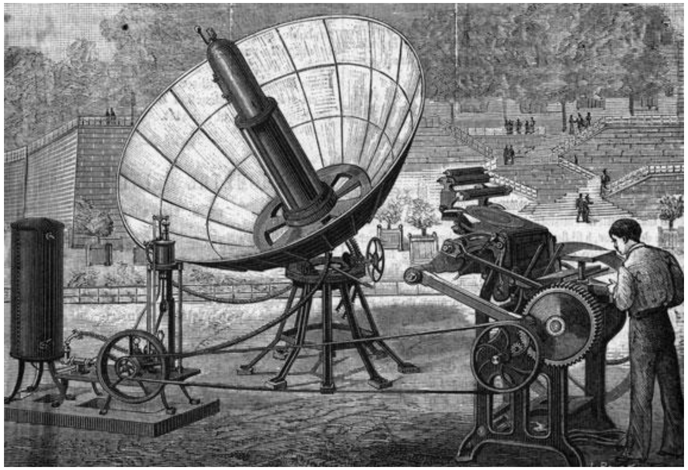
Solar collectors

- collector components
- efficiency factor
- efficiency
- heat output



Solar collectors

solar collectors

fluid
- liquid
- air

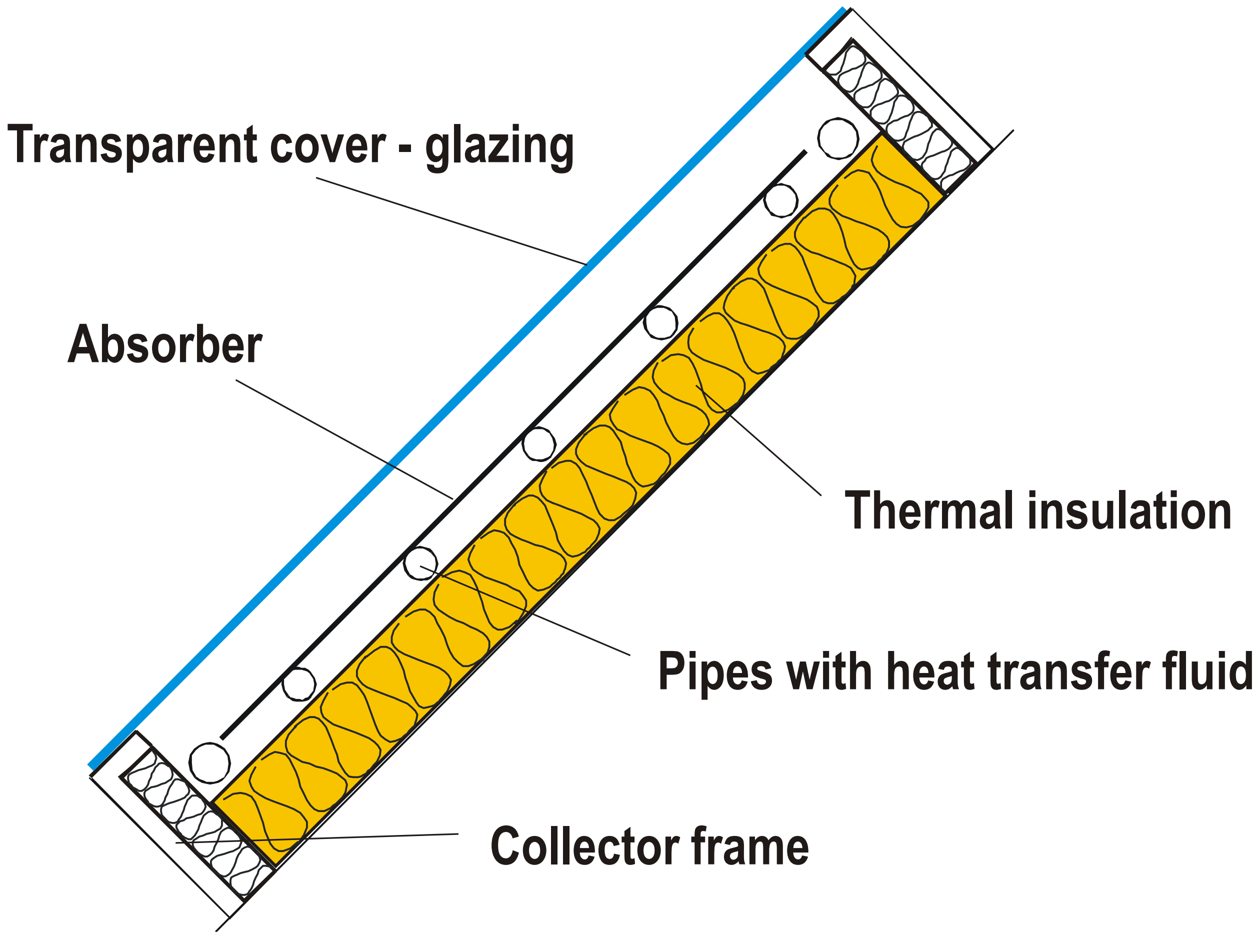
construction type
- flat plate
- tube
- concentrating

glazing
- no cover
- single
- multiple
- structure

pressure
- atmospheric (100 kPa)
- reduced (< 100 Pa)
- vacuum (< 0.1 Pa)

absorber
- plastic
- metal nonselective
- metal selective
- accummulation

Solar collector

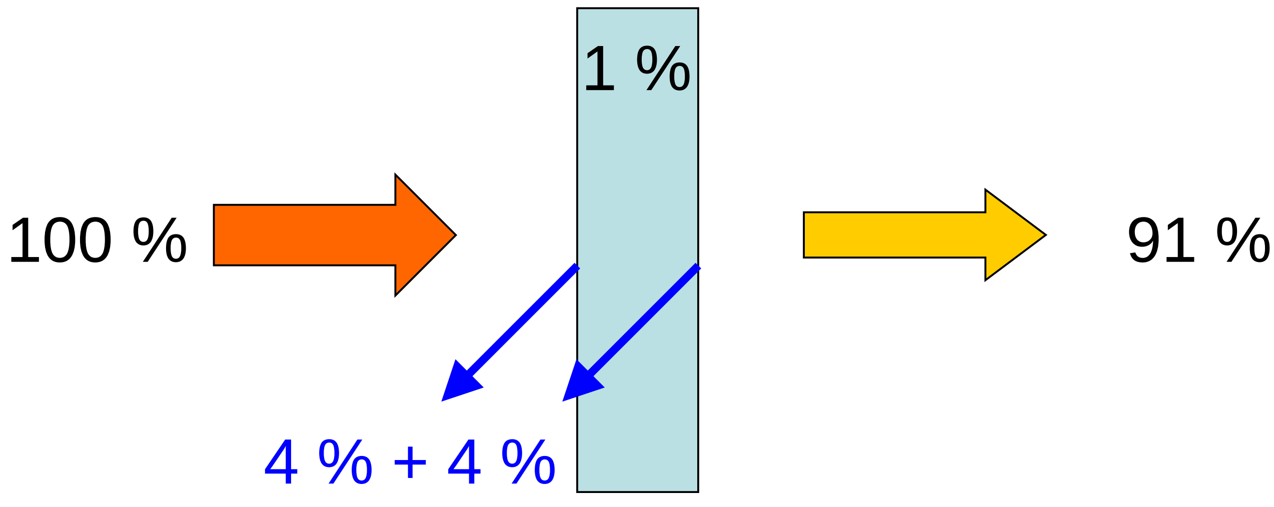


Glazing

- **single glazing**
- low content of FeO_3 („solar“, „low-iron“)
  - reduction of absoptance in material of cover
- antireflective coatings
  - reduction of reflection at interface glass-air
- prizmatic glazing (pyramids, texture)
  - increase of transmittanceat higher incident angles
- **double glazing**
  - solar glazing + foil (teflon), reduced heat loss, lower transmittance

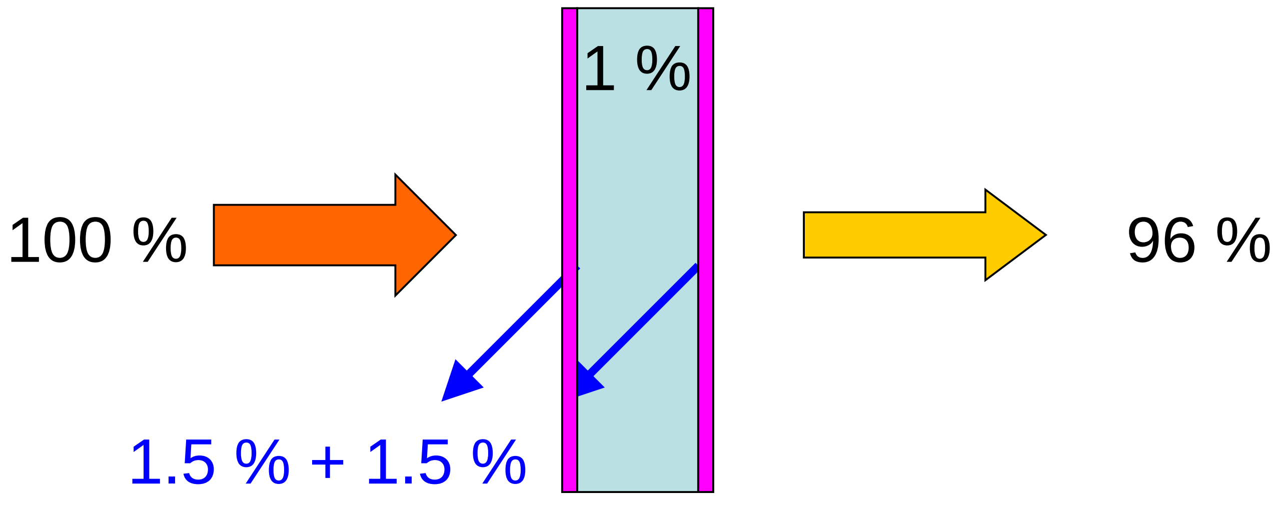
Optical losses

reflection at each interface glass-air about 4 % (normal incidence)
practically independent on thickness



Antireflective (AR) coatings

reflection for each interface glass-air is reduced to 1,5 %
layer with low refraction index (mechanically, chemically)



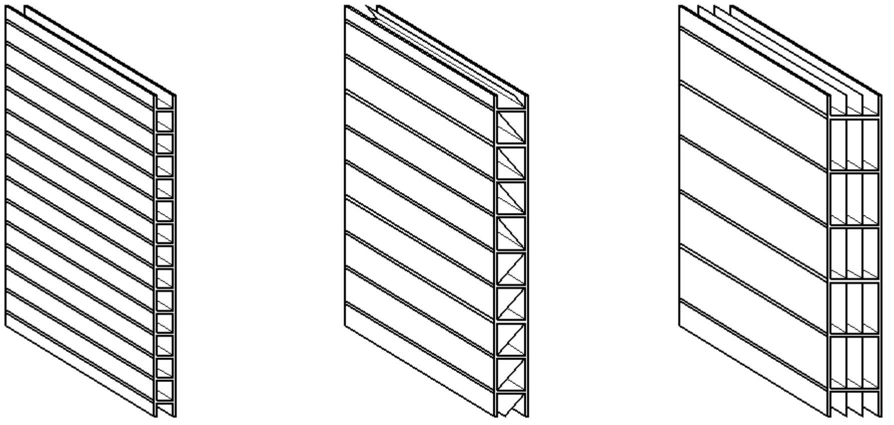
double glazing with 4 AR coatings:

transmittance **92 %** > single glazing without AR coatings 91 %

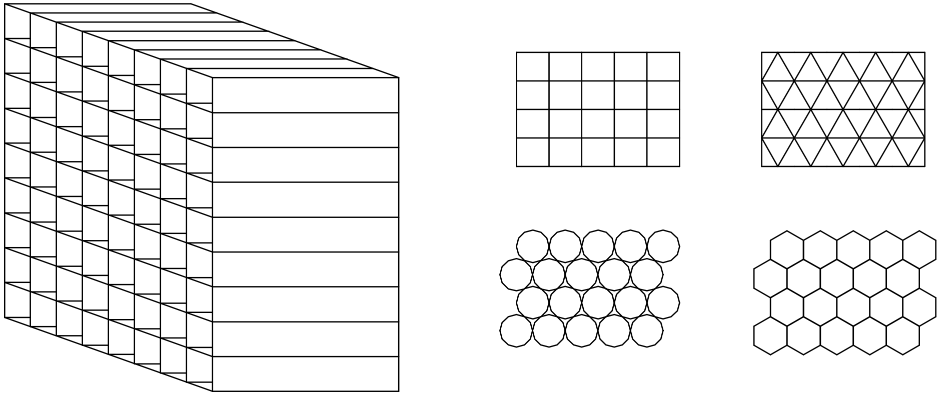
Glazing heat loss

- heat loss through cover
  about **75-85 %** total loss
- multiple glazings
- special structures

channel structures

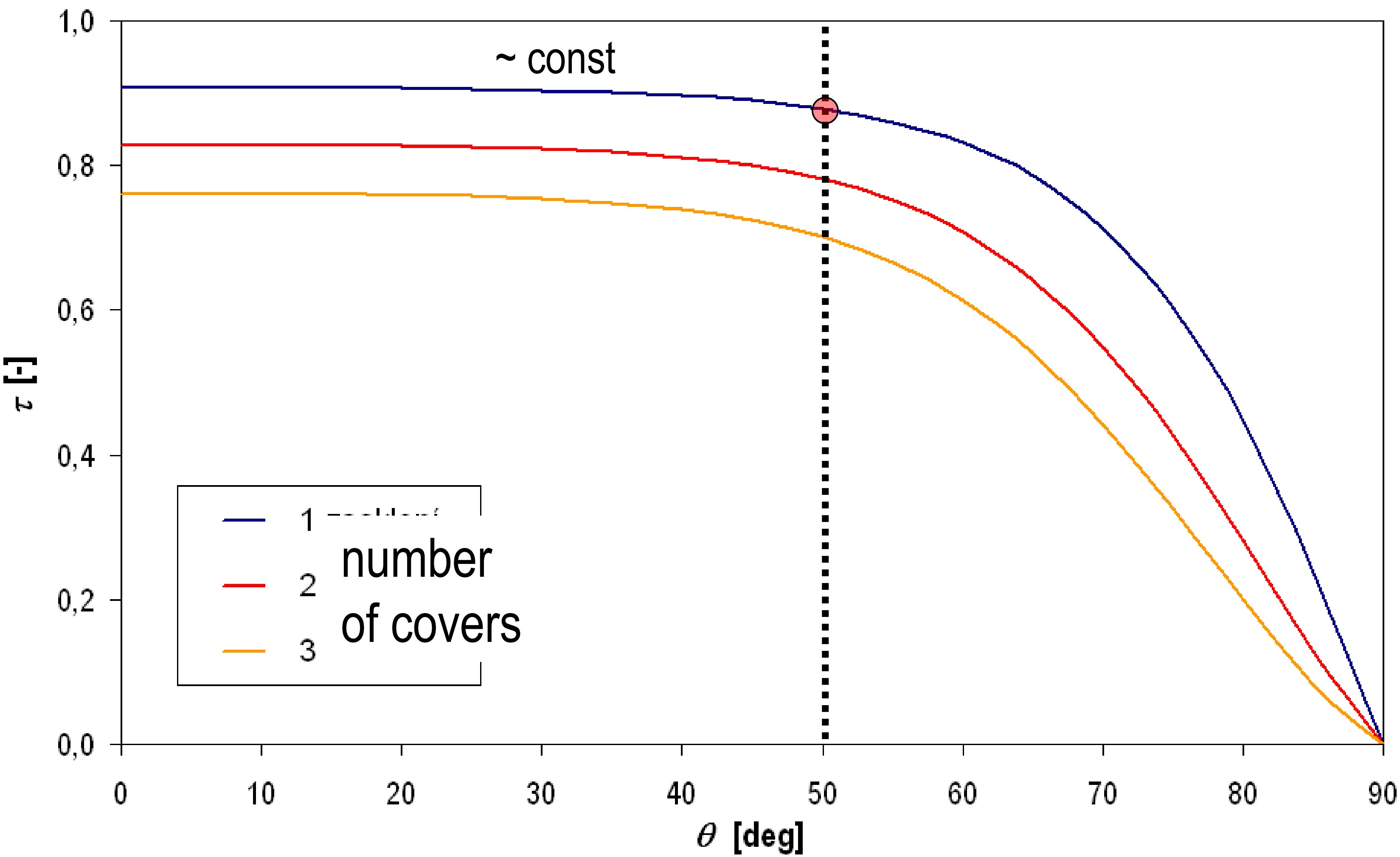


honeycomb structures



aerogel

Glazing optical properties - transmittance



Solar absorber

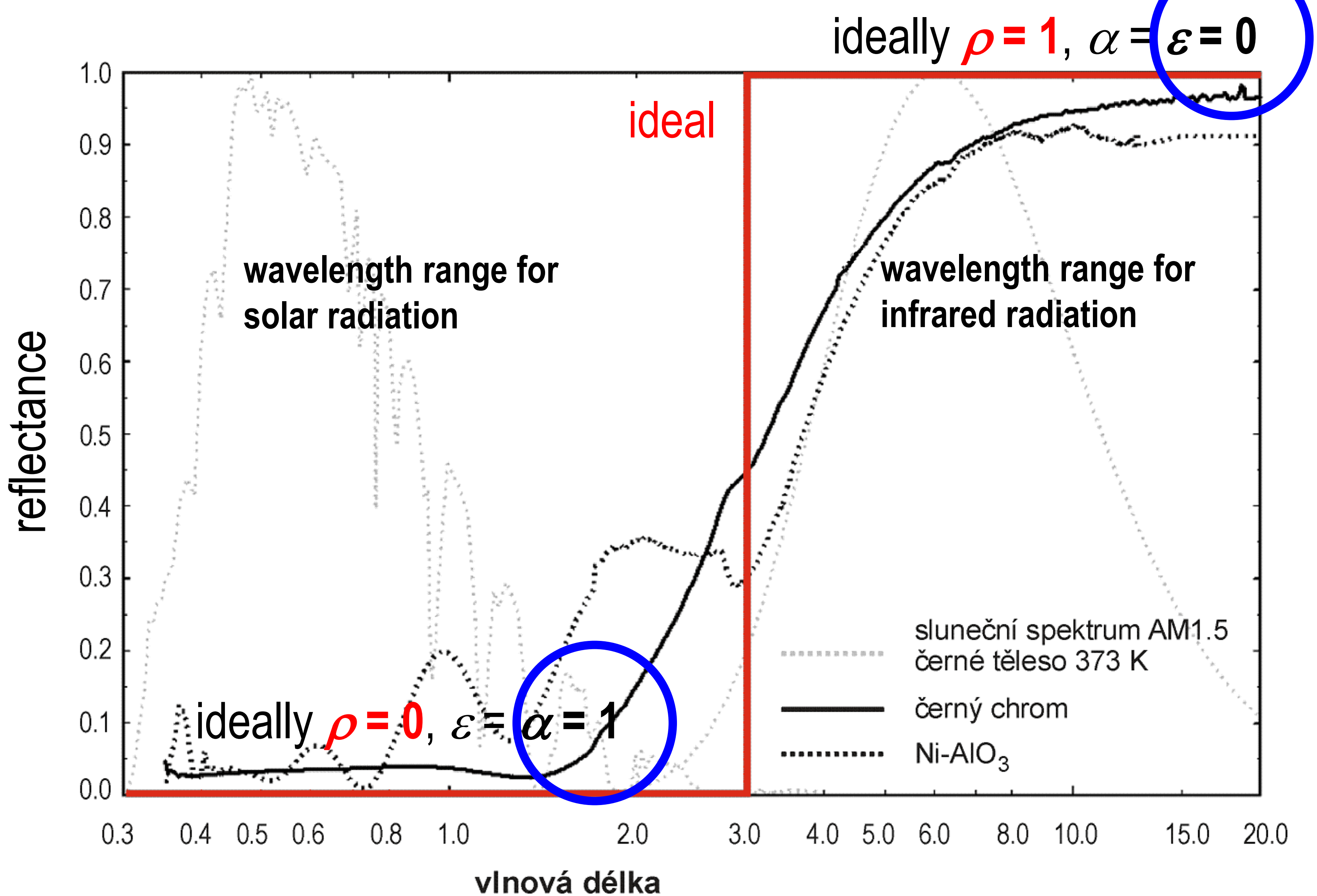
theory of radiation, radiation properties of bodies

- absorptance α + reflectance ρ = 1 (adiathermanous bodies)
- for given wavelength λ applies: absorptance α_λ = emissivity ε_λ

- perfect black body: $\alpha = 1$, $\rho = 0$ for all wavelengths
- perfect white body: $\alpha = 0$, $\rho = 1$ for all wavelengths
- grey body $0 < \alpha = \alpha_\lambda < 1$, $\rho = 1 - \alpha$ for all wavelengths
- **selective body $0 < \alpha_\lambda < 1$, $\rho_\lambda = 1 - \alpha_\lambda$**

$$\alpha_{SOL} \neq \varepsilon_{IR}$$

Selective coatings



Selective coatings

galvanic coatings

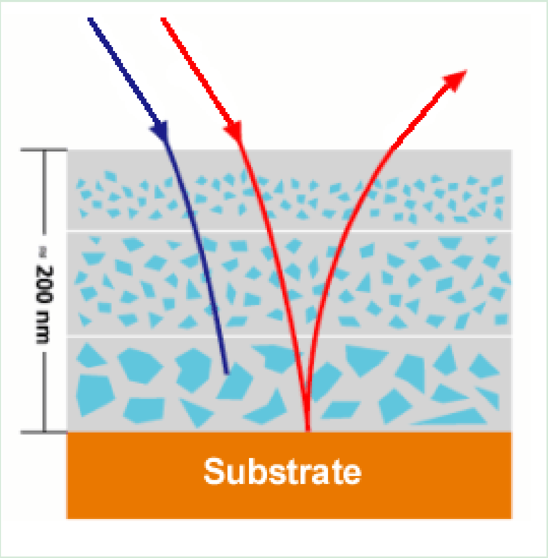
- structucture of coating by electrochemic method

  α = 0,93 – 0,96, ε = 0,10 – 0,16

ceramic-metal: cermet coatings

- sputtering, ohysical vapour deposition process, high quality coatings

  α = 0,95, ε = 0,05

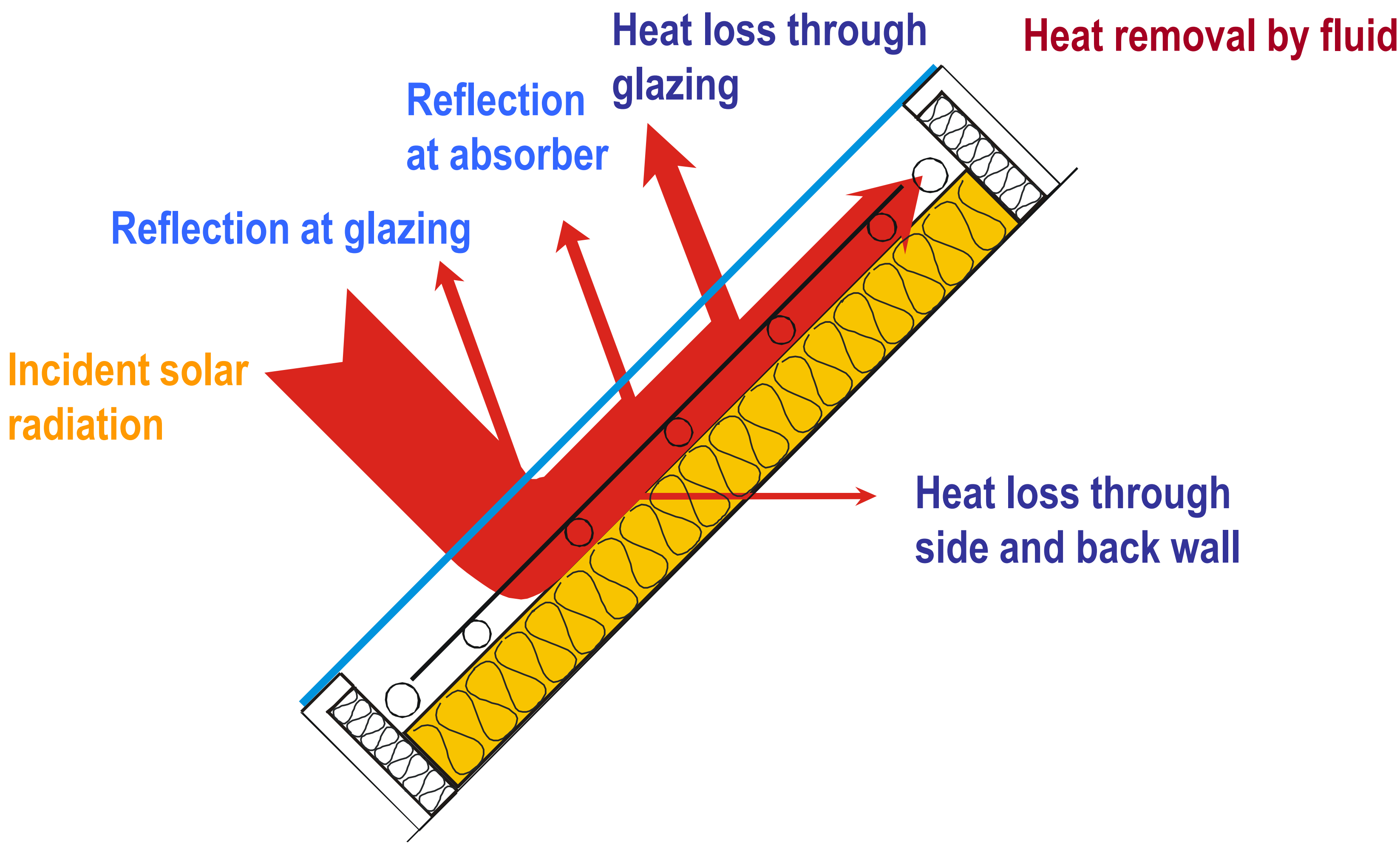


paints

- significantly worse properties

  α = 0,92, ε = 0,85

Energy balance of solar collector



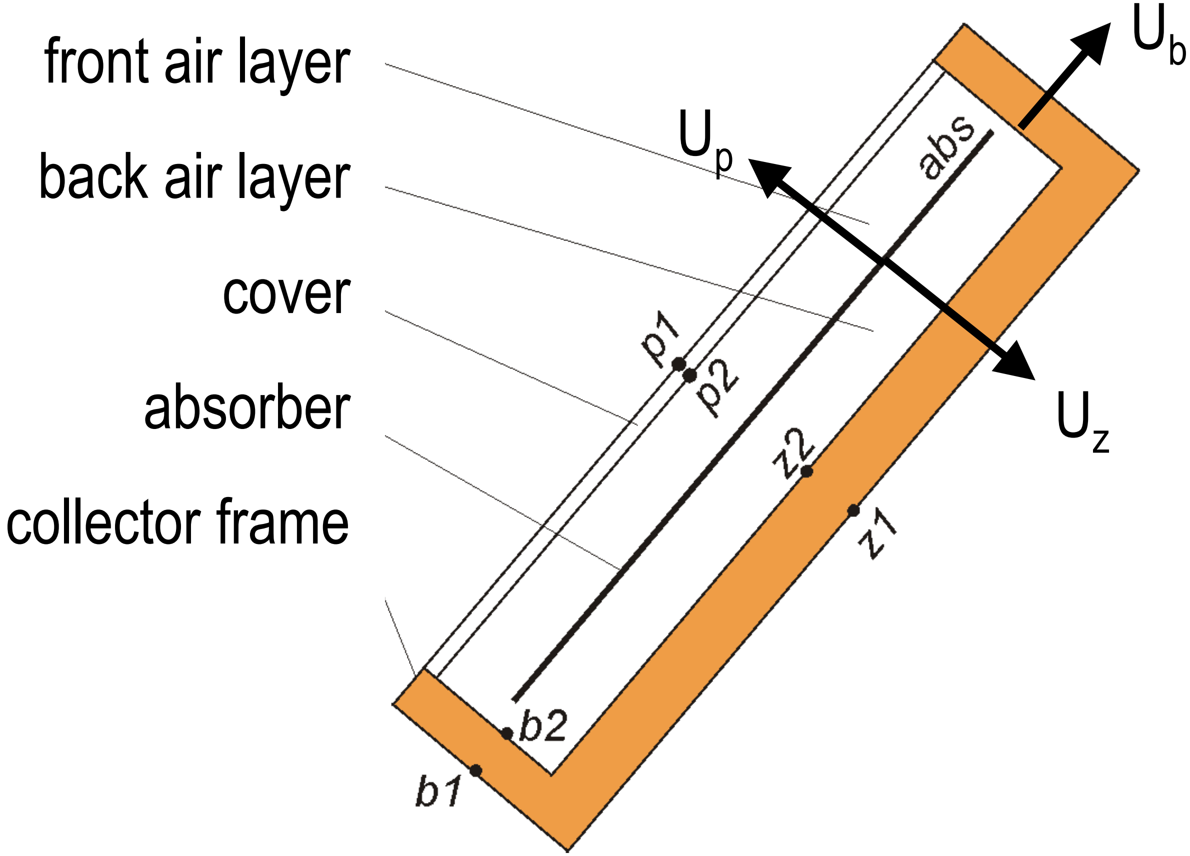
Energy balance of solar collector

$$\frac{dQ}{dt} = \dot{Q}_s - \dot{Q}_{z,o} - \dot{Q}_{z,t} - \dot{Q}_k$$ general formula

$$\dot{Q}_k = \dot{Q}_s - \dot{Q}_{z,o} - \dot{Q}_{z,t}$$ stationary conditions $dQ/dt = 0$

Q_s	incident power of solar radiation	$Q_s = G.A_k$
$Q_{z,o}$	optical losses	$Q_{z,o} = Q_s - Q_s\tau\alpha$
$Q_{z,t}$	heat losses	$Q_{z,t} = U.A_k\,(t_{abs} - t_e)$
Q_k	heat output of collector	$Q_k = M \cdot c \cdot (t_{k2} - t_{k1})$

Heat loss of solar collector



$$\dot{Q}_{z,t} = U_p A_k (t_{abs} - t_e) + U_z A_k (t_{abs} - t_e) + U_b A_b (t_{abs} - t_e) = U A_k (t_{abs} - t_e)$$

Heat output and efficiency of collector

heat output of collector:

$$\dot{Q}_k = G A_k \tau\alpha - U A_k (t_{abs} - t_e)$$

efficiency based on mean absorber temperature:

$$\eta = \frac{\dot{Q}_k}{\dot{Q}_s} = \frac{\dot{Q}_k}{G A_k} = \frac{G A_k \tau\alpha - U A_k \left(t_{abs} - t_e\right)}{G A_k}$$

$$\eta = \tau\alpha - U \frac{(t_{abs} - t_e)}{G}$$

Efficiency of solar collector

$$\eta = \boxed{\tau\alpha} - \boxed{U\frac{(t_{abs} - t_e)}{G}}$$

τ ... glazing transmittance for solar radiation [-]

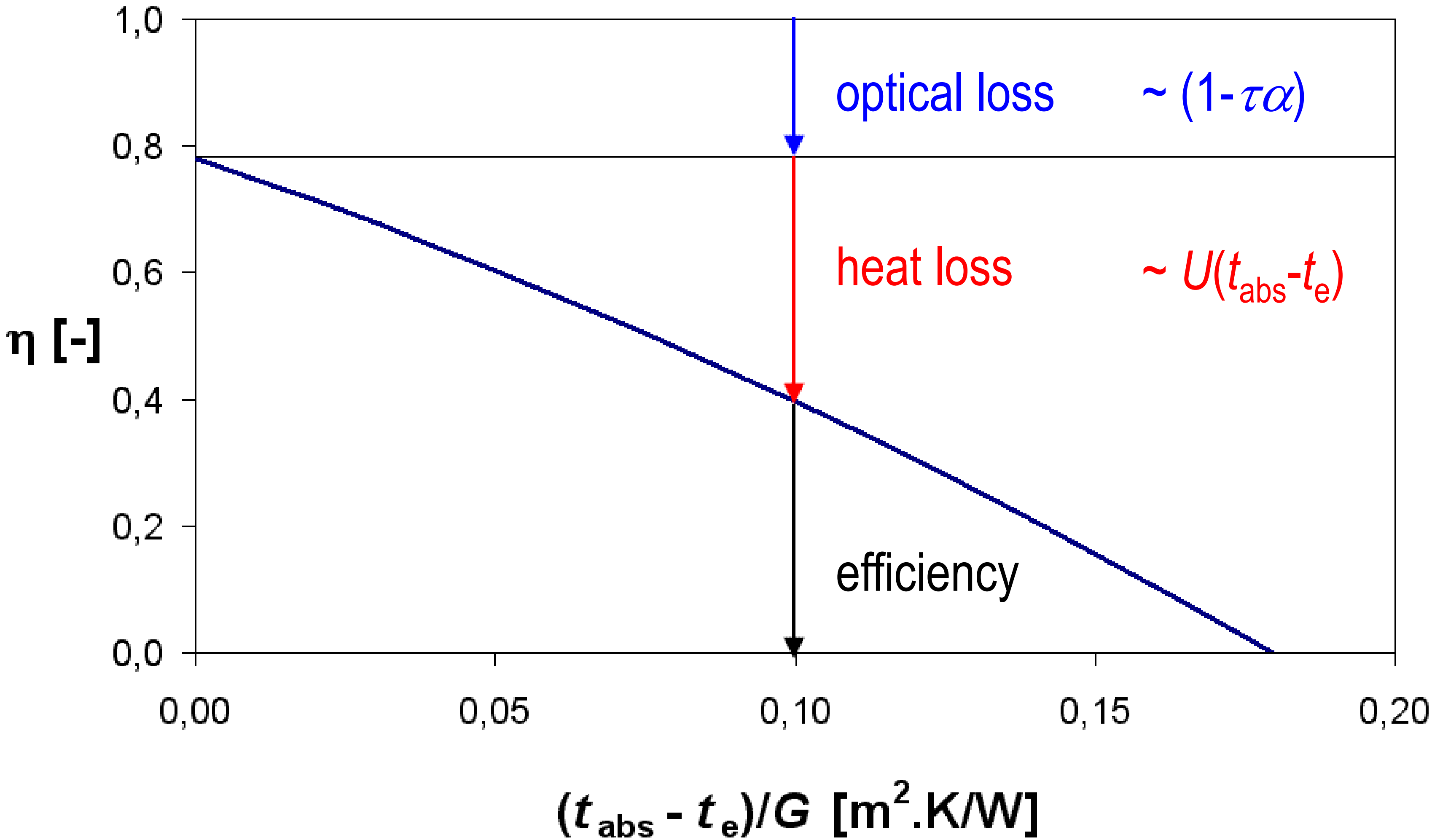
α ... absorber absorptance for solar radiation [-]

U ... heat loss coefficient [W/m^2.K]

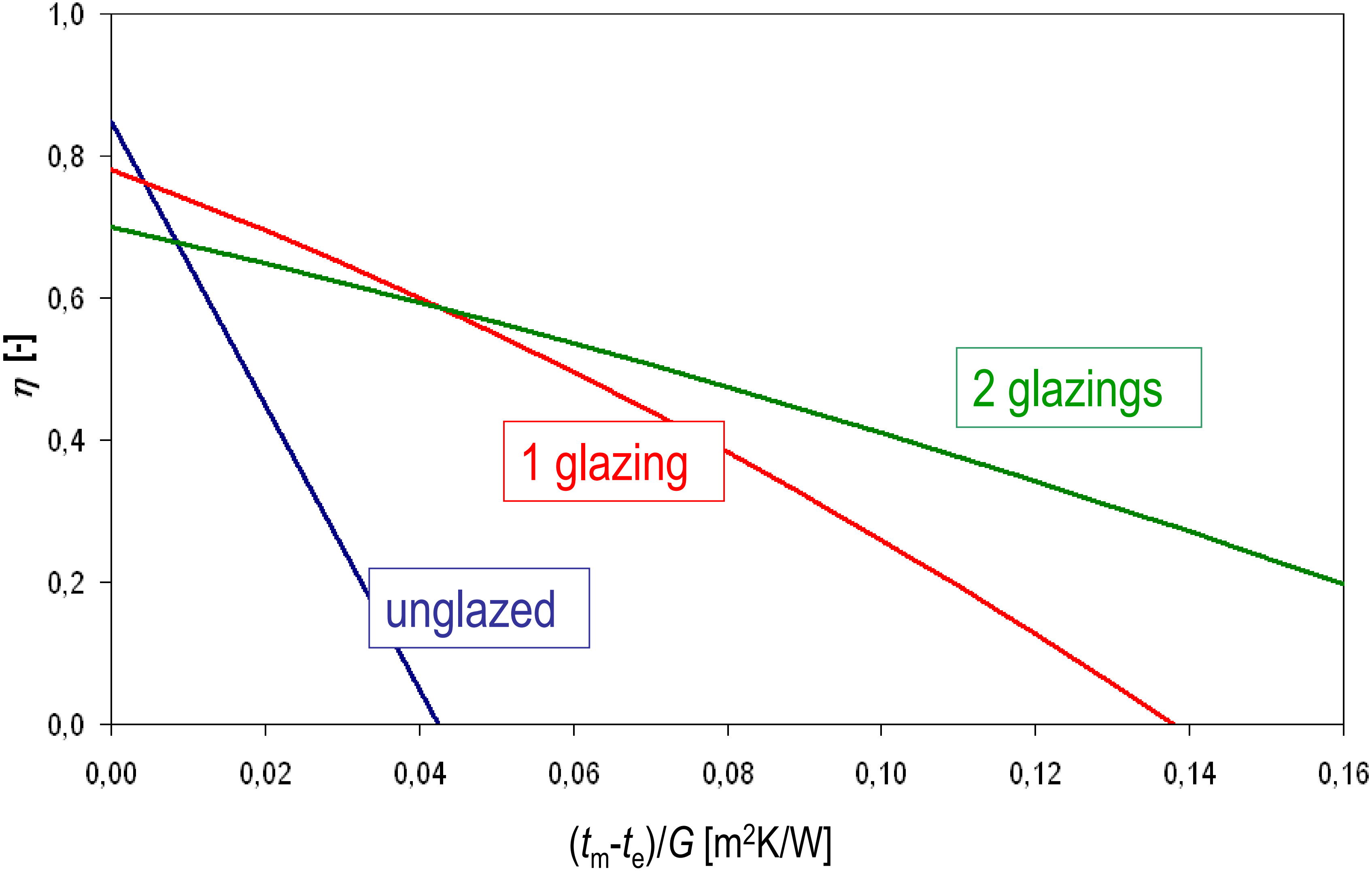
t_{abs} ... mean absorber temperature [°C]

t_e ... ambient temperature [°C]

Efficiency of solar collector



Heat loss x optical loss



Efficiency of solar collector

$$\eta = F' \cdot \left[\tau\alpha - U \frac{(t_m - t_e)}{G} \right]$$

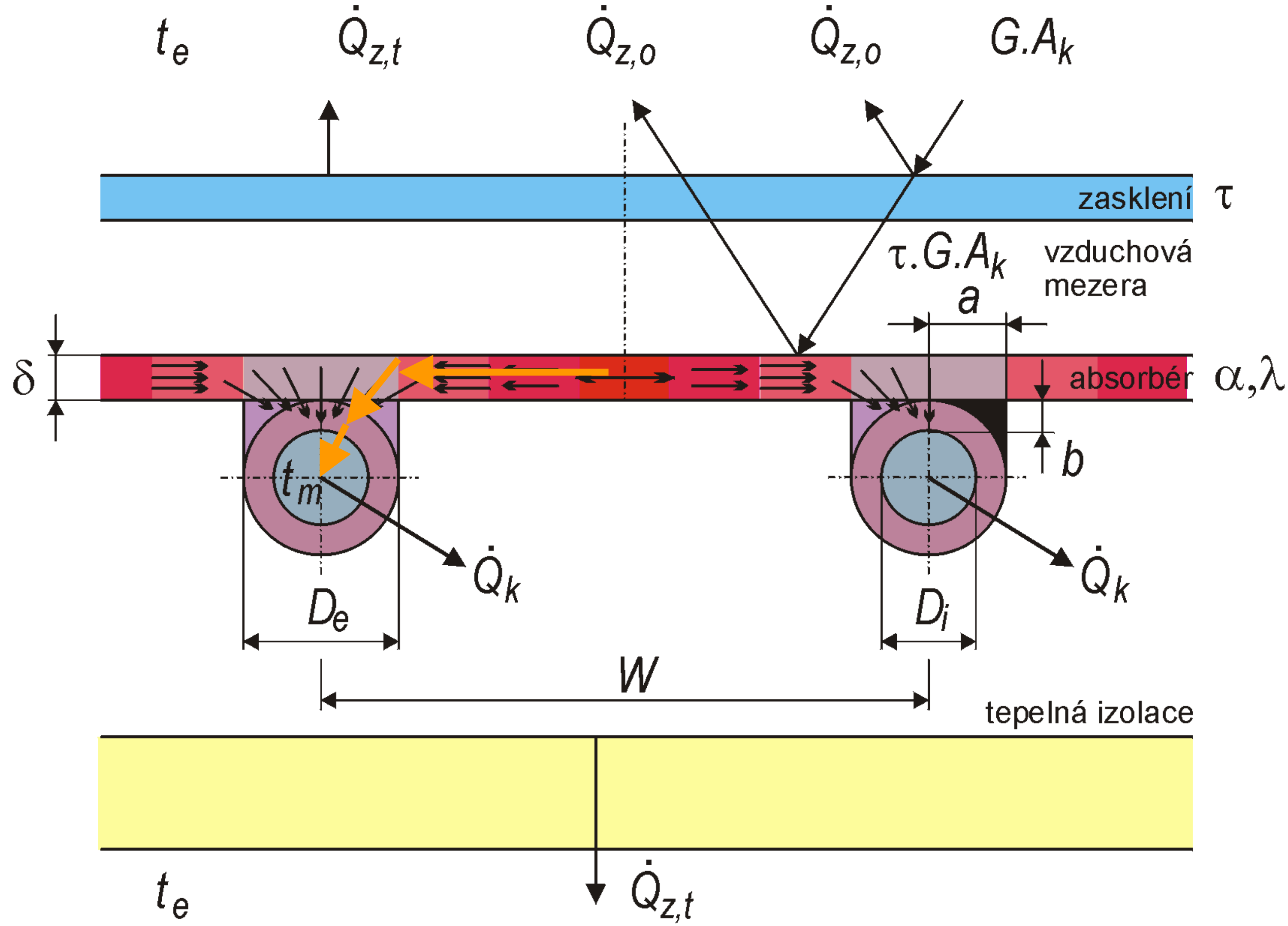
F' **... efficiency factor** **> 0.90**

depends on geometry and thermal properties of absorber

t_m ... mean fluid temperature

$t_m = (t_{k1} + t_{k2})/2$

Heat transfer from absorber surface



Efficiency factor *F'*

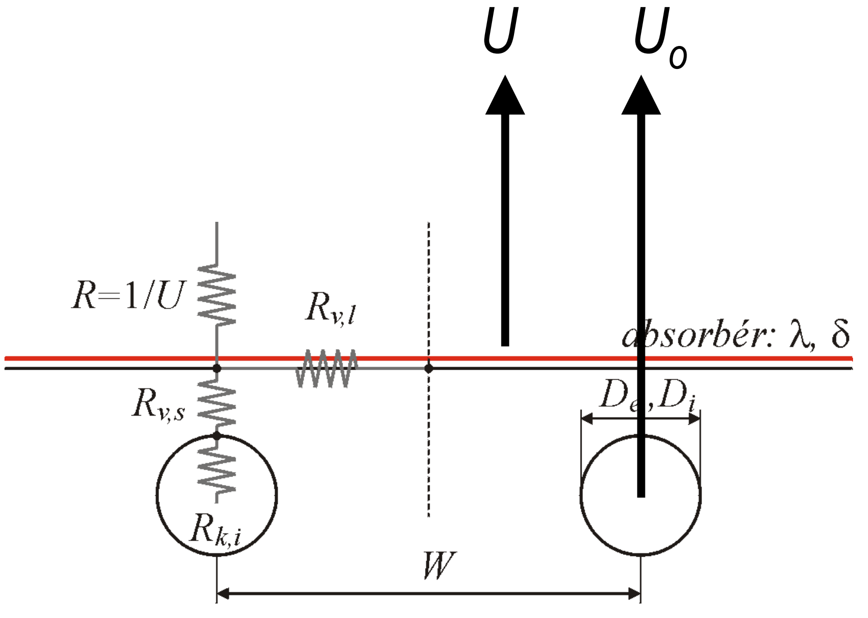
depends on

- geometry of absorber:
  - **pipe distance, pipe dimension, thickness of pipe-absorber bond, absorber thickness**
- physical properties of absorber:
  - **thermal conductivity of absorber, thermal conductance of the bond pipe-absorber**
- flow regime in pipes: **heat transfer from pipe wall to fluid**
- total heat loss coefficient of collector *U*

Efficiency factor *F'*

how efficient is the heat transfer from absorber surface to liquid?

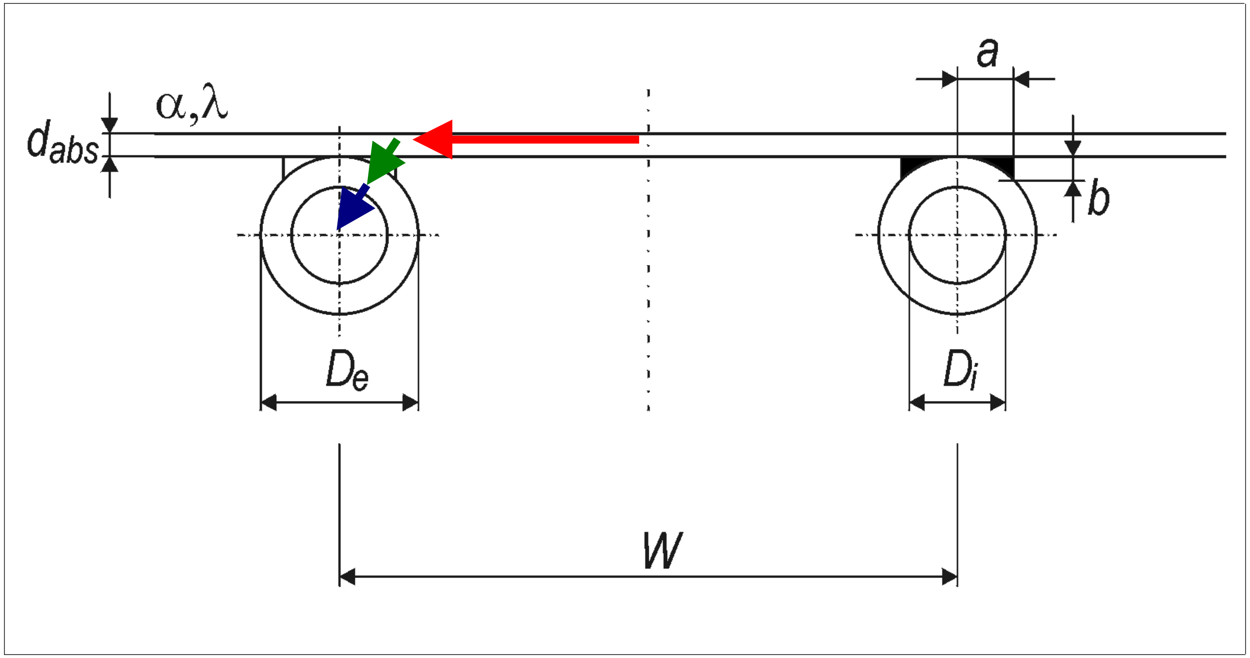
$$F' = \frac{U_o}{U} = \frac{\text{heat loss from the fluid to ambient}}{\text{heat loss from absorber surface to ambient}}$$



Efficiency factor *F'*

$$F' = \frac{1/U}{W\left[\frac{1}{U[2a+(W-2a)F]} + \frac{1}{\Lambda_{sp}} + \frac{1}{h_i \pi D_i}\right]}$$

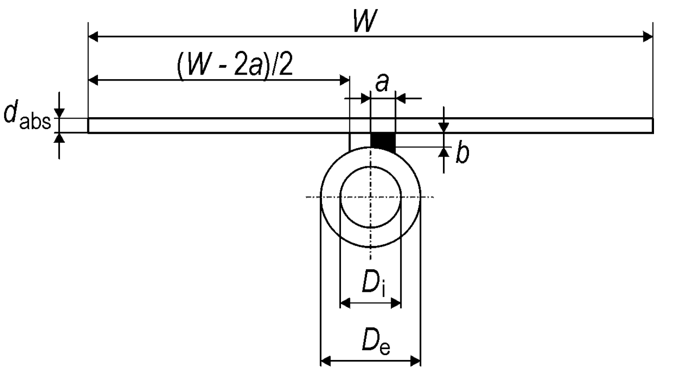
is a function of fin efficiency *F*



Fin efficiency *F*

$$F = \frac{\tanh[m(W-2a)/2]}{m(W-2a)/2}$$

for rectangular fin



$$m = \sqrt{\frac{U}{\lambda_{abs} d_{abs}}}$$

U heat loss coefficient of collector

$(W-2a)/2$ active length of the fin

higher fin efficiency = higher heat removal from absorber

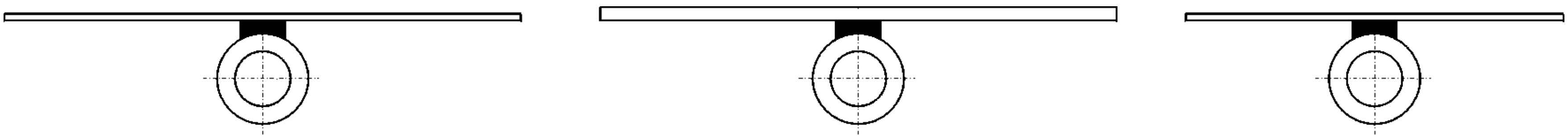
significant influence of thermal conductivity and thickness of absorber

Fin efficiency F

reference case: fin efficiency 0.96

copper absorber (**390 W/mK**), d_{abs} = **0.2 mm**, fin W^* = $W - 2a$ = **100 mm**

heat loss coefficient $\boldsymbol{U}$ **= 4 W/m²K**



aluminium (240 W/mK)

d_{abs} = 0.20 mm, W^* = 79 mm

d_{abs} = 0.32 mm, W^* = 100 mm

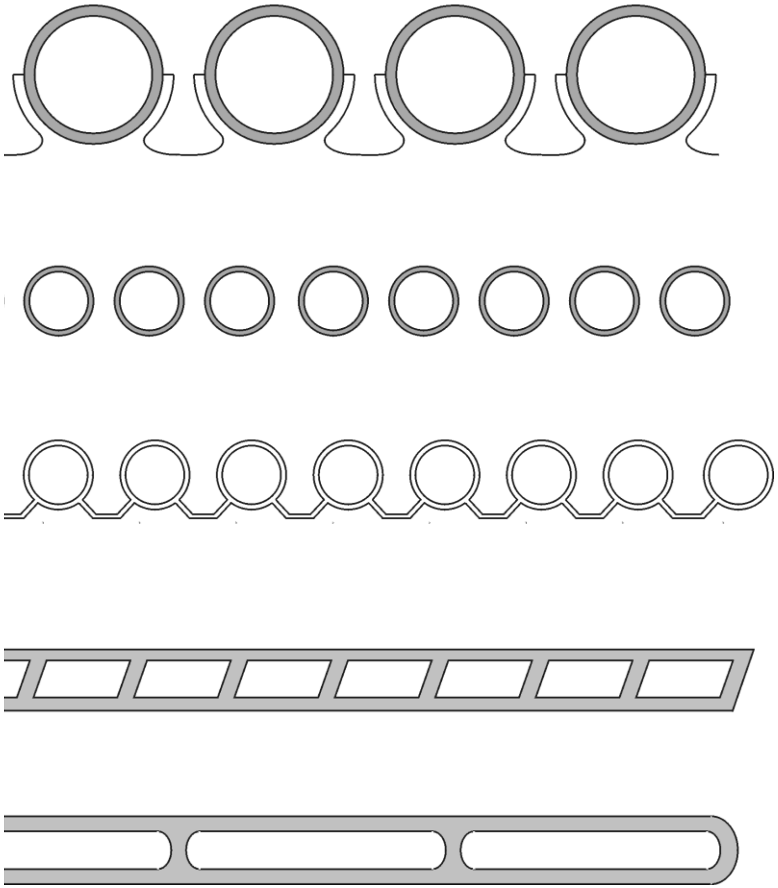
steel (80 W/mK)

d_{abs} = 0.2 mm, W^* = 45 mm

d_{abs} = 1.0 mm, W^* = 100 mm

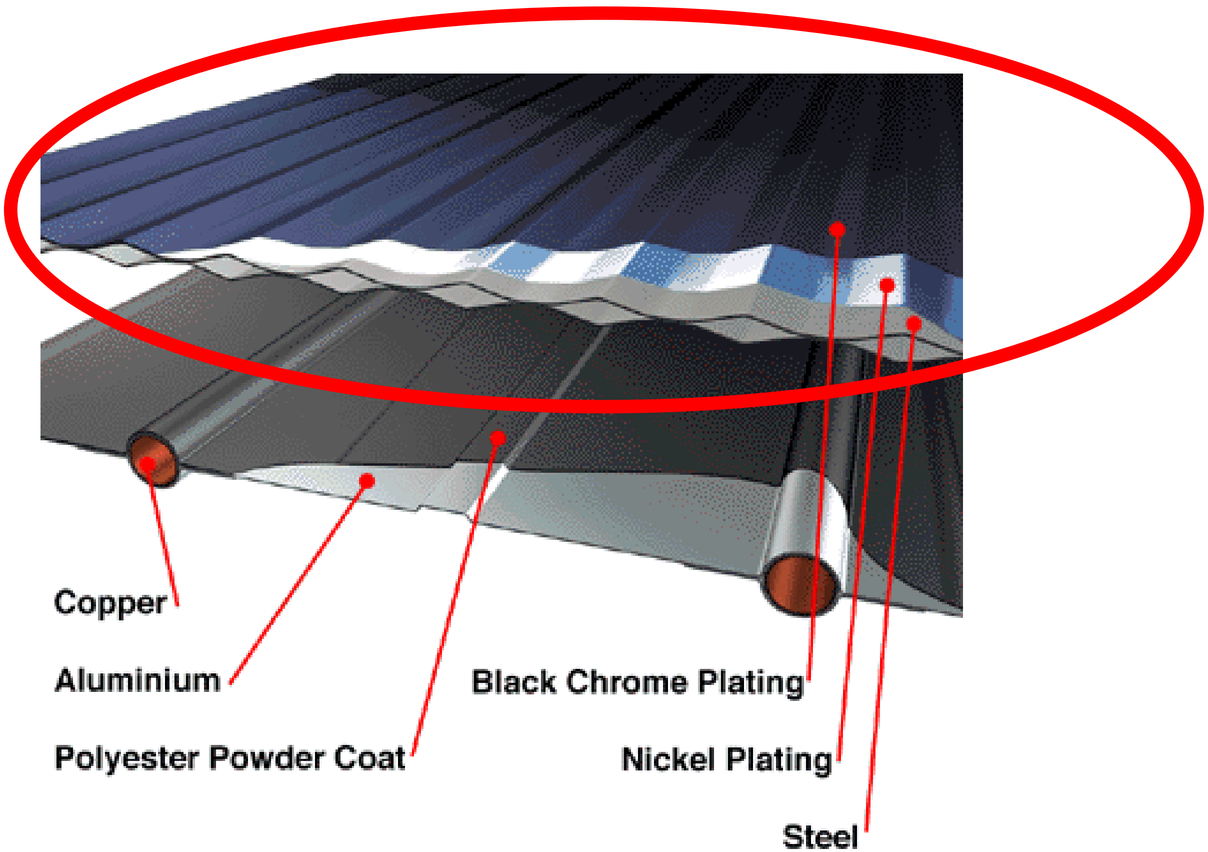
EPDM (0.14 W/mK) d_{abs} = 2.0 mm, W^* = 6 mm

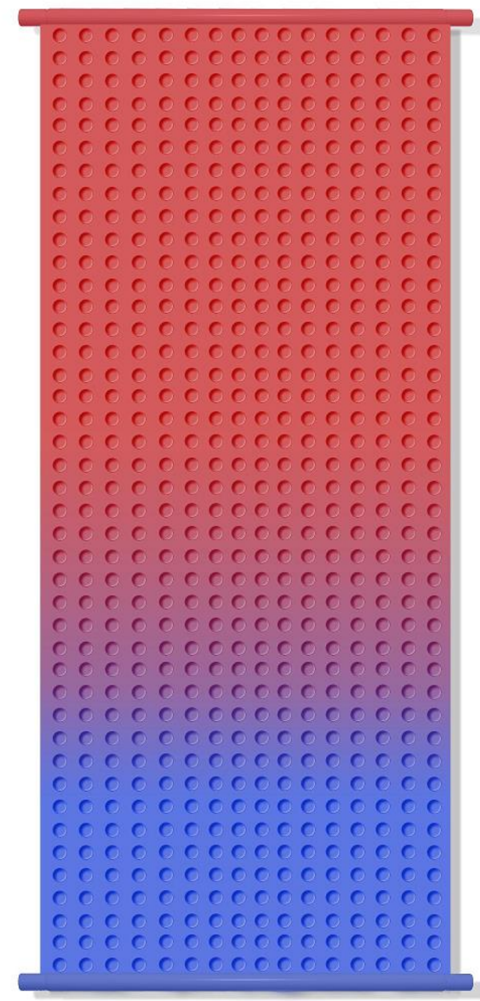
Plastic absorbers



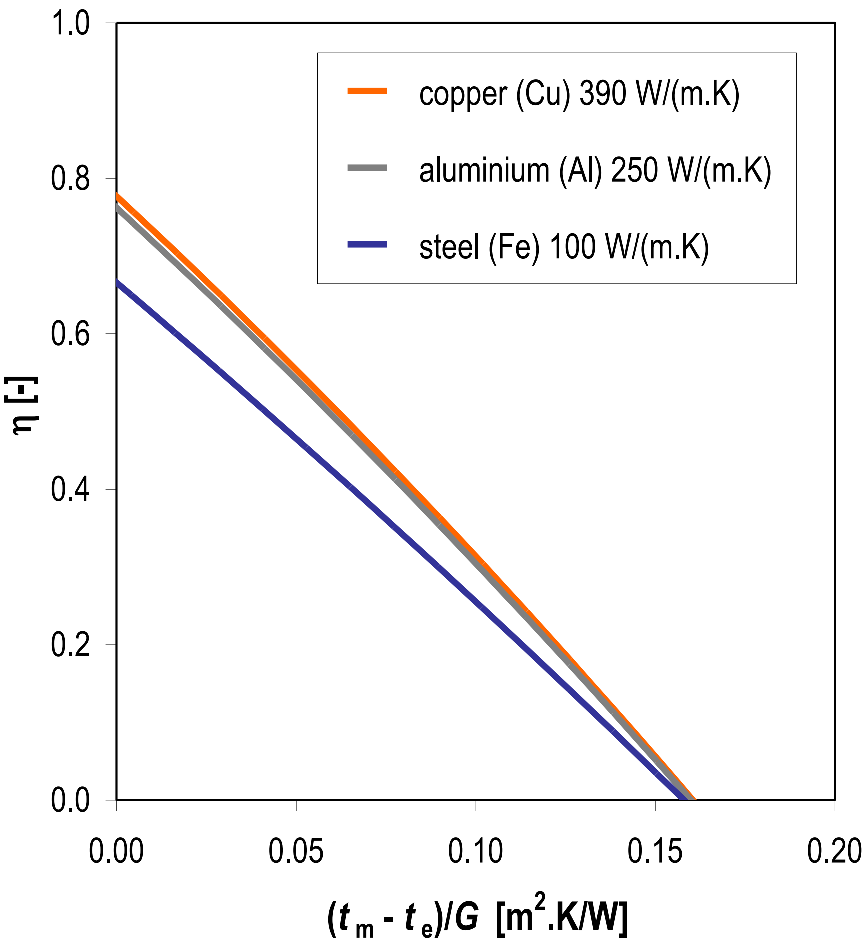
Best absorbers – fully wetted metal sheet

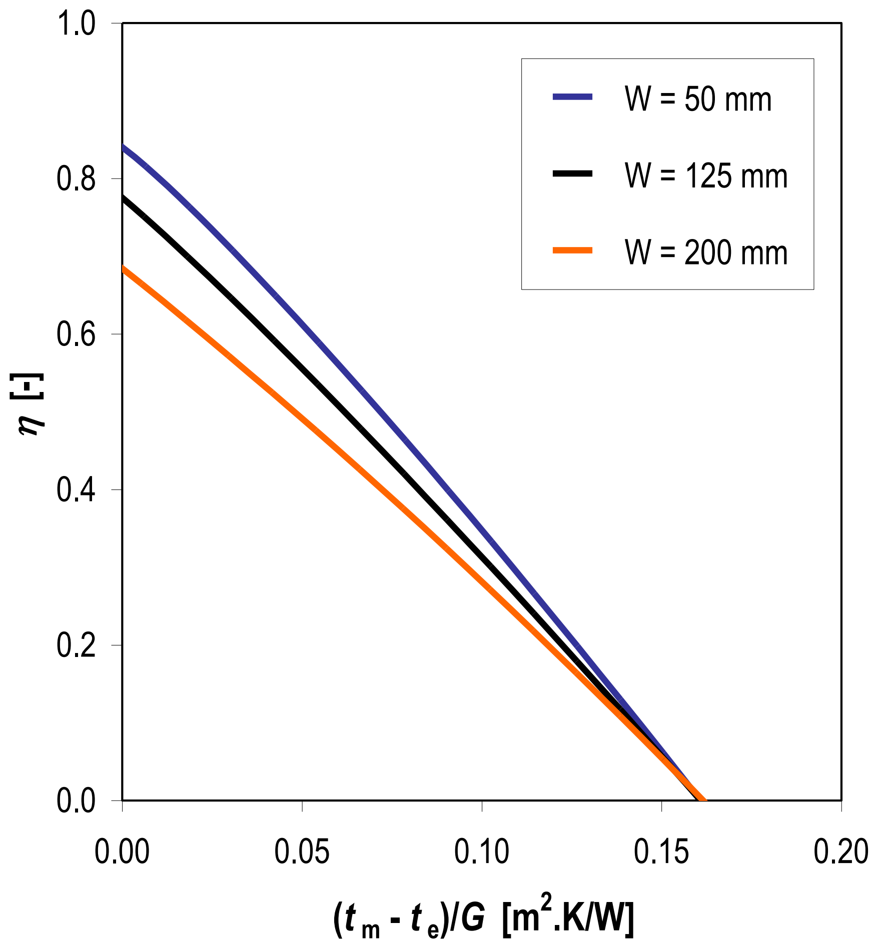
$F' = 1.0$





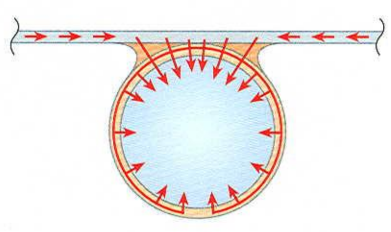
Influence of material and geometry

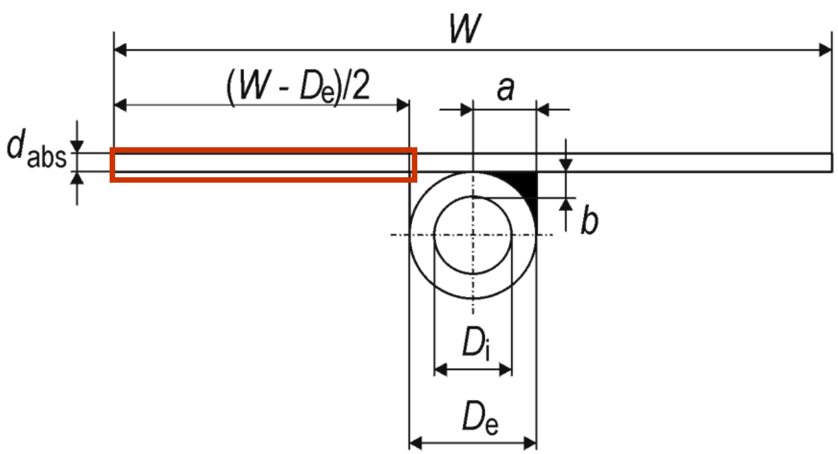




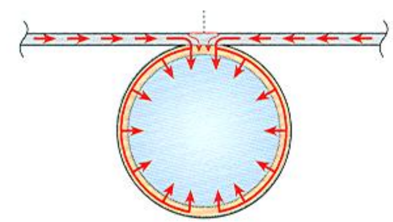
Efficiency factor *F'* – bond quality

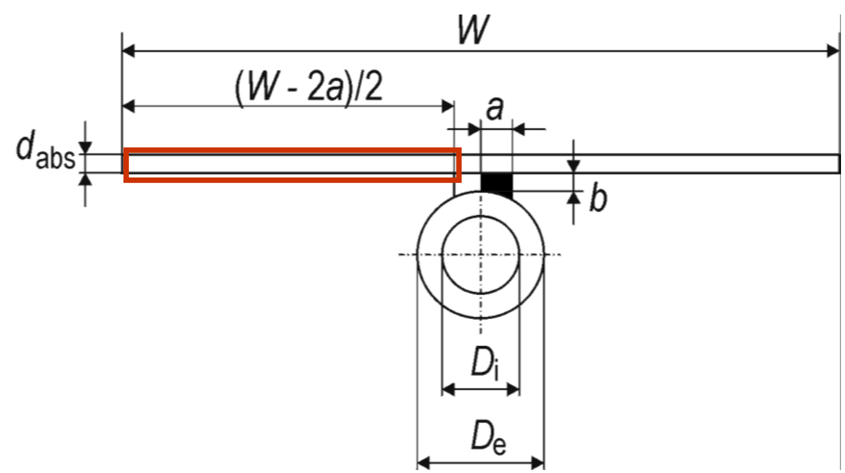
soldering





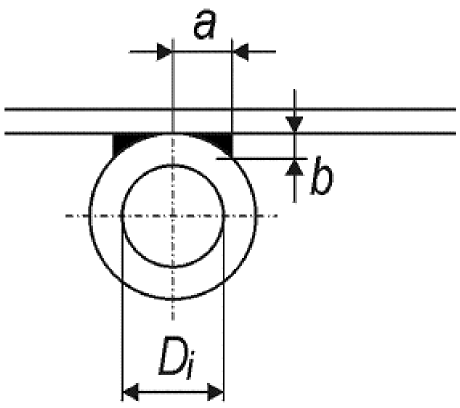
ultrasonic welding





Bond conductance

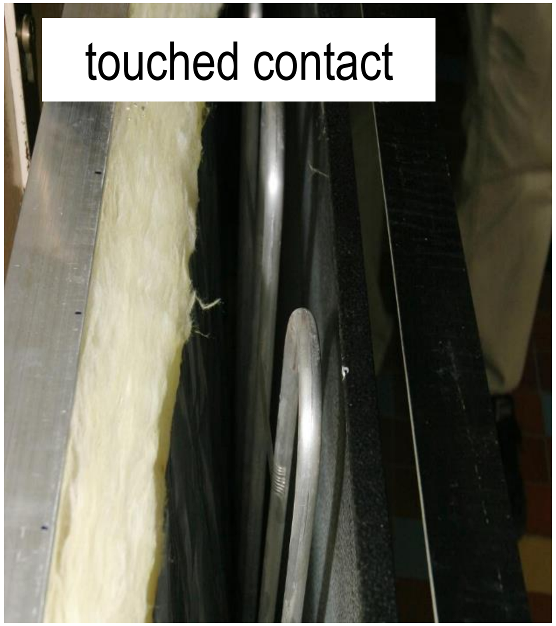
geometry, material and contact quality

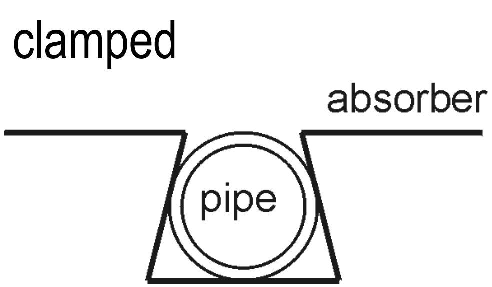


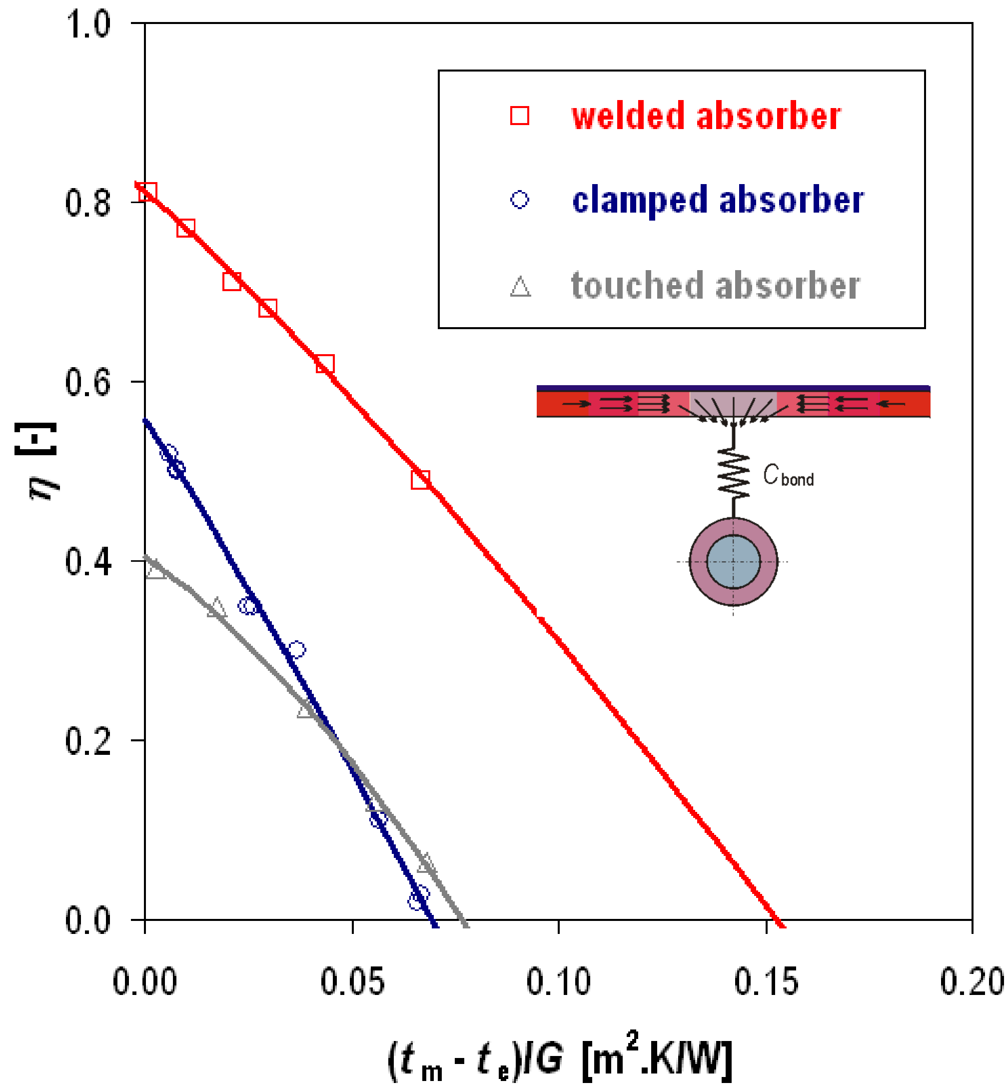
$$\Lambda_{sp} = \frac{\lambda_{sp}\, a}{b}$$

good metal-metal contact required (welding, soldering, pressing)
if bond conductance > 30 W/mK NO DIFFERENCE

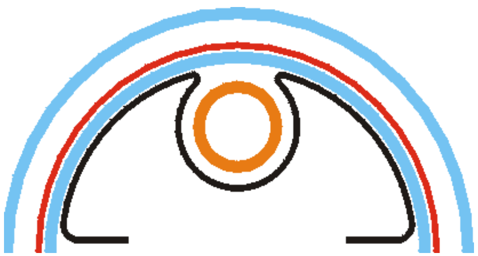
Influence of bond on efficiency

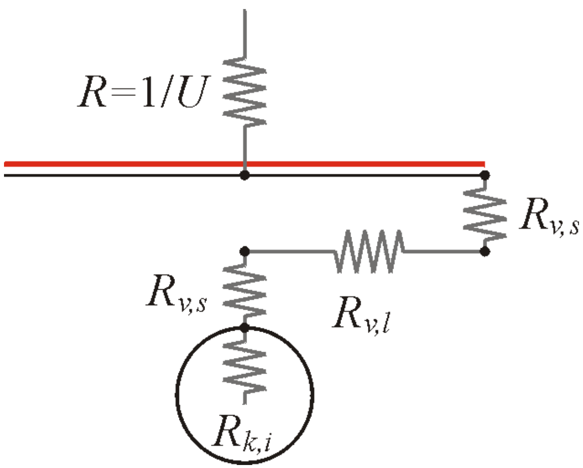






Vacuum tube (Sydney) collectors



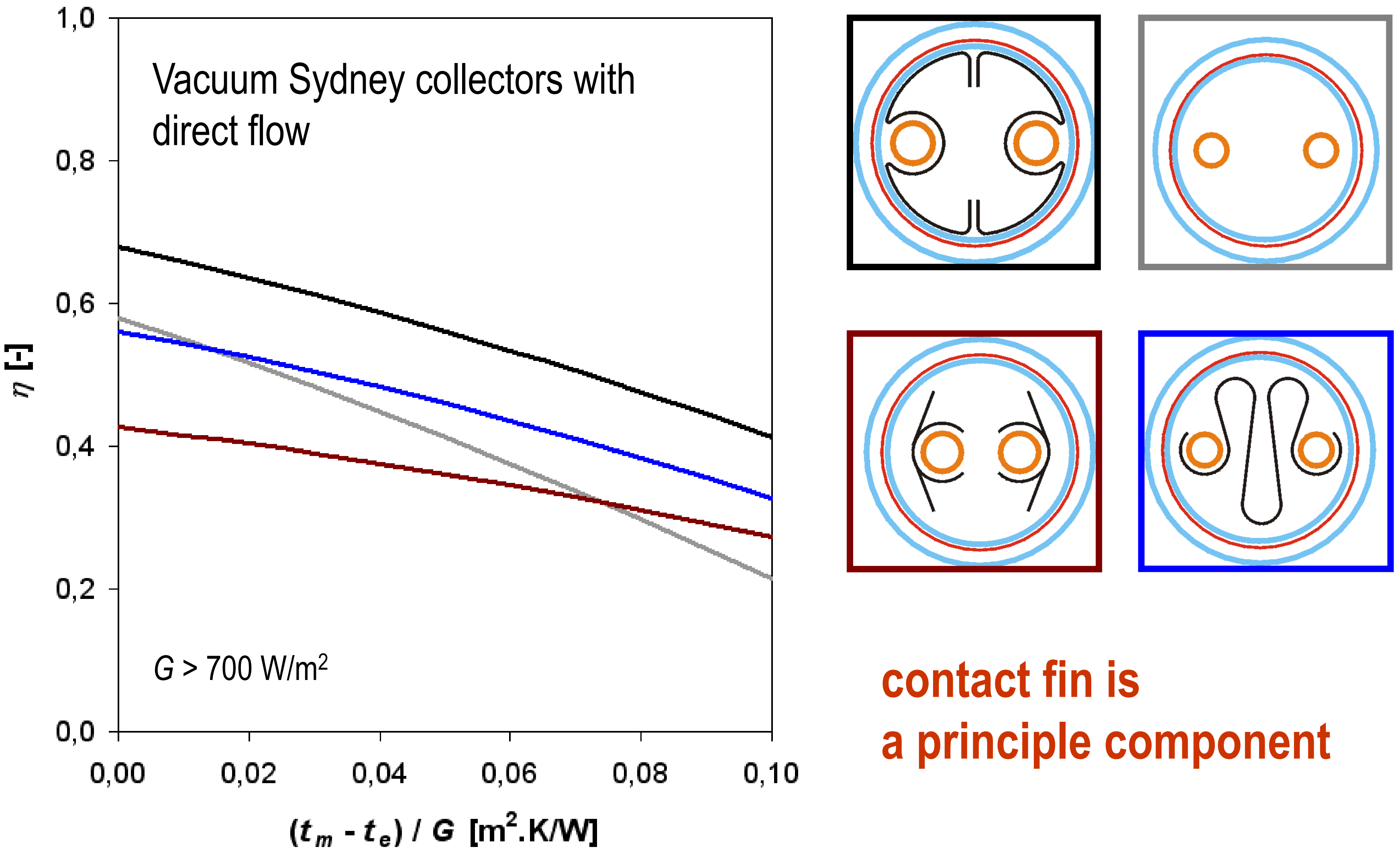


given by Sydney tube

$$\eta = F' \left[\tau \cdot \alpha - U \cdot \frac{(t_m - t_e)}{G} \right]$$

contact fin: short, conductive, thick, with a tight contact

Influence of contact fin on efficiency

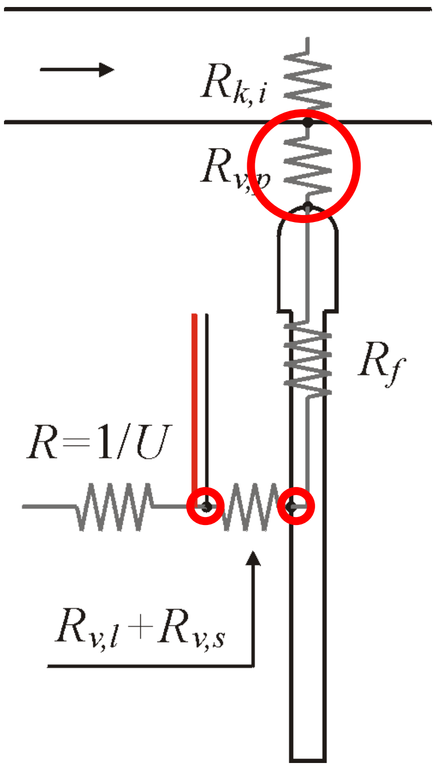


contact fin is a principle component

Contact at condenser of heat pipe

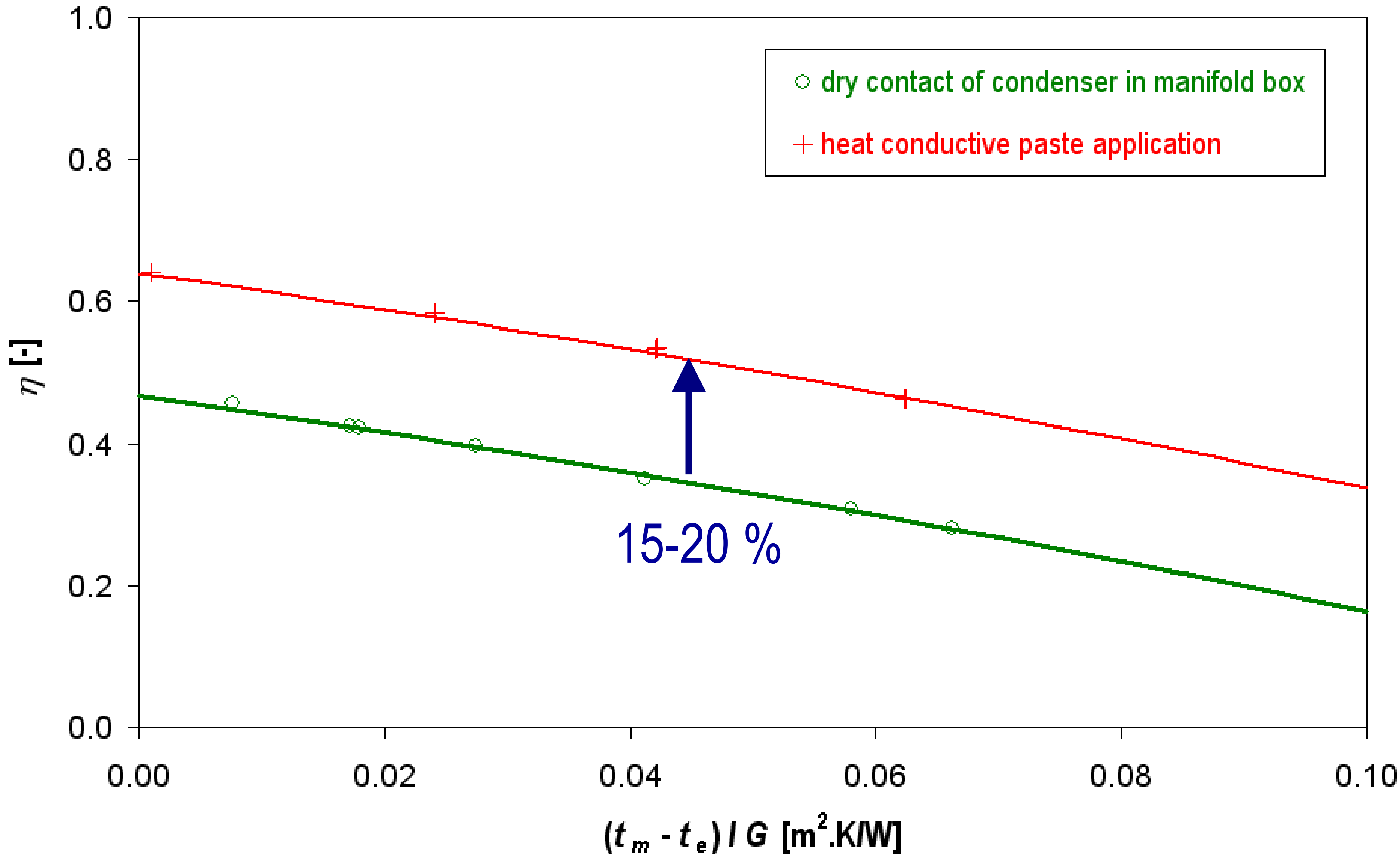
Heat pipe (phase change of working fluid inside HP)

- evaporator (contact with a fin transferring heat from absorber tube)
- condenser (put into slot wetted by fluid)



improper construction, bad thermal contact

Dry contact of condenser with manifold



Solar collectors testing (EN)

EN 12975-1,2

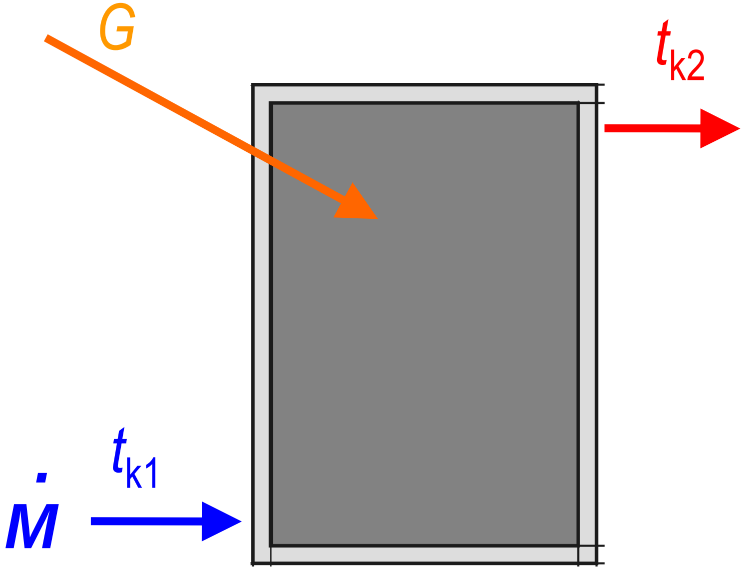
Performance tests

- heat output and efficiency of collector
- incidence angle modifier IAM (influence of incidence angle of solar radiation on efficiency and heat output – optical characteristics)
- effective heat capacity of collector

- at **stationary** conditions outdoor / indoor
  - clear sky, solar irradiance > 700 W/m^2, **normal incidence**, *w* > 3 m/s

- at **dynamic** conditions
  - changeable weather, more parameters, dynamic model of collector

Determination of heat output



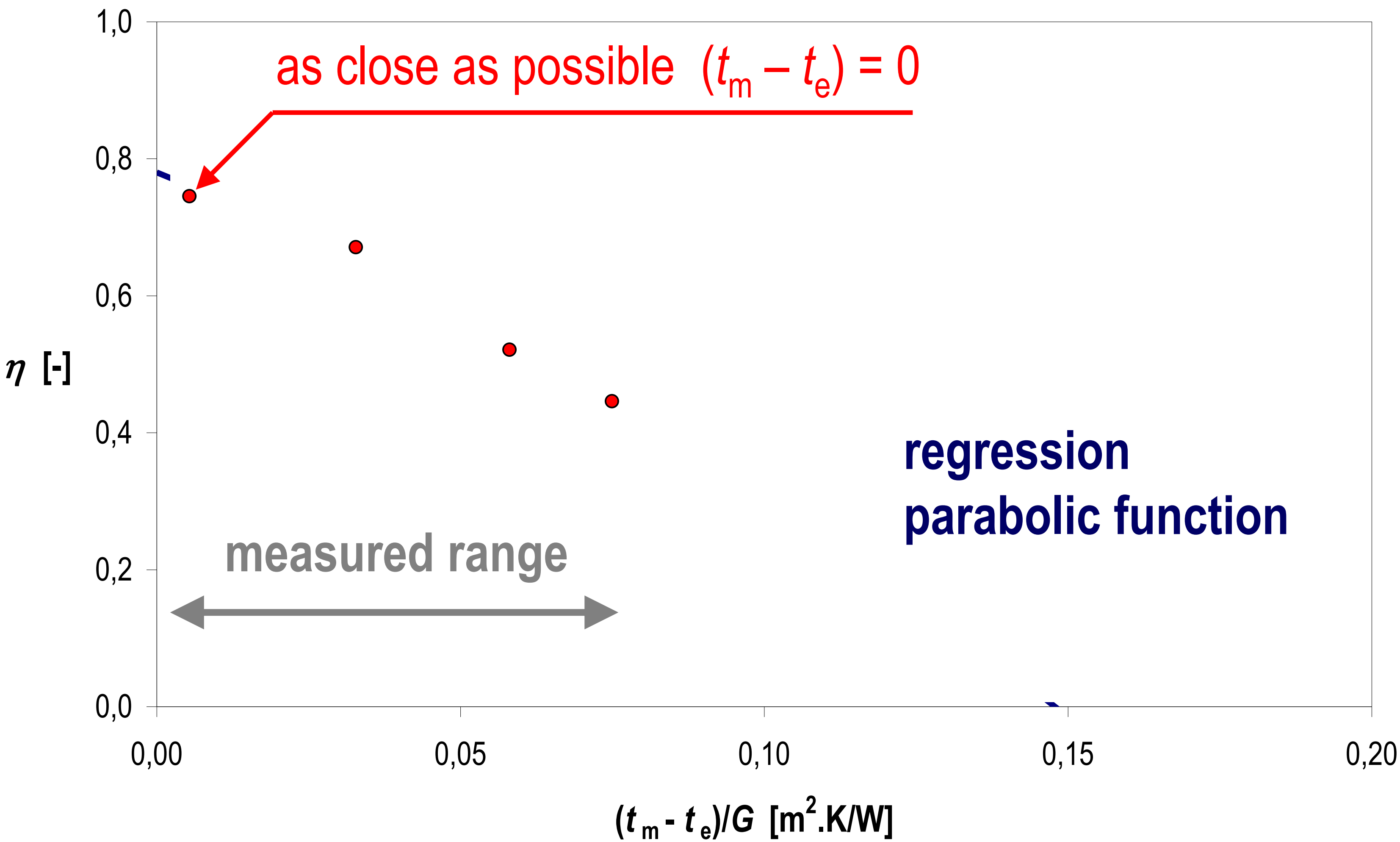
heat output [W]

$$\dot{Q}_k = \dot{M} \cdot c \cdot (t_{k2} - t_{k1})$$

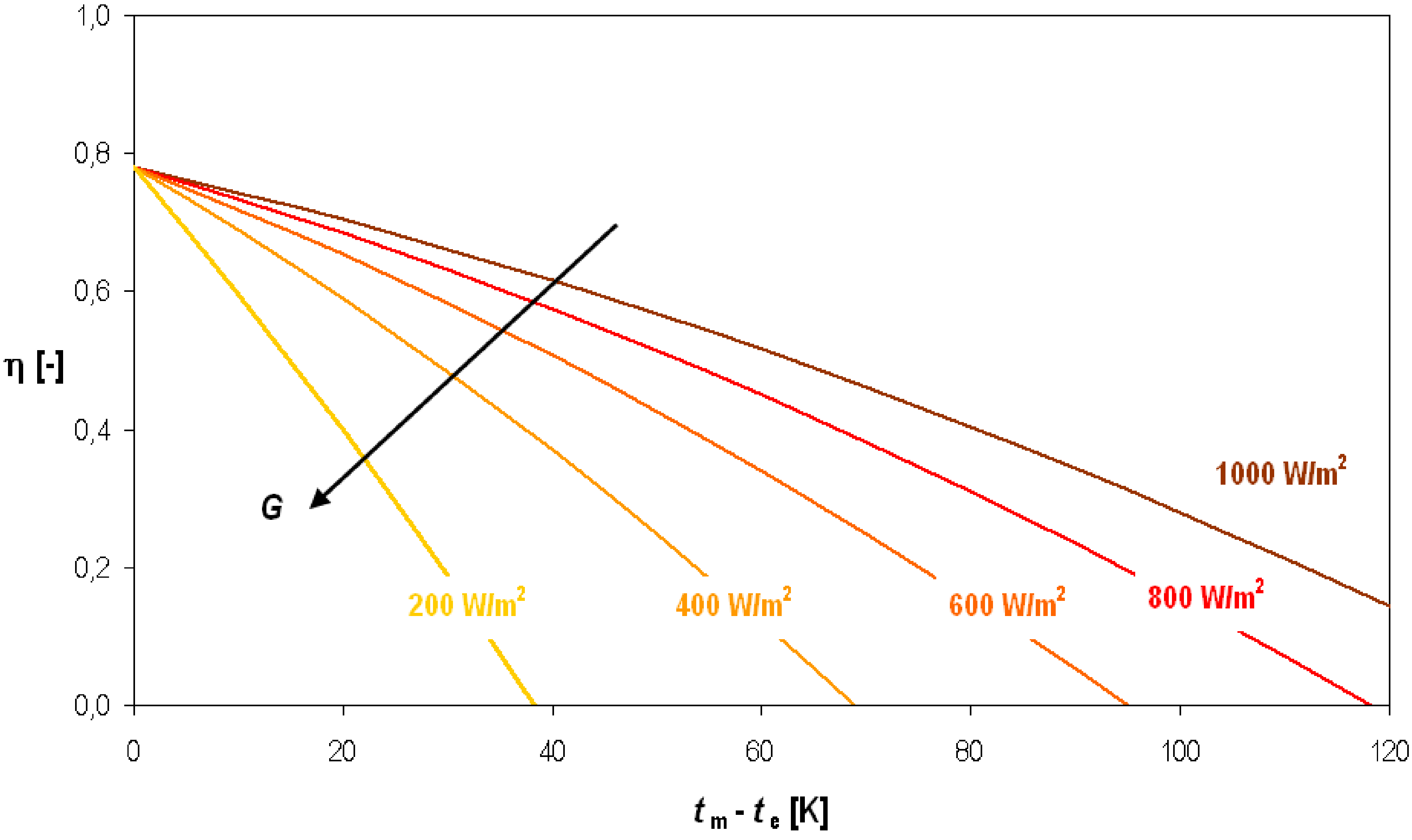
efficiency [-]

$$\eta = \frac{\dot{Q}_k}{G \cdot A_k}$$

Measured points and regression



Efficiency characteristics = f ($t_m - t_e$)



Efficiency from testing

regression parabolic function in form $y = a + bx + cx^2$

$$\eta = \eta_0 - a_1 \cdot \frac{t_m - t_e}{G} - a_2 \cdot G \cdot \left(\frac{t_m - t_e}{G}\right)^2$$

η_0 „optical“ efficiency [-], better: zero-loss efficiency

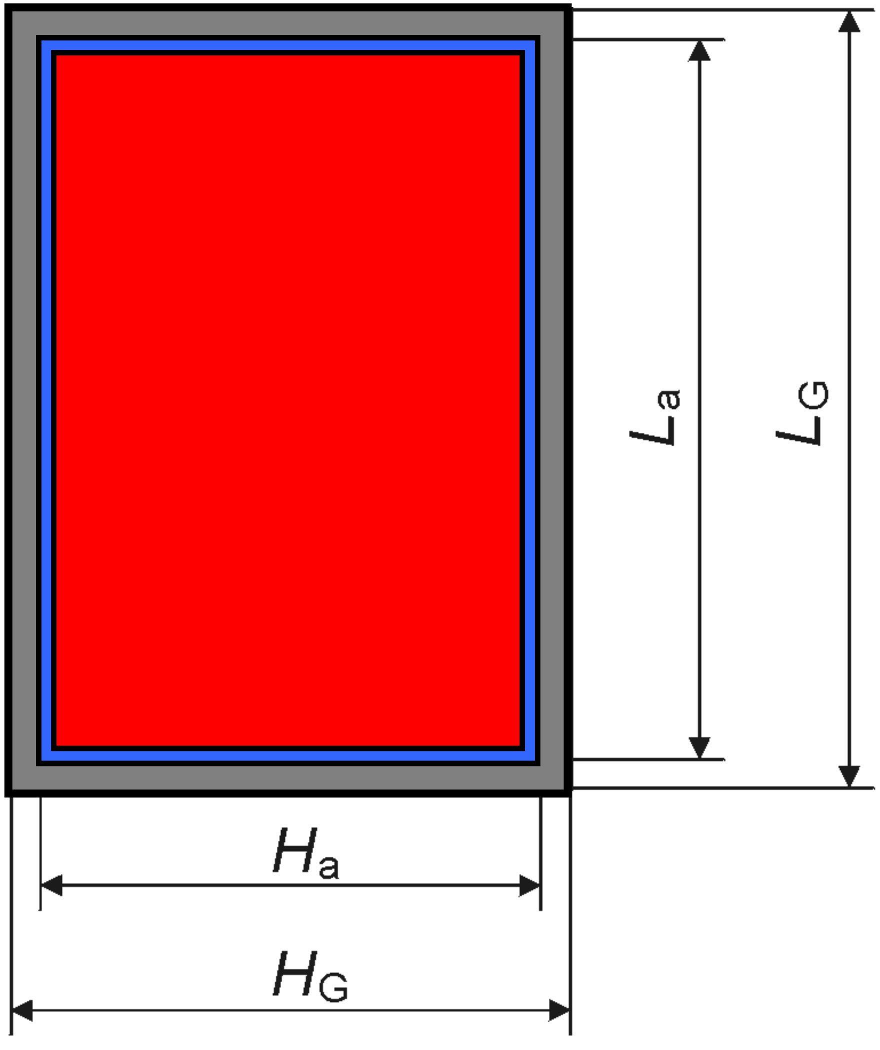
a_1 linear heat loss coefficient [W/(m^2.K)]

a_2 quadratic heat loss coefficient [W/(m^2.K^2)]

values η_0, a_1, a_2 related to **reference area A_k**

coefficients are given by producer, supplier or testing institute based on test report in accordance to EN 12975-2

Reference collector area A_k



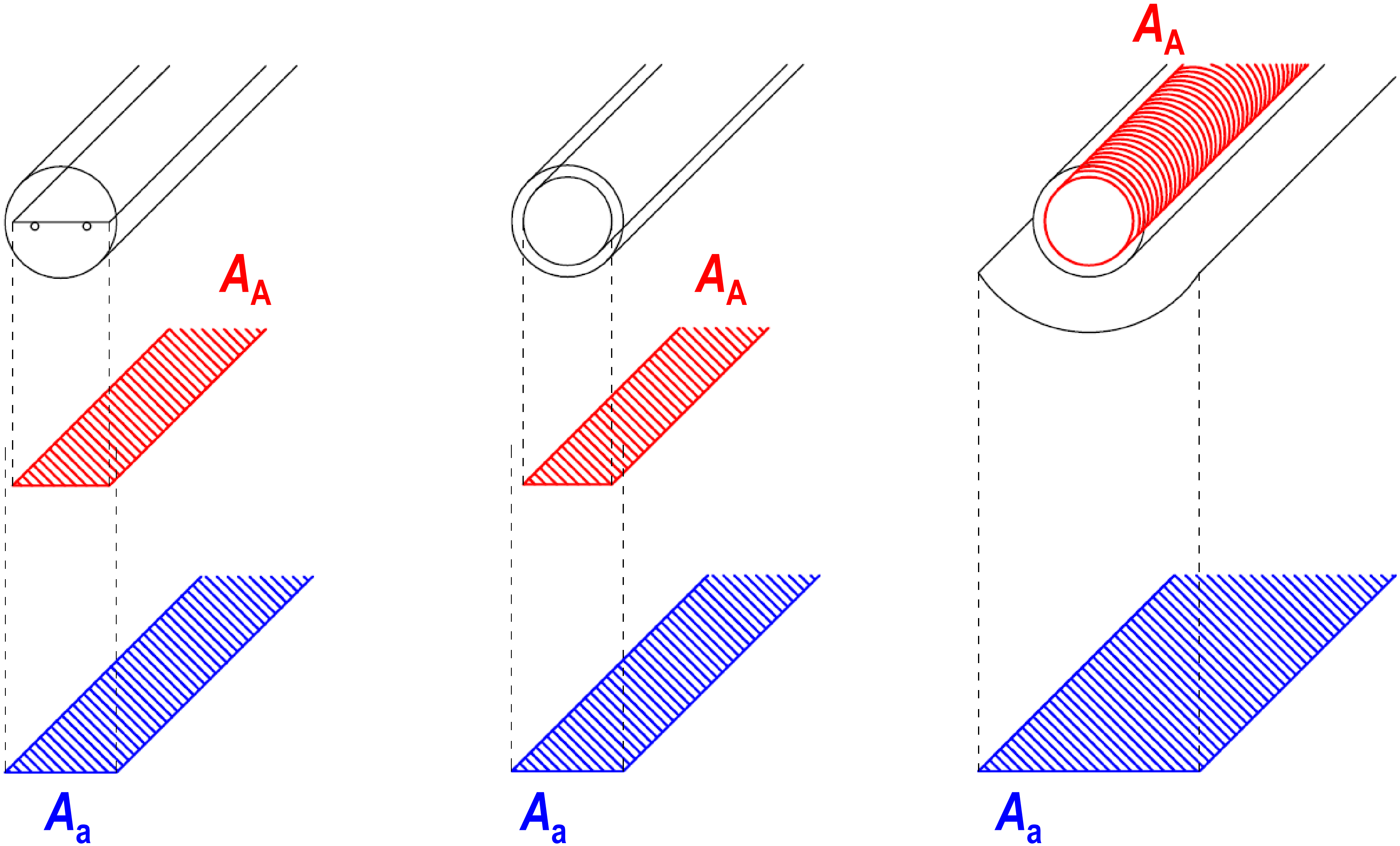
$$\eta = \frac{\dot{Q}_k}{G \cdot A_k}$$

gross area: A_G

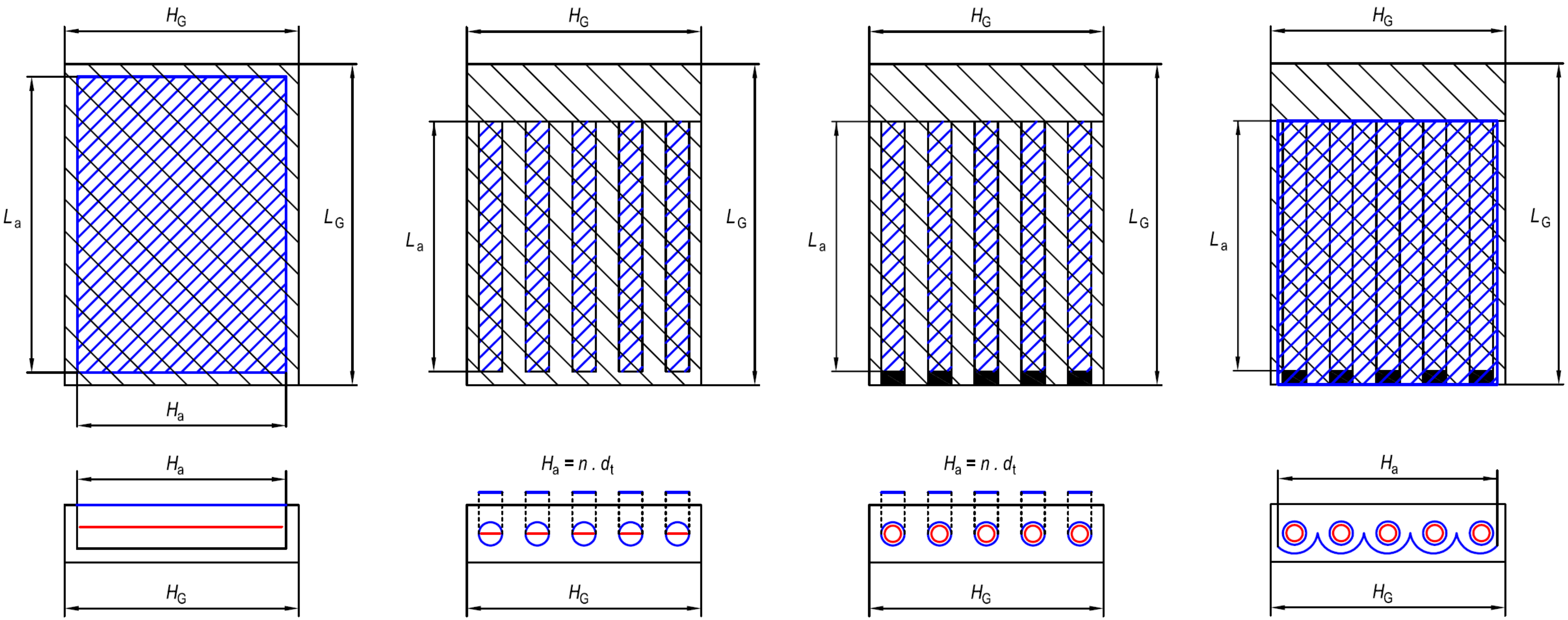
aperture area: A_a

absorber area: A_A

Reference collector area A_k



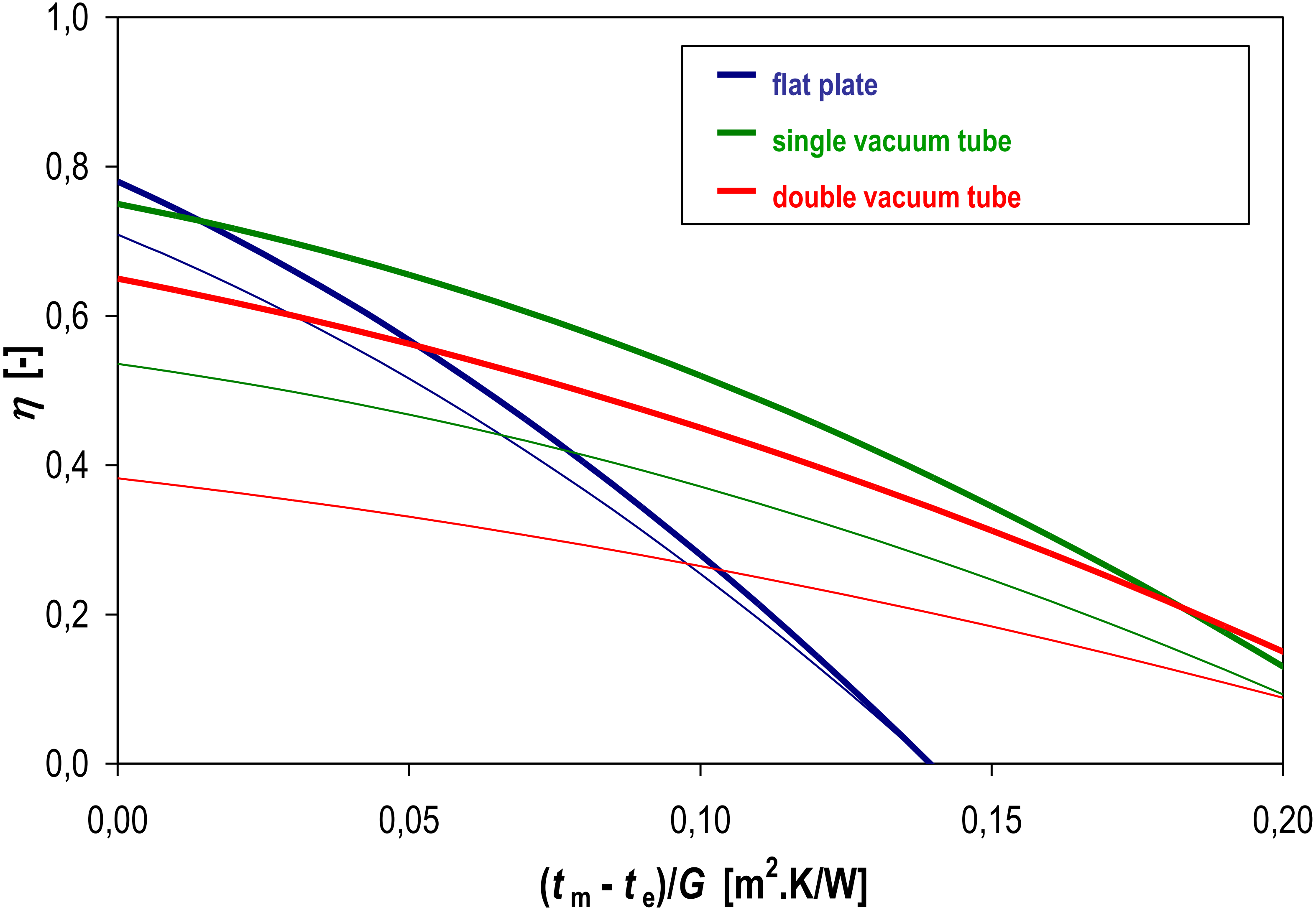
Reference collector area A_k



$A_a = 0{,}9\ A_G$ $A_a = 0{,}75\ A_G$ $A_a = 0{,}6\ A_G$ $A_a = 0{,}8\ A_G$

- aperture: comparison of collector quality, construction
- gross area: decision on potential for given application (limited space on roof)

Efficiency of solar collector $A_a \rightarrow A_G$



Typical coefficients *)

Collector type	η_0	a_1	a_2
	-	$W/(m^2K)$	$W/(m^2K^2)$
Unglazed	0.85	20	-
Glazed with nonselective absorber	0.75	6.5	0.030
Glazed with selective absorber	0.78	4.2	0.015
Vacuum single tube (flat absorber)	0.75	1.5	0.008
Vacuum tube Sydney	0.65	1.5	0.005

*) referenced to aperture area

Heat output (power) of solar collector

solar collector power (normal incidence, clear sky)

$$\dot{Q}_k = \eta \cdot A_k \cdot G = A_k [\eta_0 G - a_1 \cdot (t_m - t_e) - a_2 \cdot (t_m - t_e)^2]$$

installed (nominal) **power**

– for defined conditions (according to ESTIF):

G = 1000 W/m² t_e = 20 °C t_m = 50 °C

peak power (without heat loss)

$$\dot{Q}_k = A_k \eta_0 G$$

G = 1000 W/m²

Heat output (power) of solar collector