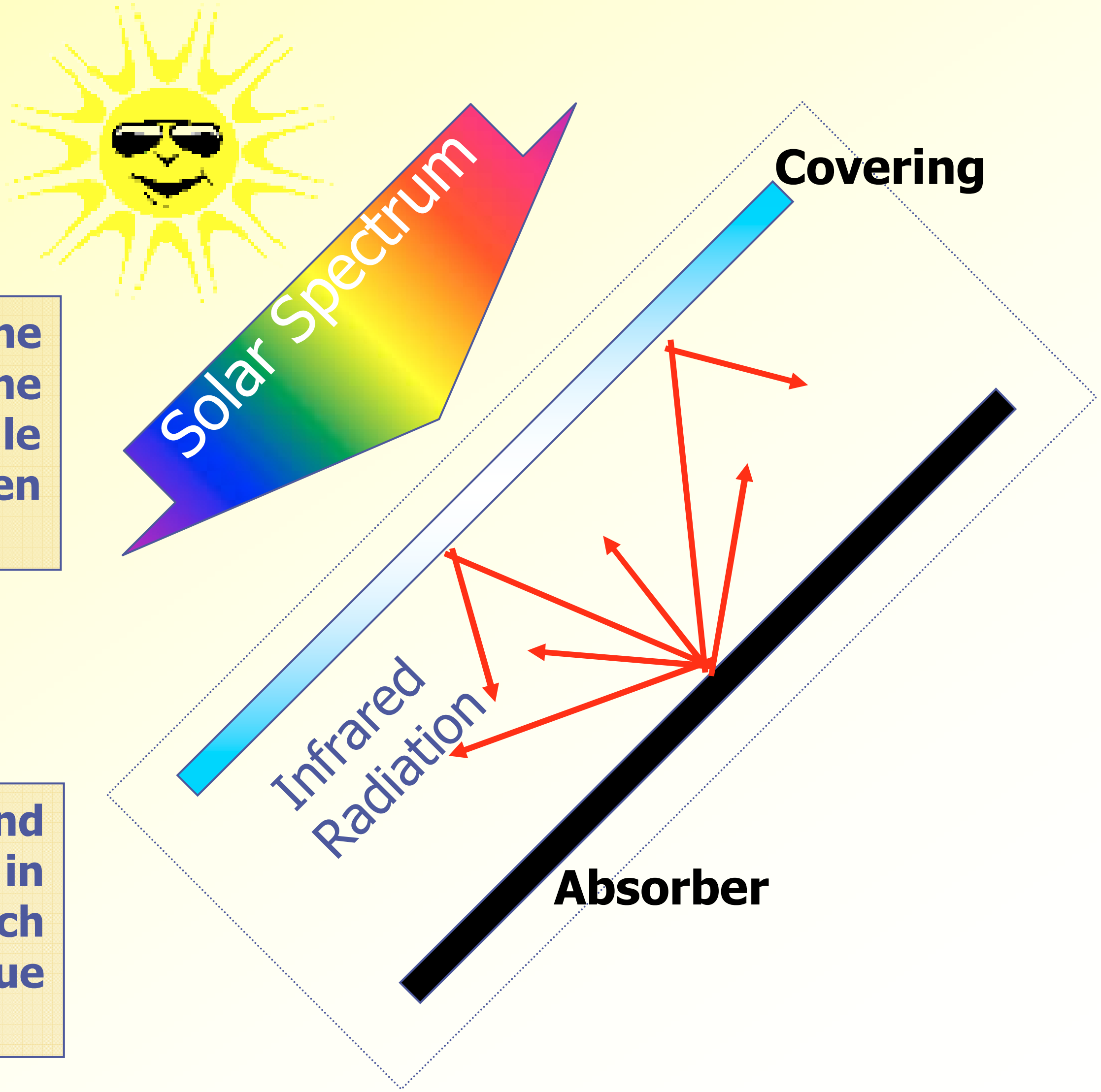
- low cost
- easy to install
- surrounding air temperature > 20 °C
- required temperature for water < 50 °C
- summer uses (camping, hotels, swimming pool, etc.)

Glazed collector basic principle

A glazed collector acts basically as a greenhouse:

The incident solar radiation is for the most part transmitted through the cover (the transmittance of a single glass cover is over 90%) and then trapped by the absorber.

The absorber plate warms up and emits in its turn radiant energy, but in the infrared spectrum, regarding which glass proves to be nearly opaque (greenhouse effect).



Glazed collectors

Working principle: the panels tubes, in which the carrier fluid flows, are in this case protected by a single or multiple transparent covering, made of glass or plastic, thus improving the performances thanks to the greenhouse effect

Most common type:

flat plate collector

Tubular collectors

An advanced type of glazed collector: **tubular collector**

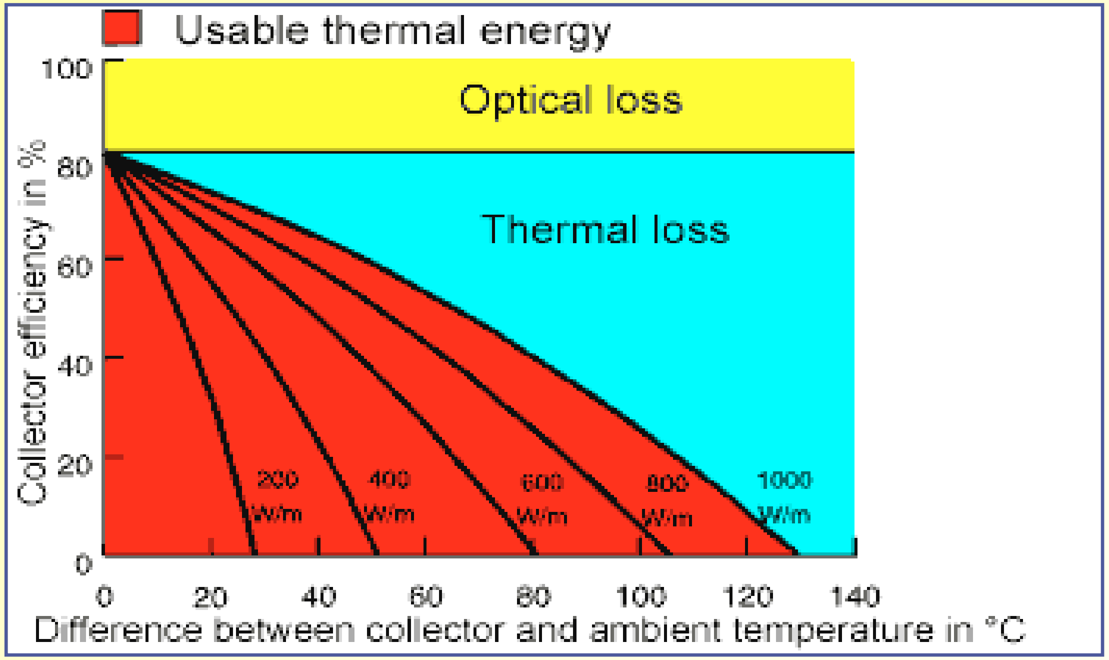
In this type of collector, the absorber strip is located in a pressure proof glass tube.

The heat transfer fluid flows through the absorber directly in a U-tube or in counter-current in a tube-in-tube system.

In case superior performances are required, the air, between the glass tube and the absorber inside it, is aspirated **(evacuated tubular collector)**.

Energy losses in a glazed collector

Energy supplied to the fluid = **Solar irradiation on collector area** − **Optical loss** − **Thermal loss**



Optical loss:

- given by $(1 - \tau\alpha)$
- possible reduction is limited
- at least 15÷20% for a flat plate glazed collector

Thermal loss:

- roughly proportional to ΔT
- increases dramatically when difference in temperature is high
- explains the use of ETC in severe climates

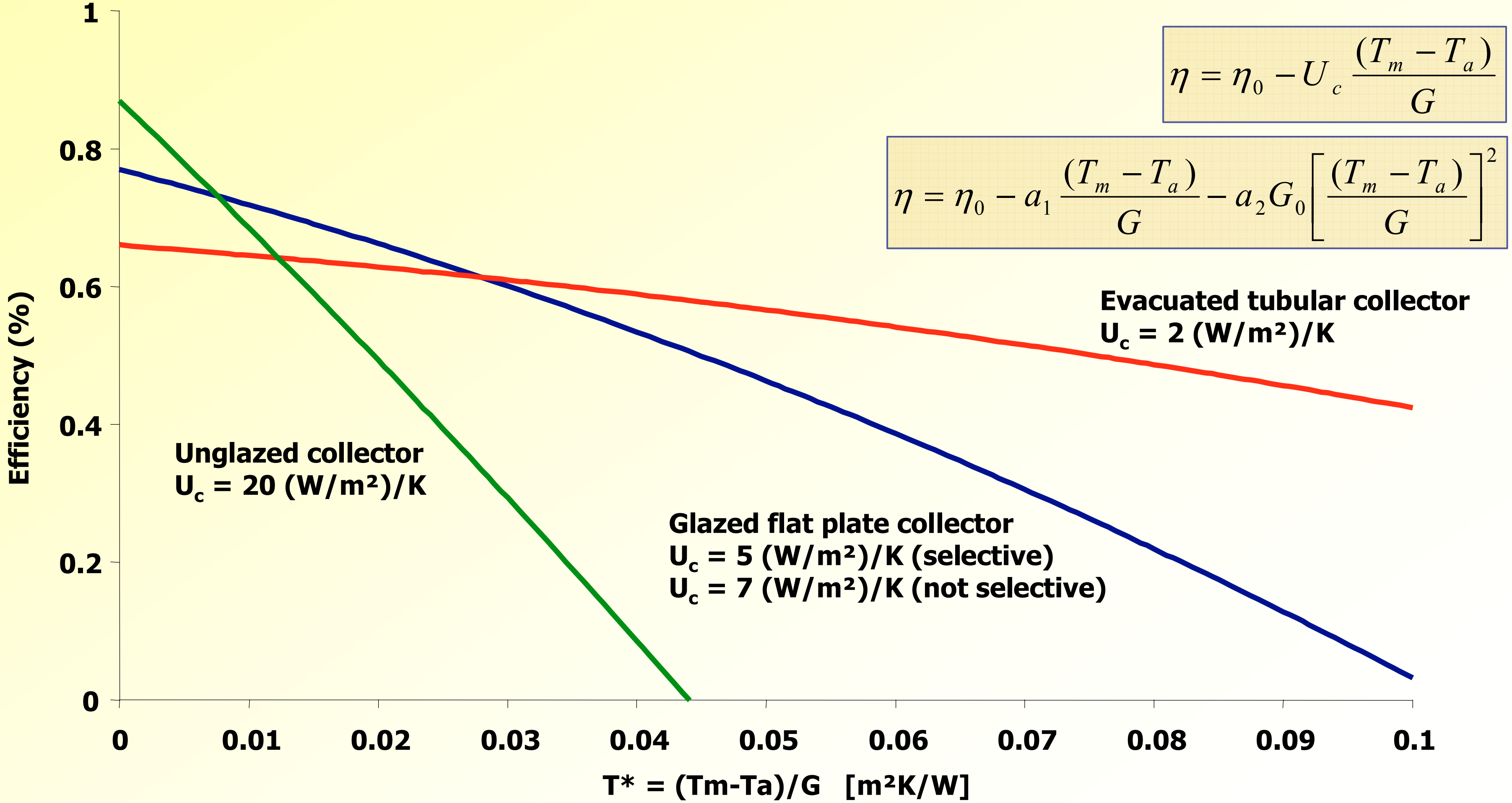
typically when ΔT is around 80 °C thermal loss is equal to absorbed irradiation (stagnation point)

Collector efficiency curve

Thermal performance of a solar collector is represented by means of a curve (or a simple straight line) which expresses the efficiency as a function of the reduced temperature.

$$\eta = \eta_0 - U_c \frac{(T_m - T_a)}{G}$$

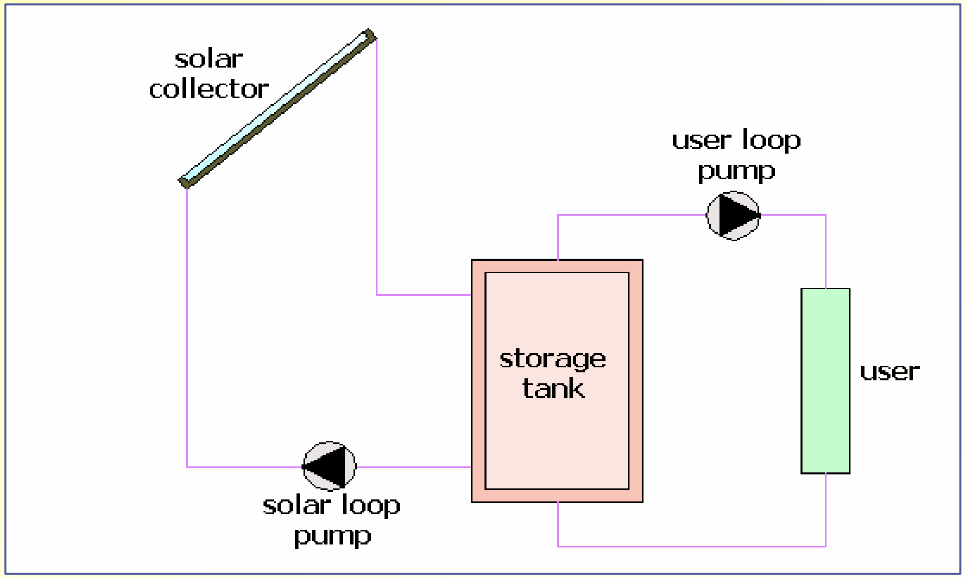
$$\eta = \eta_0 - a_1 \frac{(T_m - T_a)}{G} - a_2 G_0 \left[\frac{(T_m - T_a)}{G}\right]^2$$

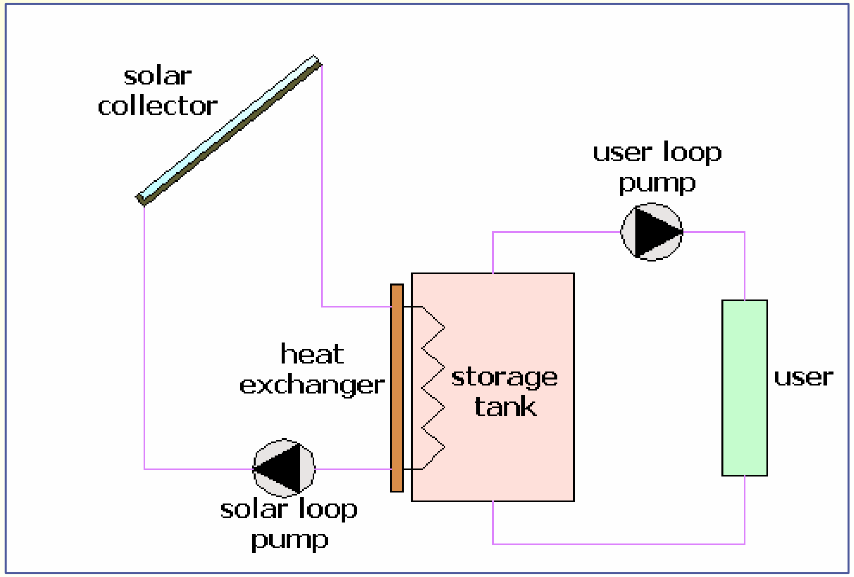


Open and closed loop systems

- Open loop system for non-freezing warm climates (danger of freezing is not present (Greece, Israel)
- Carrier fluid in the collectors is the same of the user
- Simplicity and economy are this system's advantages.
- Greater efficiency because there is not the additional loss due to heat exchanger

- Closed loop systems for continental climates (from Italy going to North:
- an anti-freeze solution is added to the carrier fluid which is different from the one that goes to the consumer
- Greater cost and volume
- no build-up of scaling in the collector.





Solar systems families: Factory Made

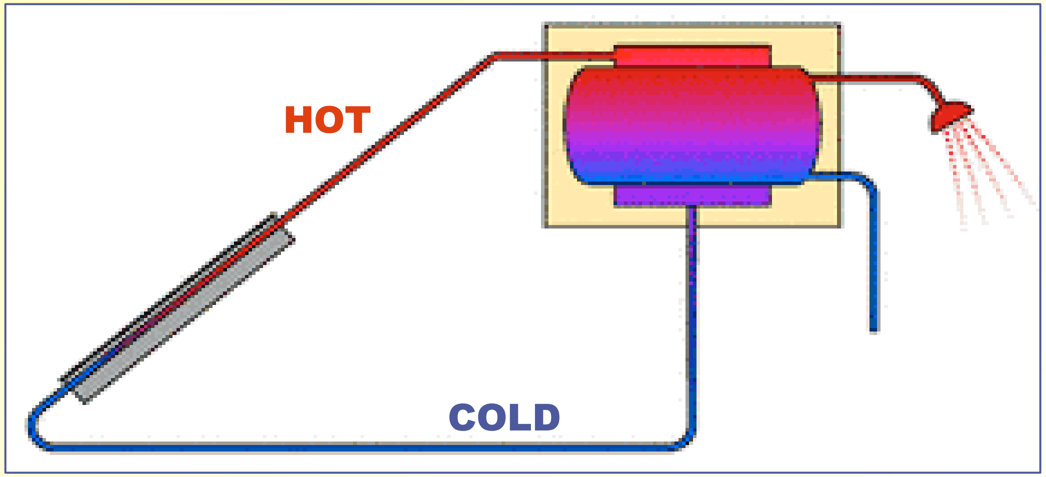
Solar systems can be divided into 2 main categories:

"Factory Made" Systems

- Pre-assembled by the manufacturer
- Natural circulation (thermosyphon)
- Single family
- Total area typically 4 ≤ m²

Thermosyphon systems

- circulation of the carrier fluid is provided solely by the heating of the same, which implies a reduction in its density thus generating a convective flow towards the top (passive systems with no moving parts)



- natural circulation of the carrier fluid must be facilitate by placing the storage tank in a higher position than the collector

- are usually characterised by a limited size (2 - 4 m²) and commercialised as "factory made" systems

- generally back-up is electric and integrated in the storage tank

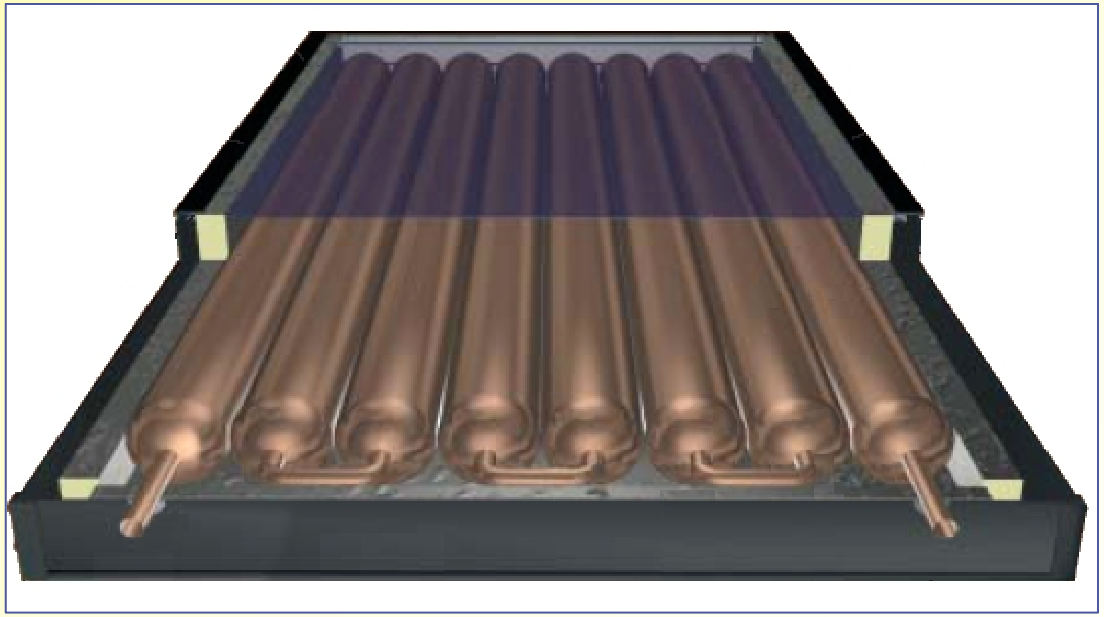
Integrated Collector Storage

The ICS system, also called batch water heater, is a not much widespread type of passive system.

The water is produced and stored inside the collector.

main remarks

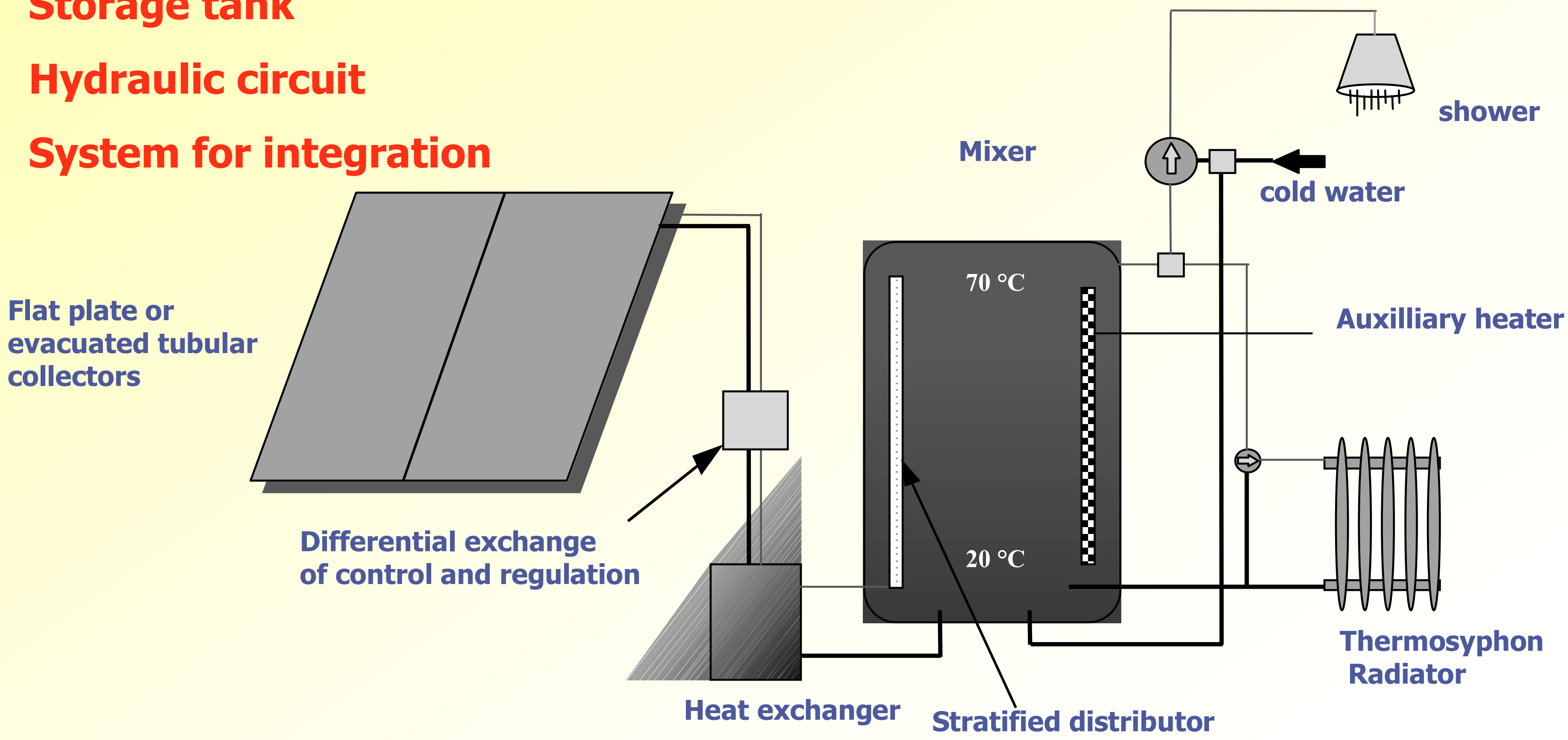
- suitable only for mild climates where there is no risk of freezing
- efficient heat transfer to the water
- superior simplicity, compactness, and economics
- unfavourable heat loss coefficient
- profitable storage only in the very short term
- typically used as a pre-heater to an existing gas or electric water heater



Components of a plant

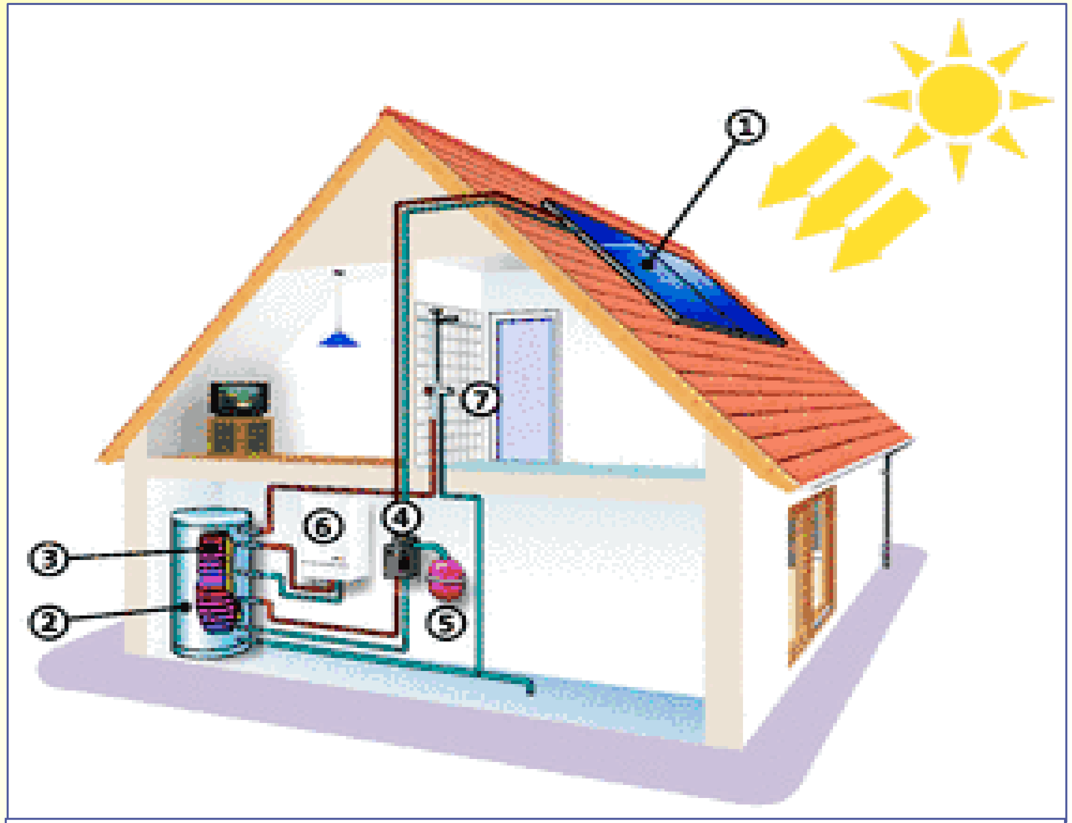
A plant for low temperature heat application using solar energy is comprises of:

1) system for collection and transfomation of energy
2) Storage tank
3) Hydraulic circuit
4) System for integration



Forced circulation systems

- circulation of the carrier fluid is provided through a pump run by a differential thermostat when ∆T between the fluid out from the collectors and the water in the tank is 5÷10 °C
- are mostly utilised when the positioning of the tank over the collectors is not possible or the length of the piping is excessive for achieving a natural circulation of the carrier fluid
- normally are intended for multi-family houses and commercialised as "custom built" systems
- the back-up can be a gas or oil heater with an additional tank in series



1. Collector - 2. Storage Tank - 3. Heat exchanger - 4. Control Unit - 5. Expansion Vessel - 6. Back-up Heater - 7. User

Solar systems families: Custom Built

"Custom Built" Systems

- Assembled with properly chosen components
- Forced circulation (pumped)
- Collective users
- Total area usually > 10 m^2

"Quality assurance" in solar thermal

The "Quality assurance" corresponds

SOLAR COLLECTORS ⟺ **Standard EN 12975**

Factory Made
SOLAR SYSTEMS ⟺ **Standard EN 12976**

Custom Built
SOLAR SYSTEMS ⟺ **Standard ENV 12977**

The Solar Energy Laboratory

External area of Laboratory

Solar Collector and Overall System Test Laboratory at ENEA Research Centre Trisaia

Collector test facilities

The Laboratory performs:

- efficiency tests both on glazed and unglazed solar collectors according to European (EN 12975) and international (ISO 9806-1 and 3) standards;
- qualification tests (Internal pressure, Internal and External thermal shock, etc.) according the same standards.

System test facilities

Furthermore the Laboratory is able to asses the daily and annual performance of solar domestic hot water systems according to **EN 12976** and **ISO 9459/2** standards.

Test sequence for solar collectors

Standard EN 12975:

- Internal pressure
- High-temperature resistance
- Exposure test (dry stagnation)
- External and Internal thermal shock
- Rain penetration
- Internal pressure (retest)
- Mechanical load
- Thermal performance (efficiency test in steady-state and transient condition, time constant, thermal capacity, Incident Angle Modifier, pressure drop)
- Impact resistance (optional)

EN 12975: Qualification test

High-temperature resistance - Exposure test (stagnazione a secco) - External and Internal thermal shocks

The aim of these tests is to check the resistance of the collector to:

- High level of solar irradiance (> 1000 W/m^2) without water;
- Exposure of collector to the ambient conditions without water until at least 30 days with minimum level of solar energy (14 MJ/m^2);
- Resistance to external and internal thermal shock.

EN 12975: Qualification test – Rain penetration

The objective of this test is to assess the extent to which glazed collectors are resistant to rain penetration.

Apparatus: Closed box with artificial rain generation

Test procedure:

- Exposure of the collector to controlled rain (T<30°C) for a period of 4 hour, with the simultaneous heating of the collector through hot water re-circulation (T>50°C).

Results:

- No vapour condensation
- Collector weight difference before and after the test < **5 g/m²**

EN 12975: Qualification test – Mechanical load

The objective of this test is to assess the extent to which the transparent cover and the mountings of the collector are able to resist at positive and negative pressure loads due to the effect of snow and wind.

Apparatus: a system with uniformly distributed set of suction cups, each connected to air compressed pistons.

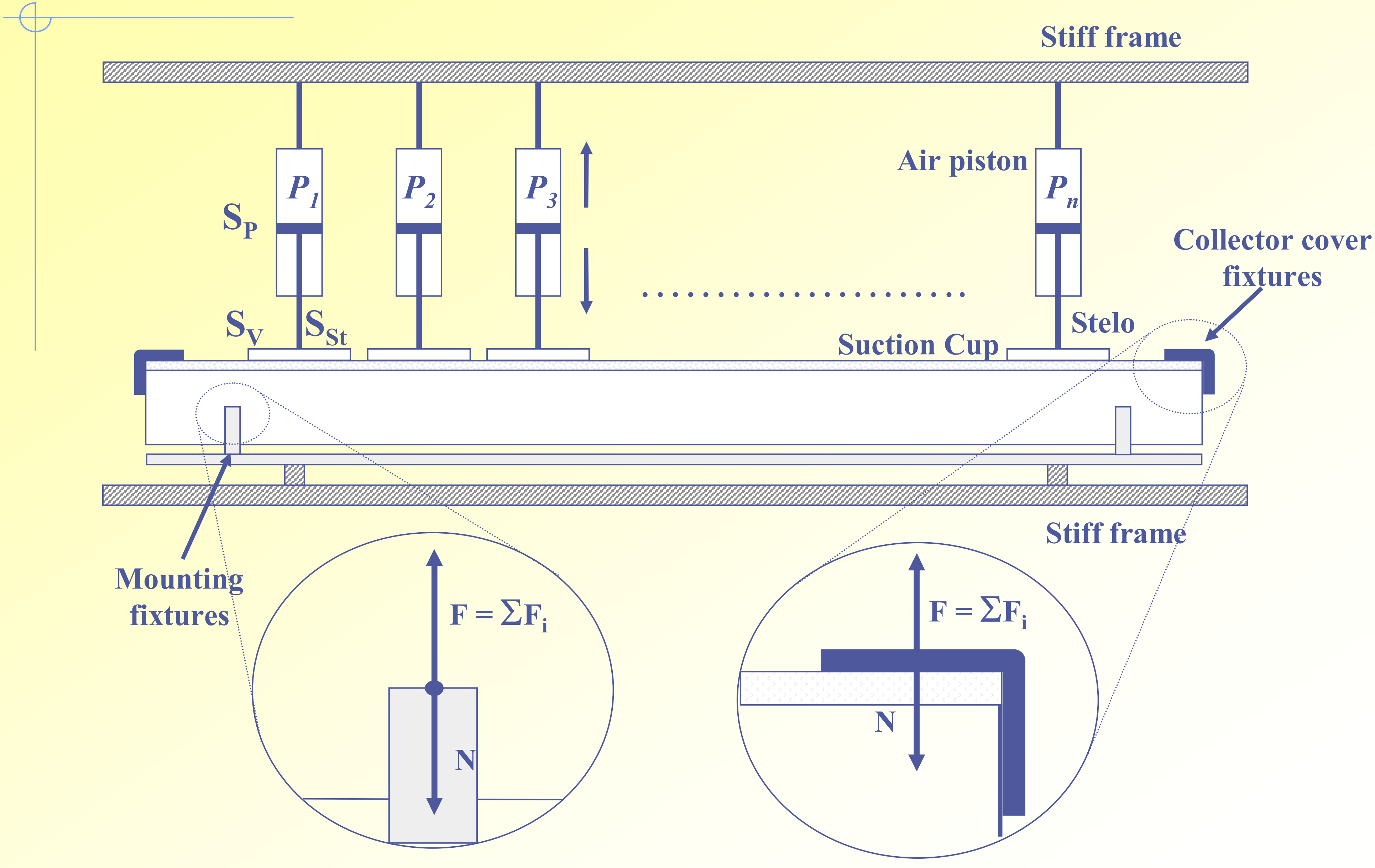
Test procedure:

- Positive pressure over the collector cover
- Negative pressure generated by the means of a uplifting strength

Range of applied pressure:

- 100 – 1000 Pa with a step of 100 Pa

EN 12975: Qualification test – Mechanical load



EN 12975: Qualification test: Impact resistance

Scope: to simulate the effect of hails on collector glazing

Scheme used: system at verticle impact

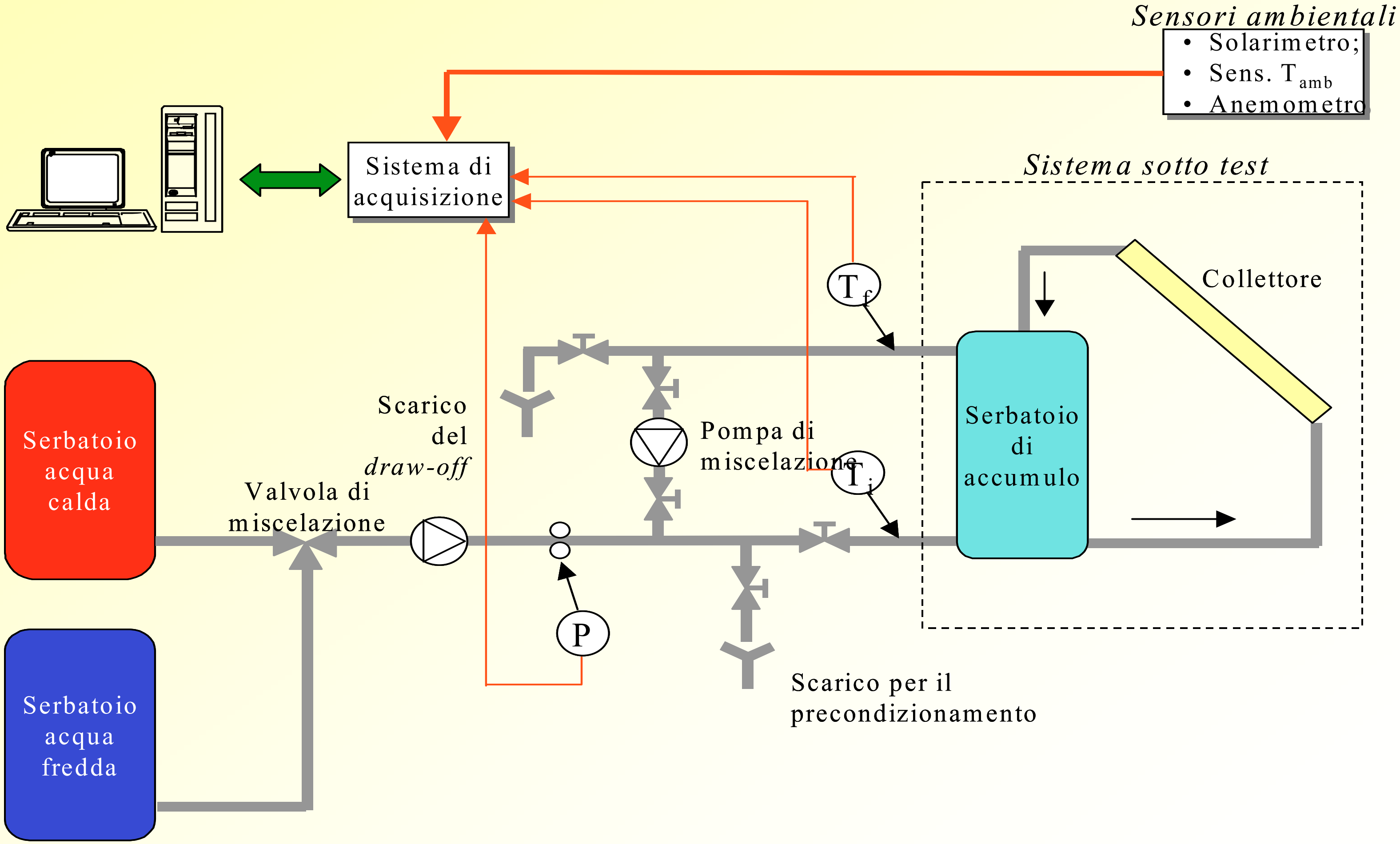
Articolazione del test:

- A series of 10 contacts realised using a steel sphere weighing 150 gm falling from a distance in the range 20 cm to 2 m with inter spacing of 20 cm.

Test foreseen as per norms for the systems

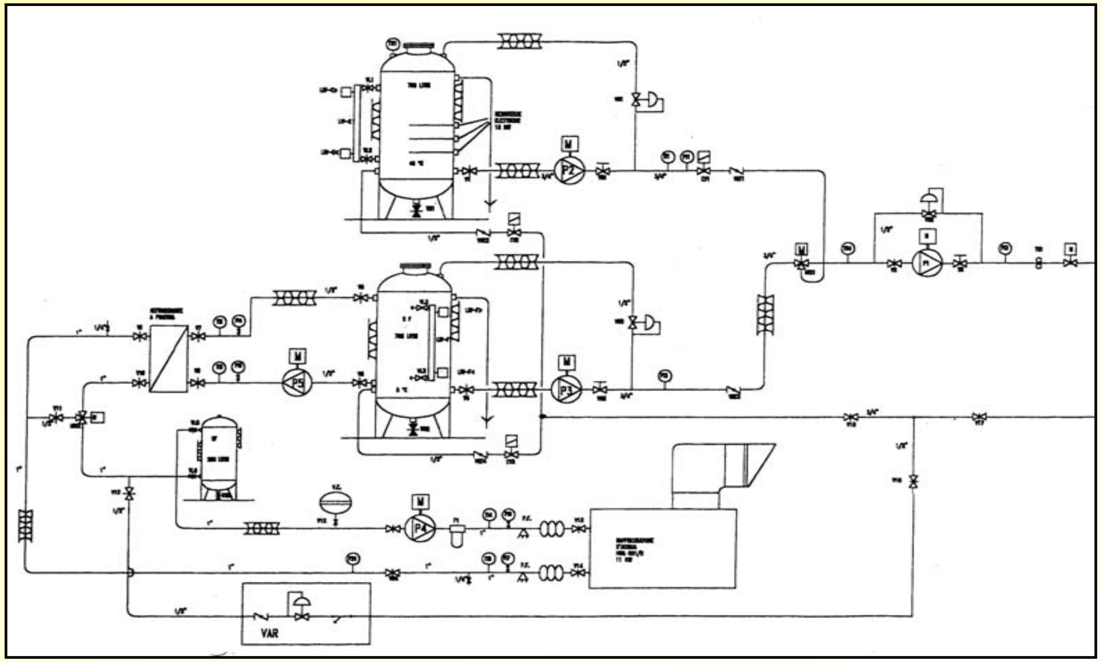
Standard EN 12976:

- outdoor characterization based on daily performance and energy performance prediction on yearly basis.



System Test Facilities

The plant allows the simultaneous performance characterization of two SDHW systems arranged in parallel.
The equipment consists of a control system that adjusts water temperatures and flow rates at the inlet of solar systems.



The adjustments are accomplished through digital PID, provided by self-tuning and controlled through a PLC.

A fully automatic data acquisition system controls the different sections of the plant and collects thermo-hydraulic and meteorological data.

Articolazione dei test

1 – Determination of daily thermal performance

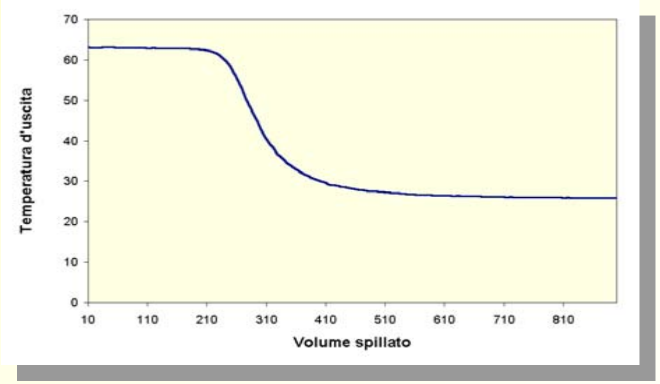
The test comprises of at least six days testing, each sub-divided in the following three phases:

- Pre-condition of system
- Exposition of Solar radiation
- Evening Draw-off

$$Q_{3V} = \sum_i \Delta Q_i = \sum_i \left[\rho c_p \Delta V_i \left(T_{out,i} - T_c\right)\right]$$

$$f(V_i) = \frac{\Delta Q_i}{\Delta V_i} \frac{1}{Q_{3V}}$$

Draw-off profile



2 – Determination of losses during the night

Test foresee:

- Pre-conditioning of system (T initial > 60°C)
- night exposure
- Final temperature evaluation attained by the system

$$U_S = \frac{\rho c_p V_s}{\Delta t} \ln\left(\frac{T_i - T_{an}}{T_f - T_{an}}\right)$$

3 – Draw-off file with initial mixing

Test foresee:

- Pre-conditioning of system (T initial > 60°C)
- System draw-off with release of water at a temperature of 30°C less than that of pre-conditioning.

Performance based on longer duration (Day by Day Method)

The method makes it possible, through an iterative process extended over 365 days/year, to know the energy stored by the system, annually.

The method is articulated according to a sequence of steps to be repeated daily, during which is calucalted:

- daily energy stored by the system + eventual residual energy stored during previous day;
- Energy contained in volume of water effectively used by the consumer;
- temperature reached by the system at the end of draw-off ;
- Amount of energy lost during night;
- temperature recorded for the system on the successive day.

I dati cosi ottenuti consentono di stimare:

$$Q_{annua} = \sum_{i=1}^{365} Q_{e,i} = \sum_{i=1}^{365} \left(Q_i \int_0^{V_i} f(V)dV \right)$$

$$\eta = \frac{Q_{annua}}{A_c H_{annua}}$$

Algoritmo utilizzato:

Passo 1: Inizializzazione (giorno #1)

1. $Q_1 = [\alpha_0 + \alpha_H H_1 + \alpha_T (T_{a,1} - T_{c,1})]$
2. $Q_{s,1} = Q_1 \int_0^{V_1} f(V)dV$
3. $T_{e,1} = T_{c,1} + \frac{Q_1 - Q_{s,1}}{C}$
4. $Q_{L,1} = C(T_{e,1} - T_{an,1})\left[1 - \exp\left(-\frac{U_S \Delta t}{C}\right)\right]$
5. $T_{s,2} = T_{c,1} + \frac{Q_1 - Q_{s,1} - Q_L}{C}$

Passo 2: Ciclo iterativo

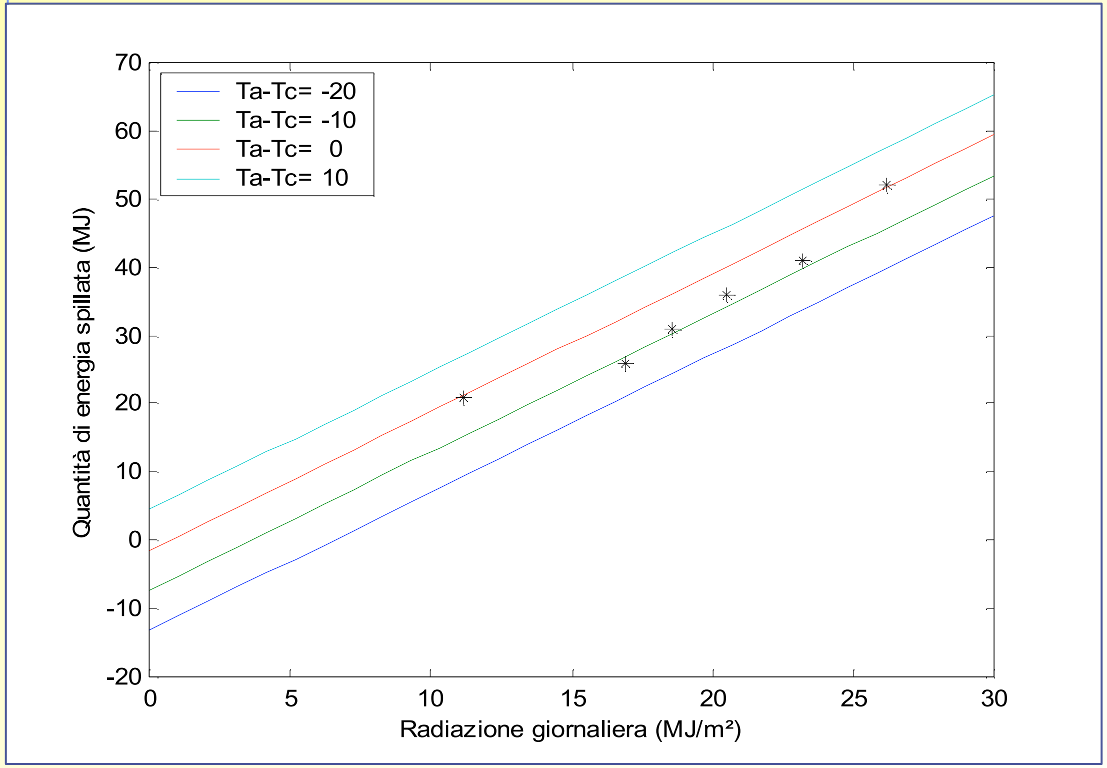
Per i = 2:365 step 1,
inizio ciclo:

1. $Q_i = C(T_{s,i} - T_{c,i-1}) + [\alpha_0 + \alpha_H H_i + \alpha_T (T_{a,i} - T_{c,i})]$
2. $Q_{s,i} = Q_i \int_0^{V_i} f(V)dV$
3. $T_{e,i} = T_{c,i} + \frac{Q_i - Q_{s,i}}{C}$
4. $Q_{L,i} = C(T_{e,i} - T_{an,i})\left[1 - \exp\left(-\frac{U_S \Delta t}{C}\right)\right]$
5. $T_{s,i+1} = T_{c,i} + \frac{Q_i - Q_{s,i} - Q_{L,i}}{C}$

Fine ciclo.

EN 12976: Thermal performance of solar systems

Characterisation of daily performance: Consists of the evaluation of energy stored by the system under different climatic conditions and various temperature for system loading.



The energy Q stored by system is correlated to the energy H incident on the collector surface and difference between T_{amb} and T_c, *as per the following relation*:

$$Q = \alpha_0 + \alpha_H H + \alpha_T (T_a - T_c)$$

SOLAR MERKET IN ITALY

At the end of 2000 a large solar thermal programme was launched in Italy. **Overall installed capacity (during the year 2001) is more or less of 350.000 m^2. Area of un-glazed solar collectors installed each year is about 2.000 m^2 and this value is almost stable over the last couple of years.**

However, due to the market penetration of modern solar technologies at faster and faster rates, **significant increase in the sale of solar collectors (approx. 15-20%) has been observed during the last couple of years.**

Market is developing for the double tube evacuated collector.

Considering the additional foreseen incentives made available during the coming years for both public and private sectors along with others specific incentives for the companies, significant market development would certainly be helpful to achieve the set-target of installing nearly 3 millions m^2 up to 2012 (target set forth in the white book).

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THANKS