Lecture 4:
Solar Thermal Heat Utilization

http://www.cs.kumamoto-u.ac.jp/epslab/APSF/

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Time and Venue:

Wednesdays: 10:20 – 11:50, Room No.: 208

Contents:

1. **Principles**
2. **Technical Descriptions**
3. **Economic Analysis**
4. **Environmental Analysis**

1. Principles

Solar thermal heat systems are installations converting solar radiation into heat in order to heat swimming pools, produce domestic hot water, cover the demand for space heating or supply other heat consumers.

Physical principles of energy conversion:
Absorption, emission, reflection and transmission

•The basic principle of solar thermal utilization is *the conversion of short-wave solar radiation into heat* (photo thermal conversion process).
•If radiation incidences on material a certain part of the radiation is absorbed. A body's capacity to absorb radiation is called absorbing capacity or **absorption *α***
•An ideal black body absorbs radiation at every wavelength and therefore has an absorption coefficient equal to **one**.

1. Principles…cont.

•**Emission ε** represents the power radiated by a body.
•The relationship between **absorption α and emission ε** is defined by Kirchhoff's law . For all bodies the ratio of specific radiation and the absorption coefficient is constant at a given temperature, and in terms of its amount, equal to the specific radiation of the black body at this temperature.
•This ratio is exclusively a functionality of *temperature and wavelength*.
•Matter with **a high absorption capacity** within a defined wave range also has a high emission capacity within that same wave range.

Reflection and transmission:
•The reflection coefficient *ρ describes the ratio of the reflected to the incident* radiation.
•The transmission coefficient *τ defines the ratio of the radiation transmitted* through a given material to the entire radiation incident

$$\alpha + \rho + \tau = 1$$

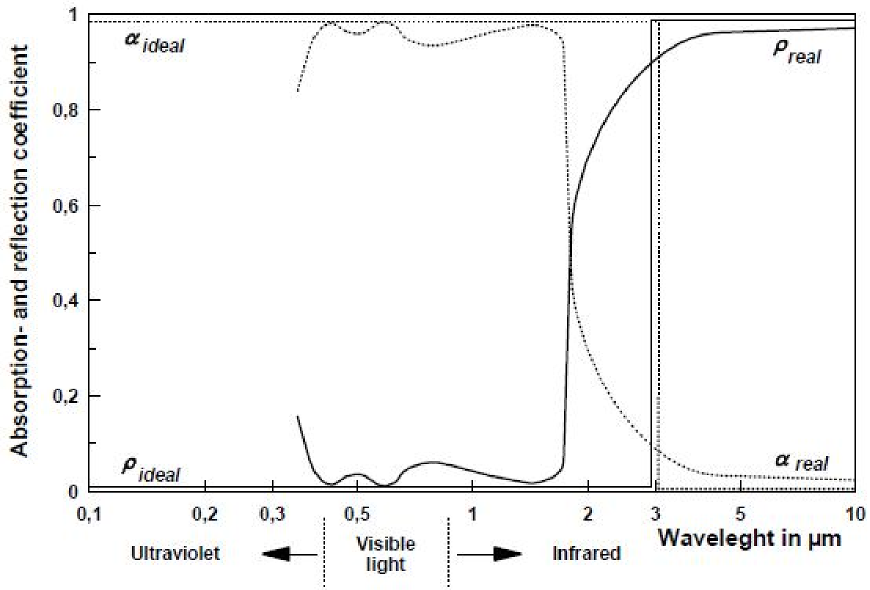
1. Principles...cont.

Optical features of absorbers

Absorbers have to *absorb radiation and partially convert it into heat.*
The absorber → for opaque for radiation (*τ = 0)*
Therefore: α + ρ =1

An ideal absorber:
*no reflection any **short-wave radiation** (*ρ = 0) and thus –*
– completely absorbs solar radiation within this wave
range (*α = 1).*
For long-wave radiation above a certain boundary wavelength, the
situation is exactly the opposite. Given an ideal absorber, it reflects all of the radiation and does not absorb any at all.

Absorption (*α) and reflection coefficient (ρ) of an ideal (ideal) and a standard real* absorber (*real)*



Within the spectrum of solar irradiance, the reflection coefficient ρ_{real} *is*
close to zero, in the infrared spectrum (> 3 µm) close to one. The absorption coefficient α_{real} *demonstrates exactly the opposite.*

1. Principles…cont.

Optical features of absorbers

Table 4.1 Optical features of absorbers (according to /4-1/)

		Solar irradiance			Infrared-radiation			α_S/ε_I
		α_S (ε_S)	τ_S	ρ_S	α_I (ε_I)	τ_I	ρ_I	
Selective	Black nickel	0.88	0	0.12	0.07	0	0.93	12.57
Absorber	Black chromium	0.87	0	0.13	0.09	0	0.91	9.67
	Aluminium grid	0.70	0	0.30	0.07	0	0.93	10.00
	Titanium-oxide- nitride	0.95	0	0.05	0.05	0	0.95	19.00
Non-selective absorber		0.97	0	0.03	0.97	0	0.03	1.00

- Absorption coefficient for various different materials, *the transmission and reflection coefficients* for the solar irradiance and the infrared range of the solar radiation spectrum.
- Compared to the non-selective absorber, selective absorber surfaces show high degrees of α_s/ε_I
- α_S is the absorption coefficient in the spectrum of solar irradiance, ε_I is the emission coefficient in the infrared radiation spectrum.
- Such surfaces are thus also called α/ε-surfaces.
- Titanium oxide with 19 for example shows a particularly high α_s/ε_I-ratio.

1. Principles…cont.
Optical features of covers

✓In order to reduce the convective thermal losses of the absorber to the environment, in many cases absorbers used in solar thermal systems have a **transparent cover.**

✓**Ideal covers** have a transmission coefficient of ***one*** in the range of solar radiation, whereas reflection and absorption coefficient equal zero in this spectrum.

In real life such conditions cannot be achieved

Table 4.2 Optical features of covers (according to /4-1/)

	Solar spectrum			Infrared radiation		
	α_S (ε_S)	τ_S	ρ_S	α_I (ε_I)	τ_I	ρ_I
Sheet glass	0.02	0.97	0.01	0.94	0	0.06
Infrared reflecting glass (In_2O_3)	0.10	0.85	0.05	0.15	0	0.85
Infrared reflecting glass (ZnO_2)	0.20	0.79	0.01	0.16	0	0.84

•Glass fulfils the required optical features within the luminous spectrum very well.
•Infrared light emitted by the collector , however, cannot pass through, but is mainly absorbed.
•If the degree of absorption is high, the temperature of the glass cover rises and the radiation losses to the environment are correspondingly high
•These losses can be reduced by vacuum-coating of layers that reflect infrared light.

1. Principles…cont.

Energy balance

General energy balance: describes the general energy balance of a medium that absorbs radiation and converts it into heat:

$$\dot{G}_{G,abs} = \dot{Q}_{conv,abs} + \dot{Q}_{rad,abs} + \dot{Q}_{refl,abs} + \dot{Q}_{cond,,abs} + \dot{Q}_{useful}$$

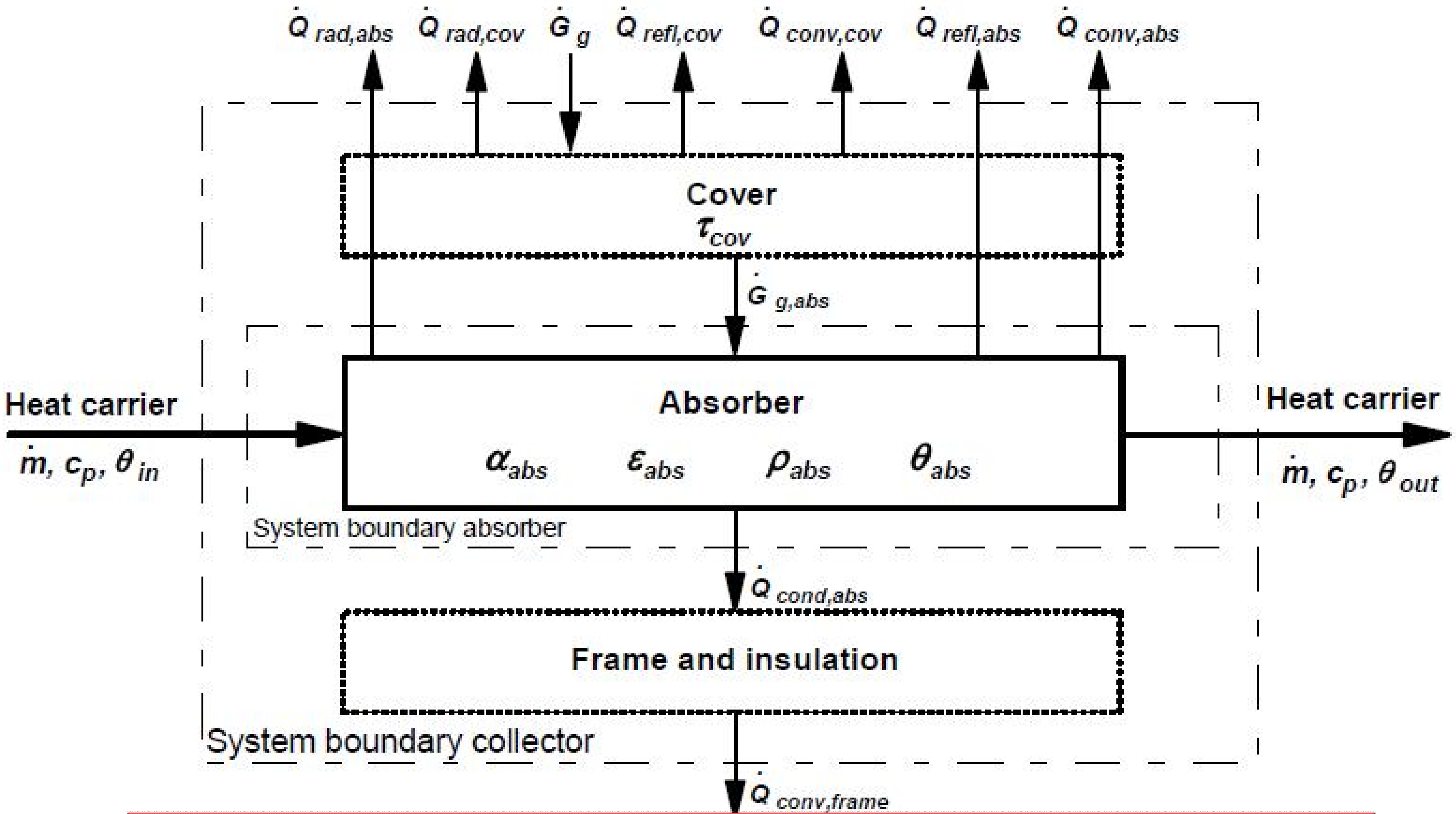
$\dot{G}_{G,abs}$ is the entire global radiation incident on the absorber surface; $\dot{Q}_{useful}$ is the utilisable thermal flow. In addition there are four different loss flows:

- convection losses of the absorber to the ambient air $\dot{Q}_{conv,abs}$,
- long-wave radiation losses of the absorber $\dot{Q}_{rad,abs}$,
- reflection losses of the absorber $\dot{Q}_{refl,abs}$,
- thermal conductivity losses $\dot{Q}_{cond,abs}$.

1. Principles…cont.

Energy balance

In solar thermal systems the absorber is normally part of a collector. Other components of the collector are frame, cover and insulation.



Stationary energy balance at the collector or the absorber

1. Principles…cont.

Efficiency and solar fractional savings

The efficiency η of the conversion of solar radiation energy into useable heat in the collector results from the ratio of the useful thermal flow transported by the heat transfer medium $\dot{Q}_{useful}$ to the global radiation incident on the collector

$$\eta = \dot{Q}_{useful} / \dot{G}_g$$

In many cases the solar fractional saving F_s is significant. It is defined in different ways by the relevant literature. In this context, it is the ratio between the utilisable emitted energy through conversion of solar radiation by the solar installation ex-storage to the actual demand for heating, domestic warm water or process heat that is to be covered partly or entirely by solar energy

$$F_s = 1 - \frac{\dot{Q}_{aux}}{\dot{Q}_{demand}}$$

2. Technical description

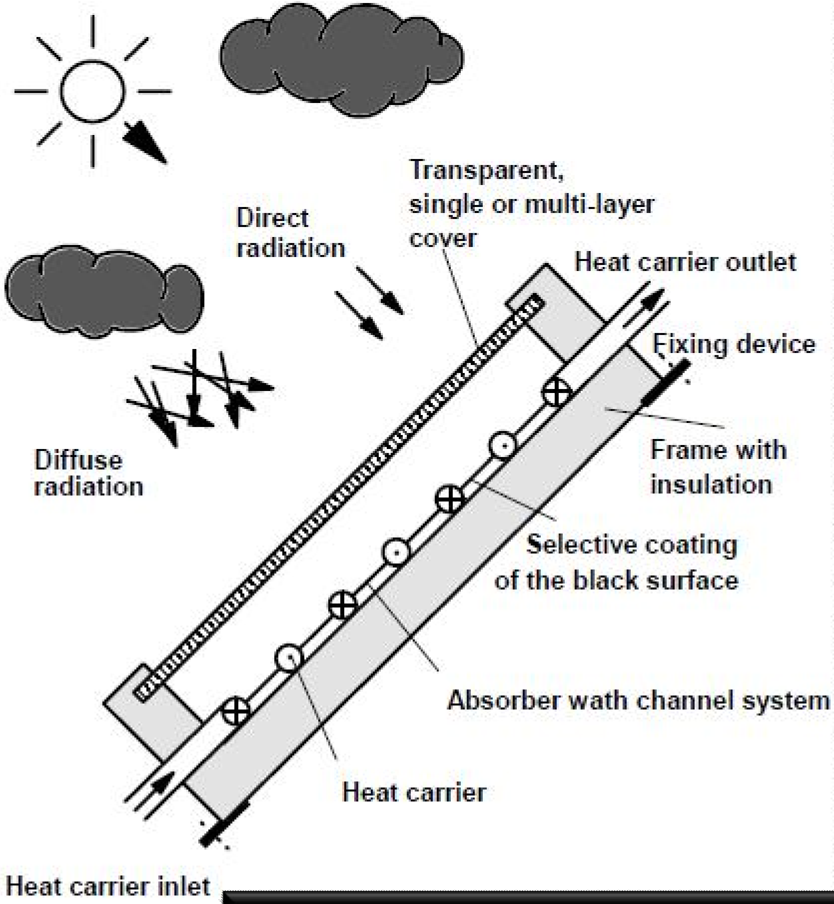
Main components: ***Collector***
Essential component: ***liquid or gaseous heat transfer medium and pipes to transport the heat transfer medium***
Others:
**heat storage with none, one or several heat exchangers plus, for certain designs,*
**pumps with a drive to maintain the heat carrier cycle*
**sensors and control instruments*

Collector consists of:
- Absorber
- Transparent
- Cover
- Frame insulation
- heat insulation
- heat carrier inlet and outlet

2. Technical description

Collector

Collector: *converting solar radiation into heat*. Part of this heat is subsequently transported by a heat carrier flowing through the collector.



liquid-type flat plate collector

Cover

Transparent material:

- Single pane
- Solar compound pane
- Plastic plates or sheets

Box

Material:

- Aluminum
- Galvanized steel plate
- Plastic
- Wood

Insulation

Material:

- Polyurethane
- Mineral wool
- Fiber-glass wool

Absorber

black

Material:

- Metall (Cu, Al, Fe)
- Plastic (e.g. Polypropylene, Polyethylene, EPDM)

Heat carrier

Material:

- Water (with antifreeze)
- Air

2. Technical description

Absorber

Characteristics:

•*Converts short-wave radiation into heat (photo-thermal* conversion)

•Function of “radiation absorption “ is carried out by a type of absorber material with quite a high absorption capacity within the luminous spectrum

•Low emission capacity, is aimed for in the thermal radiation wave spectrum

•In addition, the absorber has to enable a good heat transfer to the heat carrier and also be temperature-resistant, as normally temperatures of up to 200 ^{o}C occur in an insulated absorber with glass cover and selective coating.

•In concentrating collectors temperatures are generally even higher.

Materials for absorber:

- Mainly copper and aluminum.
- Market increase of solar thermal collectors is continuing, polymeric materials and
- steel could become more important in the future.
- In the simplest case, this basic material is painted black on the side receiving radiation (maximum absorber temperature approximately 130 ^{o}C).
- For a large number of absorbers, this side is also coated selectively (maximum absorber temperature approximately 200 ^{o}C).

2. Technical description

Absorber..cont.

Other important parts:

•The heat carrier flows through the channels inside the absorber.

•The energy proportion of the solar radiation on the absorber converted into heat inside the absorber is partly transported to the heat carrier (by heat transfer).

•The system of pipes in the absorber can vary in terms of pipe material, pipe cross-section, length and pipe allocation within the collector.

2. Technical description

Cover

Characteristics:
**cover of collectors ought to be as transparent for solar* radiation as possible and retain the long-wave thermal reflection of the absorber.
*At the same time it has to reduce convective thermal losses to the environment.

Materials:
Suitable materials are glass sheets, synthetic plates or synthetic foils (e.g. made of polyethylene or Teflon).

Notes for synthetic covers: The high level of material stress often leads to brittle and tarnished synthetic materials.
Furthermore, the outer area can also be scratched very easily by atmospheric exposure. Thus transmission values of synthetic covers are often not stable long-term.

<u>most applications for cover :glass characterized by</u>:
•high level of transparency and resistance to hail.
•low iron contents can reduce the absorption capacity in the short-wave spectrum → Thus it is avoided that the glass sheet heats up.
•Convective thermal losses to the colder environment are reduced.
•Often infrared-reflecting layers are vacuum coated on the bottom side of the cover to reflect the long-wave heat radiation from the absorber to the cover into the direction of the absorber.
•Thus losses can be reduced even further.

2. Technical description

Collector Box & other components

The collector box: holds the components required for radiation transmission, absorption, heat conversion and insulation.

Materials:
aluminum, galvanized steel plate, synthetic material or wood.

Functions:
It gives the collector mechanical firmness and makes it environment-proof. However, a low level of ventilation has to be ensured in order to reduce high or low pressure caused by temperature fluctuations and remove possible humidity.

Other components. *Thermal insulation made of standard insulation material (e.g.* polyurethane, glass fibre wool, mineral wool) belongs to the group of other components.

2. Technical description
Installation

Collectors are mainly installed on pitched roofs; in this respect the integration into the roofing or the on-roof installation, on top of the tiles, are common technical solutions.

*Integration into the roof is less visible and cheaper than the on-roof installation. It is preferably used for new buildings or larger collector arrays on already existing roofs. Additionally, *roofing costs are saved for the parts of the roof where the collectors are installed*.

*Installation of collectors on flat areas (e.g. on flat roofs, in gardens) facilitates optimal adjustment and incline when compared to the installation on pitched roofs.

- ✓Mainly standardized frames are used to integrate the collector.
- ✓Frames need to be arranged so that shading is avoided.

2. Technical description

Collector designs and practical applications

According to the heat carrier and the way they absorb radiation:

− Non-concentrating swimming pool liquid-type collectors
− Non-concentrating glazed flat-plate liquid-type collectors
− Non-concentrating glazed air collectors,
− Radiation-concentrating liquid-type collectors
− Radiation-concentrating air collectors

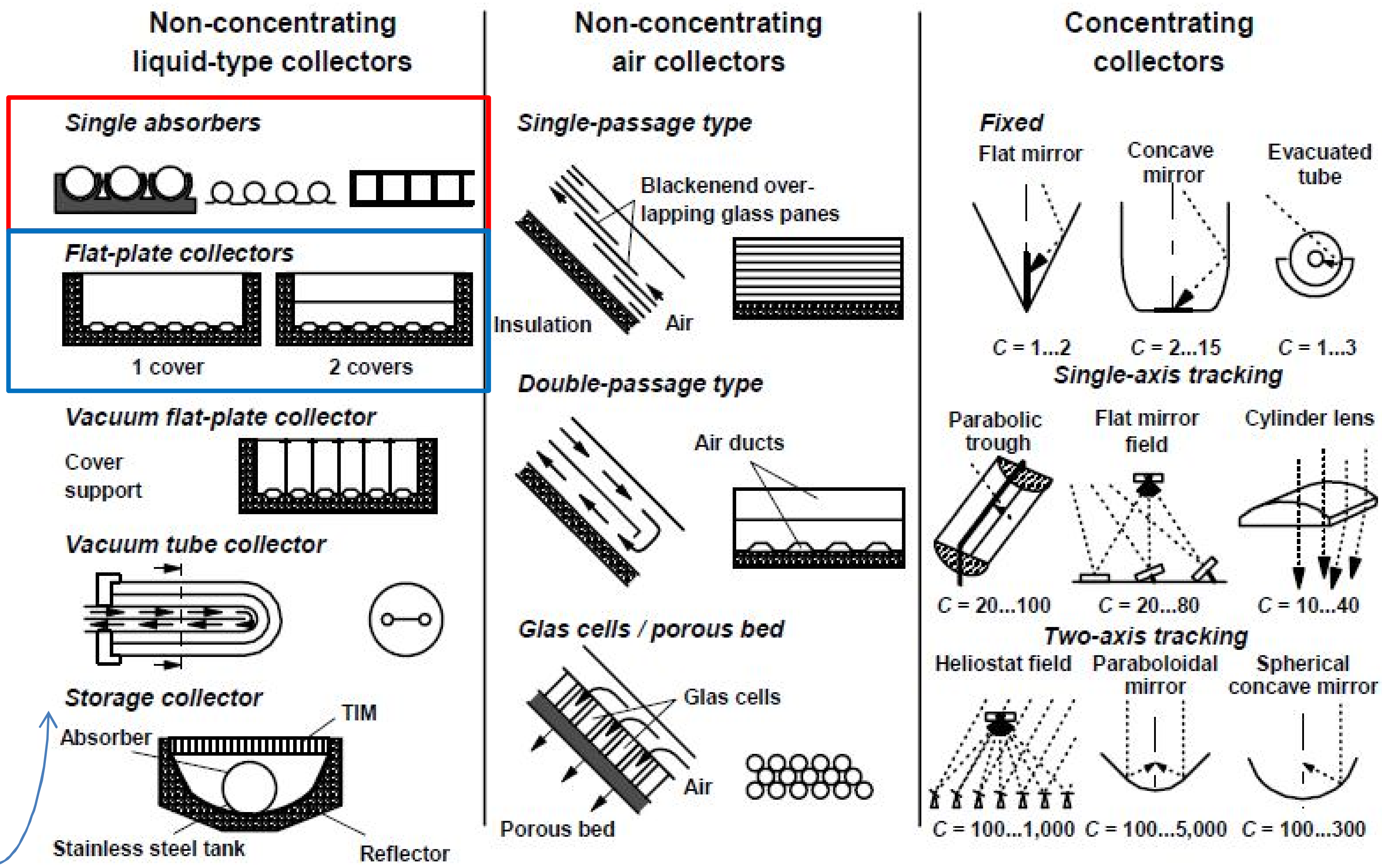


Fig. 4.4 Overview of different collector types (C concentration ratio; defined as the ratio of the optically active collector area to the absorber area exposed to radiation; TIM transparent insulation material; see e.g. /4-2/ and various other sources)

a special type of flat-plate collector

2. Technical description
Collector designs and practical applications…cont.

Non-concentrating swimming pool liquid-type collectors:

•The basic design (used most frequently in its simplest form) consists of: an absorber mat with a corresponding system of pipes for the heat

•This collector design is often referred to as the collector type absorber

•It is preferably used for heating open-air swimming pools.

•This application needs water at a temperature around ambient temperature.

•Heat insulation to the ambient is not needed, because there is no driving force (temperature difference) for heat losses.

•Therefore a transparent cover and an insulation on the back side of the collector are not needed and the optical losses are only due to the reflection coefficient of the absorber

•(The absorber material is mainly EPDM (ethylene-propylen-dienmonomers) which is able to withstand UV radiation and temperatures up to 150 C.

•This absorber type is very cheap and results highly efficient for the swimming pool application.

2. Technical description
Collector designs and practical applications…cont.

Non-concentrating glazed flat-plate liquid-type collectors:

- higher temperature levels be required, glazed flat-plate collectors (many cases).
- They can be built with one or more transparent cover sheets.
- In order to further reduce the convective thermal losses from the absorber to the cover, the space between the two can be evacuated, which turns the collector into a vacuum flat-plate collector.
- Due to the pressure difference, the cover sheet has to be supported from the inside in that case.
- Heat losses to the back of the collector are avoided by insulation material.
- Absorber, cover and insulation are fixed by a collector case.

2. Technical description
Collector designs and practical applications…cont.

Non-concentrating air collectors:

•Due to the low heat transfer coefficient between the absorber and the air, the contact area between absorber and air flow has to be large.

•This is for example ensured by ribbed absorbers, multi-pass systems or porous absorber structures.

•As no frost, overheating or corrosion problems can occur, air collectors have a simpler design when compared to liquid-type collectors

•**Disadvantages:** the large channels and the often significant drive capacities required for fans.

(The reason why air collectors are not widely used for the heating of buildings or the supply of domestic hot)

•Nevertheless, they are used in individual cases, e.g. for solar food drying systems and low-energy houses with exhaust air heat recovery that are already equipped with air distribution and collector systems and thus do not require a water heating system.

Concentrating liquid-type or air collectors:

•These collector types reflect the direct share of solar radiation through mirror areas and thus concentrate the direct radiation on the absorber area.

•The level of concentration of solar radiation is the **concentration ratio** or the concentration factor C. It is defined as the ratio of the optically active collector area to the absorber area impinged on by radiation.

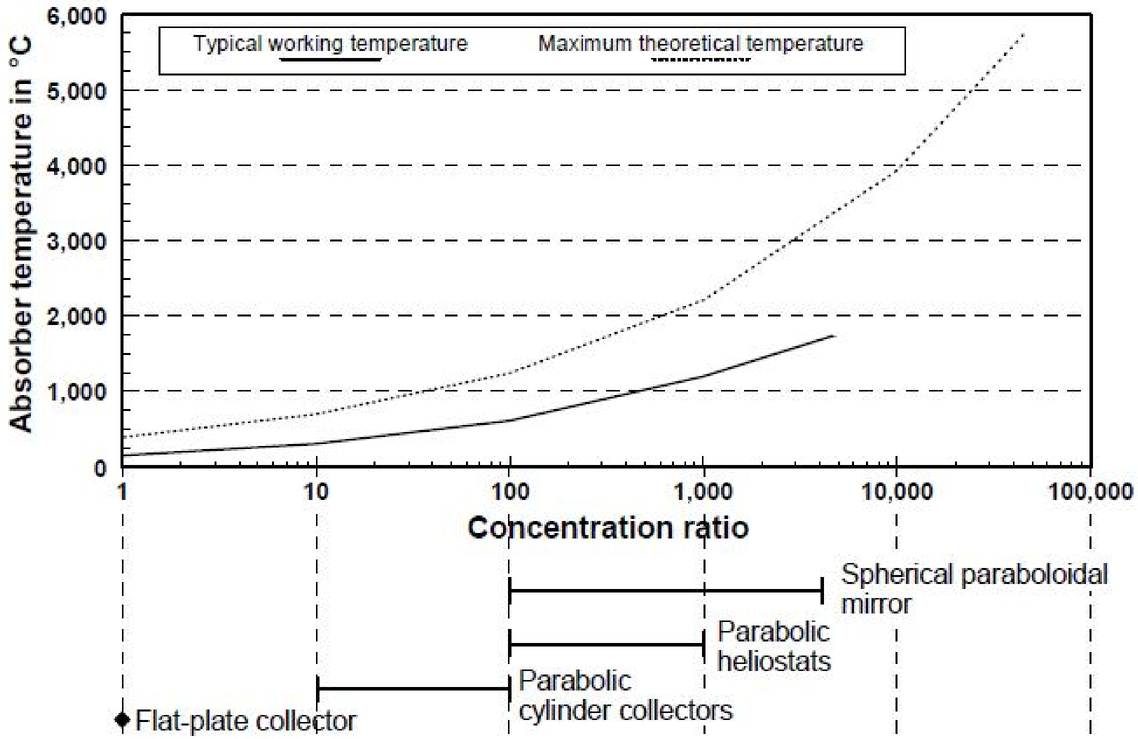
•The maximum theoretical concentration ratio of 46,211 is the result of the distance between sun and earth, and the sun radius.

•Technically, concentration factors of up to a maximum of 5,000 can be achieved at present

the temperature that can be achieved in the absorber depends on the concentration factor

*The theoretical maximum absorber temperature just equals the surface temperature of the sun in the case of a maximum concentration ratio (approximately 5,000 K).

*The temperatures that can be realistically achieved in the absorber are significantly lower. Rotation parabolic mirrors, for example, can achieve absorber temperatures of a maximum of 1,600 °C



2. Technical description

Data and characteristic curves

Optical and thermal losses are the decisive factors for the collector efficiency

<u>Optical losses are determined by:</u>

- ✓The product of the cover transmission coefficient and the collector absorption coefficient.
- ✓This loss is only dependent on the material and – approximately – radiation and temperature-independent.

<u>Thermal losses are described together with:</u>

Other non-constant losses by a constant heat transition coefficient

- ✓As a first approximation, this loss is linearly dependent on the difference between the absorber and the ambient temperature and inversely proportional to radiation

2. Technical description

Data and characteristic curves…cont.

In the case of large temperature differences, assuming the linear dependency on the temperature, an increasing deviation from the real efficiency curve is observed.

It becomes obvious that the approximation line for the efficiency is getting flatter with an increase in radiation and thus *a change in the temperature difference between absorber and the environment has less impact*.

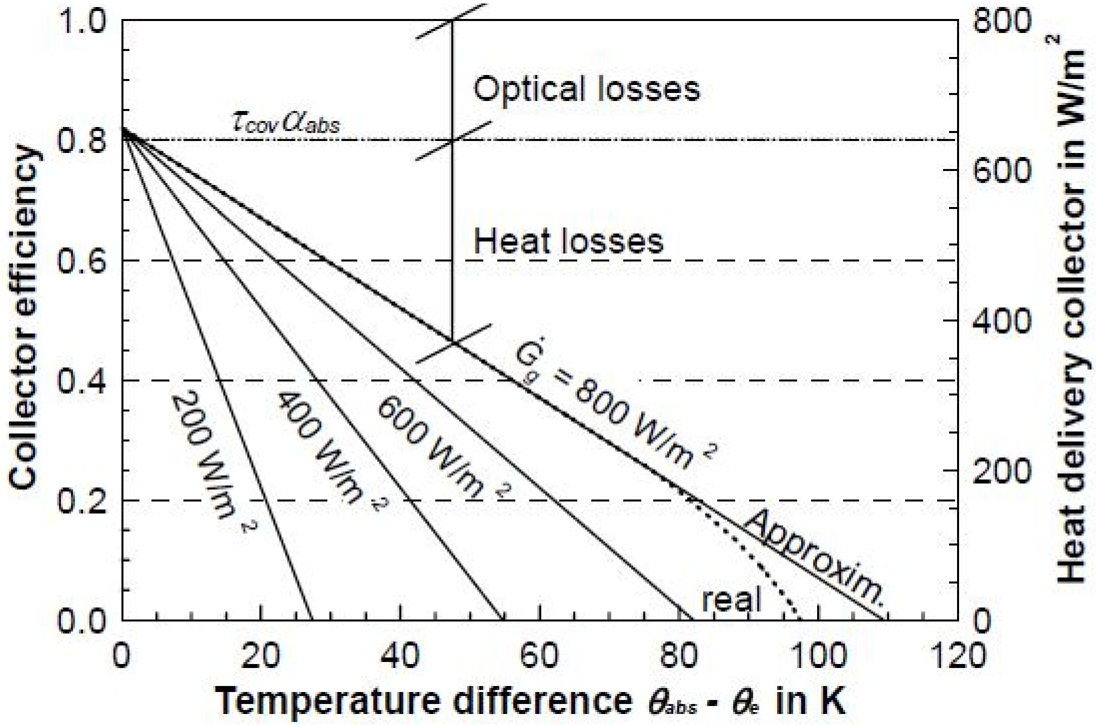


Fig. 4.6 Characteristic curves of single flat-plate collectors ($\tau_{cov}\alpha_{abs} = 0.82$; $\dot{G}_g$ global radiation on horizontal receiving area

2. Technical description

Data and characteristic curves…cont.

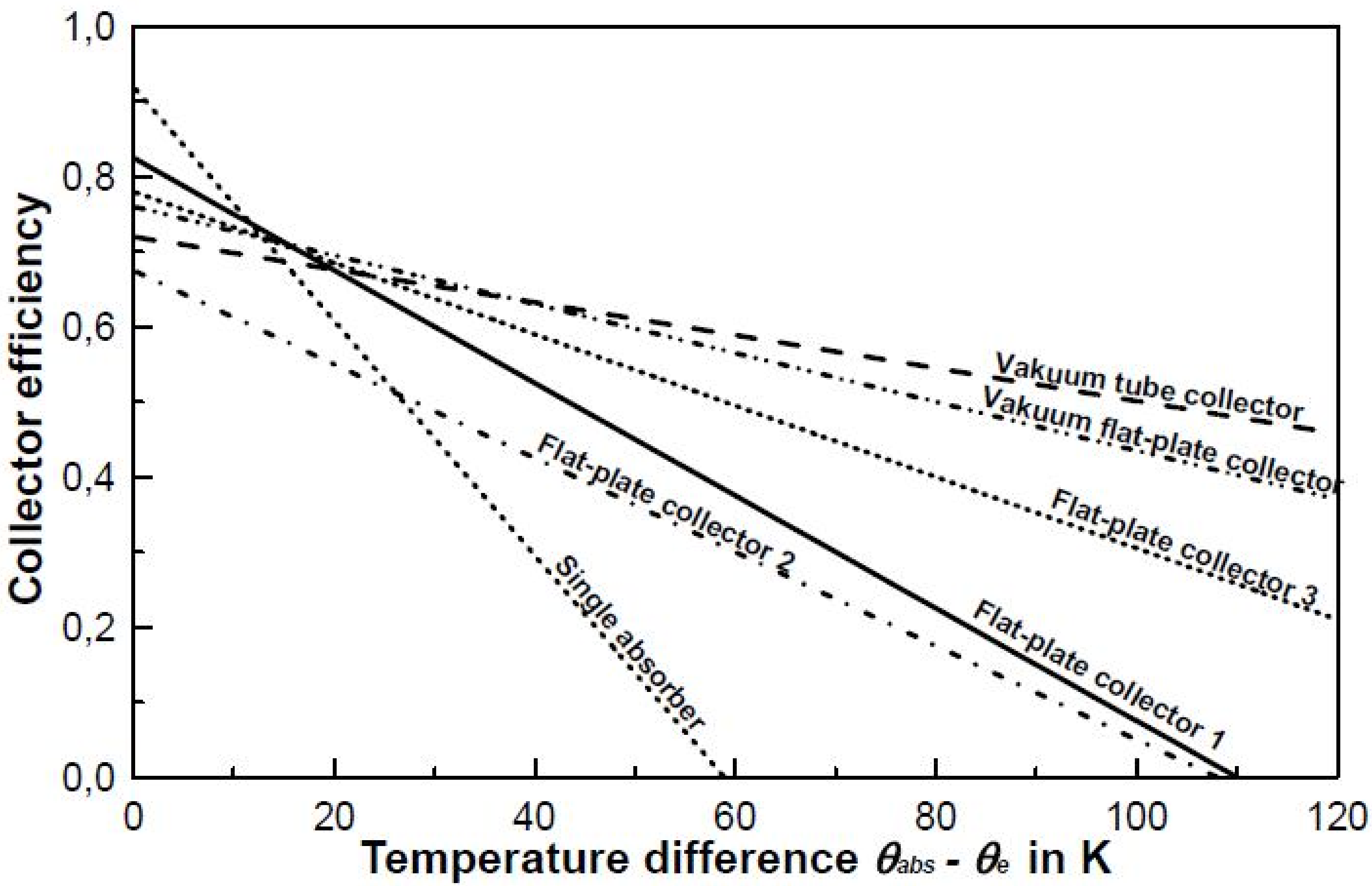


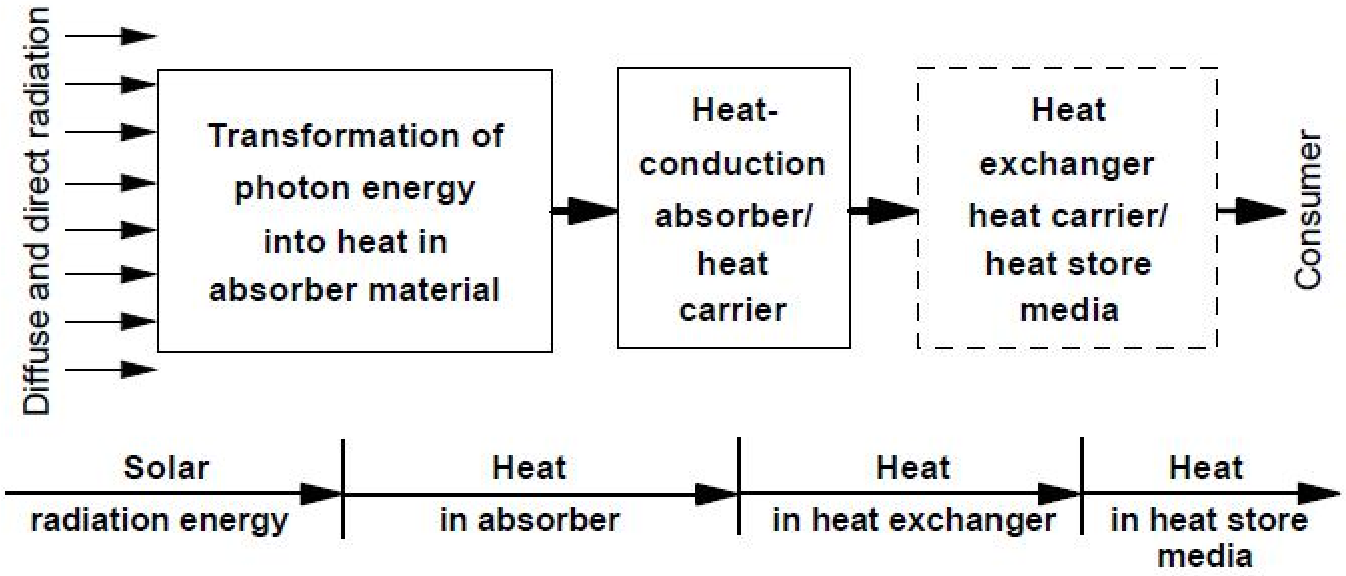
Fig. 4.7 Characteristic curves of various non-concentrating liquid-type collectors at a global radiation of 800 W/m^2 (e.g. /4-1/, /4-2/, /4-3/)

2. Technical description

Further system elements:

- Heat Storage
- Sensor and control systems
- Heat transfer medium
- Pipes
- Heat Exchangers
- Pumps

2. Technical description
Energy conversion chain



Energy conversion chain of solar thermal heat utilisation

2. Technical description

Losses

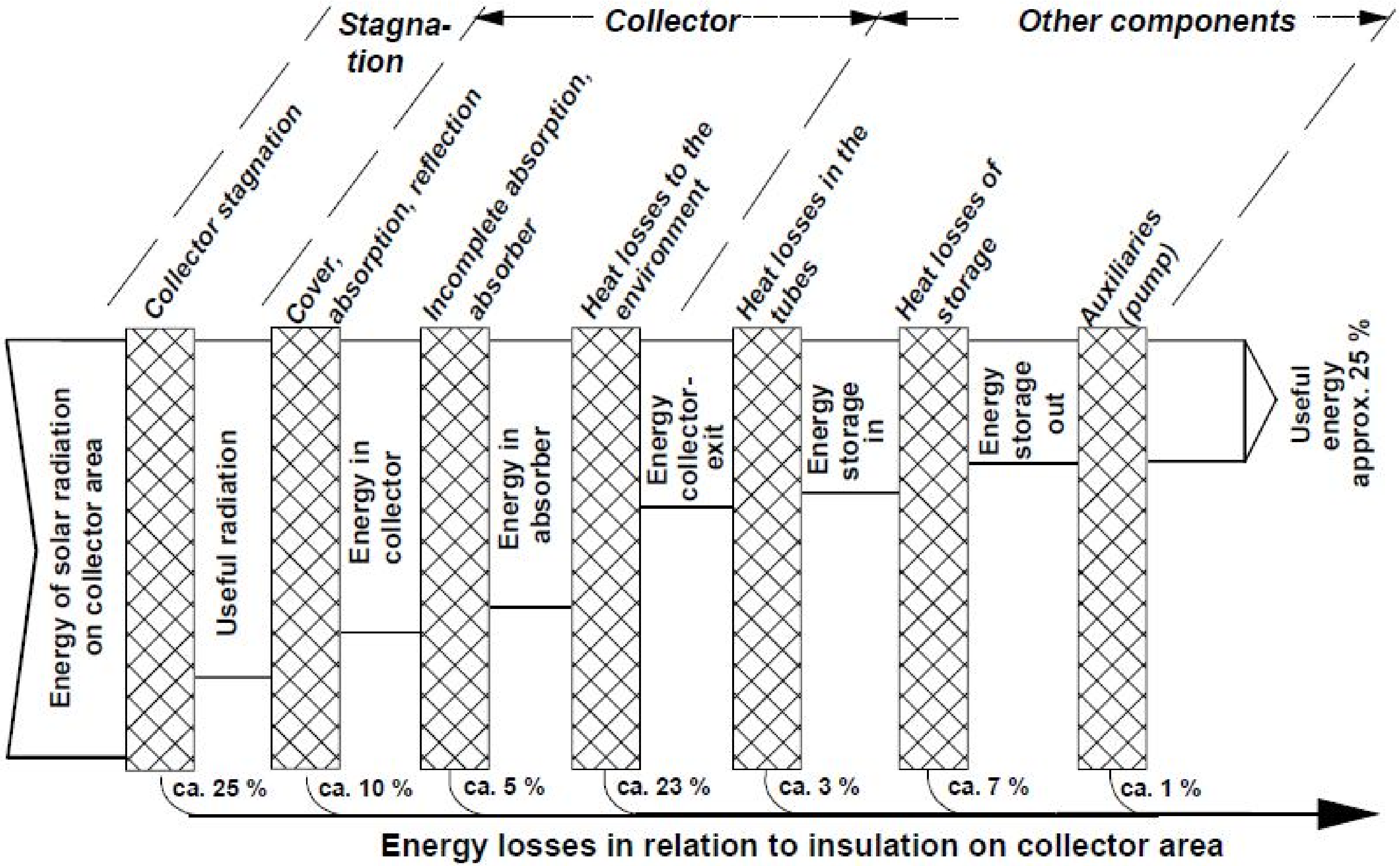


Fig. 4.10 Energy flow of a solar thermal forced-circulation system with flat-plate collector to support the domestic water supply

2. Technical description

System design concepts

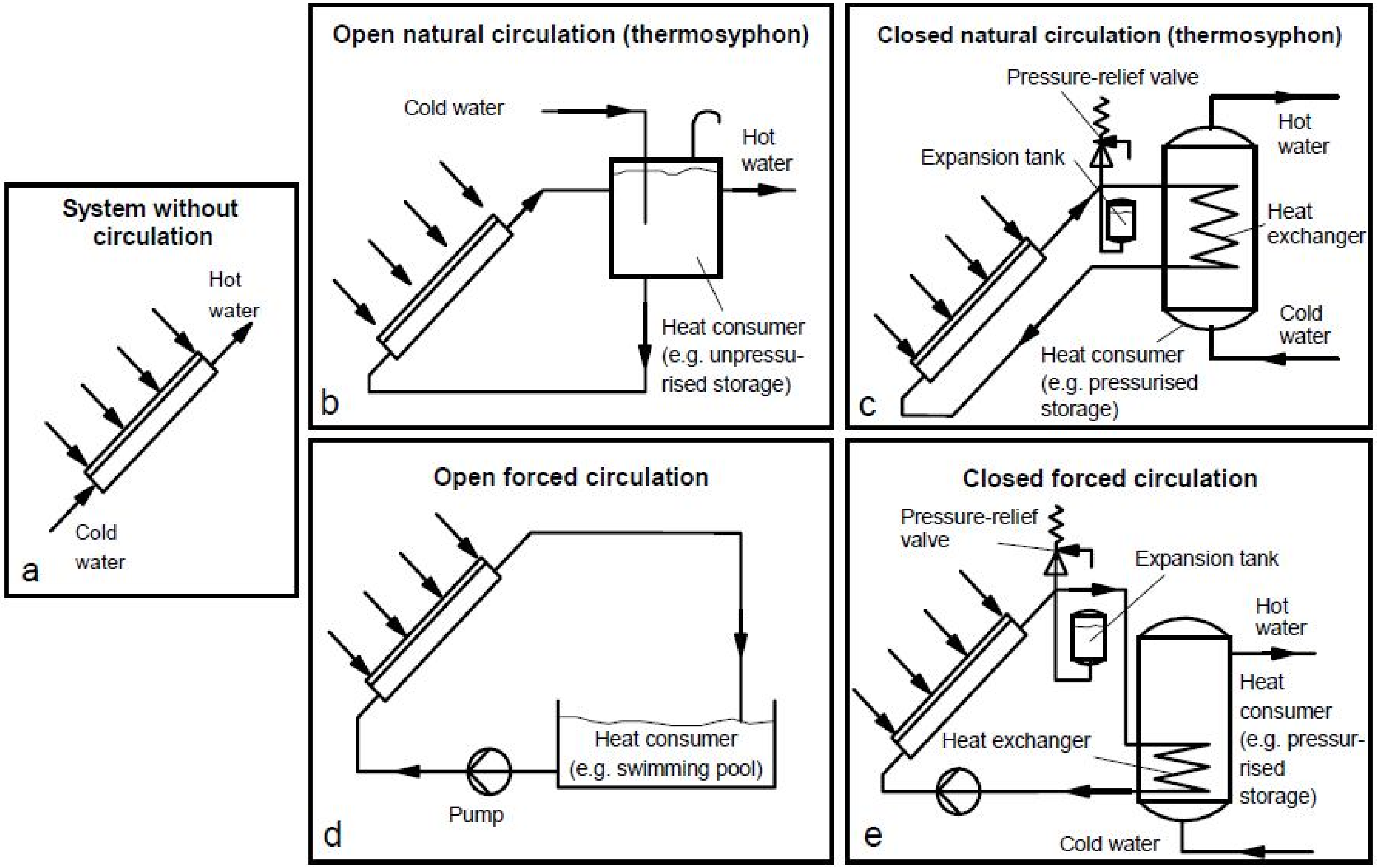


Fig. 4.11 Basic concepts of active solar thermal systems

2. Technical description

Applications:

- Solar heating of open air
- Swimming pools
- Small systems
- Solar-supported district heating systems

3. Economic Analysis

- Investment
- Operation Costs
- Heat Generation Costs

3. Economic Analysis
Investment

- Collector
- Storage
- Other system components
- Installation & operation
- Total investments

Collector

The approximate costs of the collectors currently available are **between 50 and 1,200 €/m^2**
The decisive factor is the collector type:
*_simple absorber mats_: ~ 40 and 80 €/ m^2
*_single-glazed flat-plate collectors with black or selective absorbers_: between 200 and 500 €/ m^2 depending on the plant size.
*_Vacuum pipe collectors, multi-covered flat-plate collectors or collectors improved by transparent heat insulation_: more than 700 €/ m^2 and sometimes above.

- Apart from the technology, the collector costs also **depend on the size of the collector**
- Collector modules with large areas are cheaper, relative to their size, than small collectors; in some cases large collector modules have been offered at 220 €/ m^2, or even less for very large collector areas (i.e. below 200 €/ m^2), including installation and piping

Storage

•The costs for the storage depend mainly on the **storage volume**;
•Investment costs for smaller systems with a storage content between 200 and 500 l including the heat exchanger are between 1.5 and 3 €/l storage volume or 100 to 200 €/m^2 collector area.
•**Heat-insulated steel tanks of up to 200 m^3** are currently the state-of-the-art of technology.
•A 100 m^3 storage costs between 300 and 400 €/ m^3
•Larger reservoirs in the ground are significantly cheaper. Total costs between 75 and 80 €/m^3 were estimated for a ground reservoir with a size of 12,000 m^3. This includes the labor and material costs for setting up the building site, ground works and drainage plus steel and concrete works.
•Other sources quote costs between 50 and 80 €/ m^3 for heat-insulated ground reservoirs with metal foils for sealing and volumes between 7,000 and 40,000 m^3.

Other system components

- pipes
- sensors
- control instruments
- Pump
- the anti-freeze
- all installations related to security technology (e.g. security and shut-off valves, expansion tank).

For decentralized domestic hot water supply systems:

✓normally 20 to 30 m of pipes have to be installed

✓Thus, the costs for the pipes including the heat insulation are between 40 and 70 €/m^2 collector area

✓In total, the investment costs for these components are between 60 and 90 €/ m^2 collector area

For centralized solar thermal domestic hot water systems:

*the total costs of other components can vary between 65 and 130 €/ m^2.

As a first estimate, this range can also be taken as being representative for larger solar-supported district heating systems

Installation & operation

<u>Solar thermal systems for domestic hot water heating for households:</u>

•often partly or entirely self-installed.

•Costs for the potential people in charge of the system are generally very low.

•However, if the system is installed by a company, the specific installation costs are between 70 and 250 €/m2 of collector area. These costs include:

- ✓installation of the collectors **(~20 to 30 % of the overall installation costs)**
- ✓mounting of pipes (**accounts for the largest share of the costs**)
- ✓connection to the solar storage
- ✓installation of the sensors and the control instruments and the pump
- ✓connection to the residual heating system
- ✓charging and commissioning of the system

<u>For central solar thermal domestic hot water support and the larger solar district heating systems:</u>

•The specific costs for installation and commissioning of the system are often lower.

•The installation costs for larger collector arrays are approximately between 10 and 20 % of the overall collector costs or between 30 and 50 €/m^2.

•The total costs for installation and commissioning of the system are approximately between 50 and 100 €/m^2.

Total investments

Standard domestic hot water systems available in the marketplace usually cost between 5,000 and 6,000 €.
In comparison,
Self-installation systems exclusively designed for domestic water heating are significantly cheaper; most of these systems cost between 3,000 and 5,000 €.
Systems with a larger collector area are proportionally cheaper.

Table 4.7 Investment and maintenance costs plus specific heat generation costs for the analysed solar thermal reference systems (for technical data see Table 4.6)

System[a]		SFH-I	SFH-II	SFH-III	MFH	DH-I
Collector area	in m^2	25	25	7,4	60	620
Useful solar heat	In GJ/a	14.4	17.4	6.7	70.7	610/490
Investments						
collector	in €	6,100	6,100	2,600	13,430	132,500
storage[b]	in €	3,400	3,400	1,000	3,400	24,000
control	in €	400	400	300	610	6,500
installation, small parts[c]	in €	3,700	3,700	1,300	13,100	54,000
Subtotal	In €	13,600	13,600	5,200	30,540	217,000
credit tiles[d]	in €	-200	-200		-730	-6,500
credit storage[e]	in €	-750	-750	-750	-2,200	
overall solar system	in €	12,650	12,650	4,440	27,600	151,500
	in €/m^2	500	500	600	460	250
District heating network	in €					1,360,000
Solar share of DH	in €					84,200
Heat transfer station (DH)	in €					6,000
Operating costs[f]	in €/a	220	230	86	540	3,500 / 4,800
Total annual costs[g]	in €/a	1,200	1,200	430	2700	19,600 / 27,900[h]
Heat generation costs	in €/GJ	82.8	68.9	63.8	37.7	32.2 / 45.8[h]
	in €/kWh	0.30	0.25	0.23	0.14	0.12 / 0.16[h]
Equivalent fuel costs	in €/GJ	66.2	55.1	51.0	37.0	31.5 / 44.8[h]
	in €/kWh	0.24	0.20	0.18	0.13	0.11 / 0.16[h]

[a] systems SFH-I, SFH-II, MFH and DH-I with solar-supported space heating and domestic water heating, system SFH-III exclusively for solar-supported domestic water heating; [b] solar storage according to Table 4.6; [c] including piping and insulation; [d] SFH-I, SFH-II, MFH and DH-I are roof-integrated systems, SFH-III is a system installed on the roof without tile credit; [e] costs domestic hot water storage without solar system; [f] at an interest rate of 4.5 % and an amortisation period over the technical life-time of the system; [g] operation and maintenance; [h] solar system of the district heating network without/with pro rata costs for the network and the heat transfer station.

3. Economic Analysis
Operation costs

*During Normal operation, **Maintenance costs** only occur for the exchange of the heat transfer medium and for small repairs (e.g. exchange of seals).
•The operation of the solar thermal system also requires auxiliary energy as the heat transfer medium is normally pumped through the collector circuit →(**the operation cost**)
•The related costs largely depend on the price for electricity.
•At an electricity price of 0.19 €/kWh and a demand for electricity between 0.008 and 0.03 kWh per provided kilowatt hour of thermal energy, operation costs are around *6 to 10 €/a for decentralized solar thermal systems for domestic hot water heating* and *between 18 and 25 €/a for solar combined systems*.

✓**Maintenance costs** for most parts of the system are between 1 and 2 % of the overall investment (without installation and commissioning).
✓Thus, the **entire annual maintenance and operating costs for solar thermal domestic water heating and the combined systems** are at approximately 0.9 to 1.8 % of the overall investment (including installation and commissioning).

3. Economic Analysis
Operation costs...cont.

For a larger solar-supported district heating system:
annual total costs of approximately 1 % of the overall investment costs → for maintenance and miscellaneous costs (e.g. insurance) (excluding installation and commissioning of the system)

Heat generation costs:

The specific energy supply costs can be derived from **the absolute investments indicated plus the costs for maintenance and operation**. The investments are amortized over the technical lifetime of the system (20 years)

4. Environmental analysis

Solar energy systems are characterized by:

*noise-free operation without direct substance releases

Analysis of local environmental aspects:

*construction

*normal operation

*Malfunction

*end of operation

4. Environmental analysis
construction

•Only the production of the absorber is of particular environmental significance.

•**In the past:** galvanic coating methods were used that required a high level of energy input and produced problematic waste.

•**Recently:** vacuum coating or sputtering, which is much less problematic in terms of environmental impact during the production process, has increasingly gained importance

→The anti-reflection glasses that have recently been increasingly used to **cover the solar collectors** can also be produced following environmental criteria

Material for solar storages can be produced and processed with little environmental impact have increasingly been used over the last few Years

•E.g: polyurethane foams (PU) that can cause environmental problems during production and disposal, have been replaced by polypropylene (PPP)

4. Environmental analysis construction…cont.

*During the production process: no environmental effects occur that exceed the general average.
*If the appropriate environmental protection regulations are adhered to, *a very environmentally-friendly production is generally possible.*

The rooftop installation of collectors can be dangerous.
But, *the risk of dying as a result of falling from the roof during system installation*, is comparable to that of a roofer, chimney sweeper or carpenter, and is thus considered low.

4. Environmental analysis
normal operation

•As the operation of solar collectors does not release any substances, *they can generally be run in a very environmentally-friendly way.*

•Additionally, **collectors installed on the roof** are relatively similar to roofs in terms of their absorption and reflection behavior → hardly any negative impacts

•The roof areas covered with collectors that can sometimes be seen from far away **only have a minor impact** on the visual appearance of cities and villages.

•The space utilization of solar collectors is also quite low, as generally already existing roof areas are used.

•Only if collectors are installed on free areas, a negative impact on the microclimate might be possible. However, it is limited mainly to the shadow area and is negligibly low.

•Evaporation during collector standstill ought to be prevented by an appropriate system design and thus **not be a health risk**.

4. Environmental analysis
malfunction

•Environmental effects caused by **larger failures** cannot be expected from solar collector systems.

•*Health risks for human beings or groundwater or soil contamination* by a possible leakage of the heat transfer medium containing antifreeze compound are very unlikely due to an advanced technology.

- •Such problems can also be avoided by regular inspections and the use of food-safe heat transfer media (e.g. propylene-glycol-water-mixes).

•Fires at the collectors can only be expected if the entire building on which they are installed is on fire.

•Possible dangers of injuries by falling collectors that have not been correctly installed on the roof can normally be avoided by maintaining the generally valid health and safety standards; the danger potential is at the same level as that of roof tiles.

4. Environmental analysis

malfunction…cont.

- **Legionella** can multiply significantly in domestic hot water systems and thus become a danger for human beings if they get in contact with the infected water.
- However, this is not a problem specific to solar systems, but this problem has also occurred in solar systems in the past.
- As legionella die quickly at a temperature of approximately 60 ^{o}C, this danger can be easily limited by appropriate technical measures (following standards)
- The potential environmental impacts of solar thermal heating are also low in case of an accident.

4. Environmental analysis
end of operation

•In principle, **recycling** main parts of solar thermal systems (e.g. solar collector, storage) is possible.
•The producers in Germany, for example, are also committed to take the collectors back after the end of the technical lifetime and recycle the materials as part of the German Blue Angel Agreement.
•Thus, <u>there are environmental effects common for certain materials</u> being recycled.