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Lecture #4 **Solar collectors**

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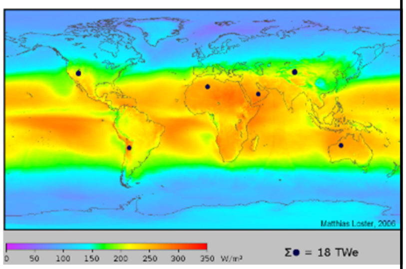
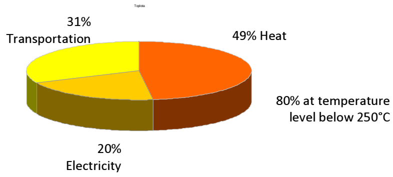
Intro

- Solar radiation is most important energy source for the planet Earth. Less that 0,05 % of primary energy needed nowadays is provided using non-renewable energy sources.
- Almost 50% of all final energy in EU is needed inform of heat, 80% of that at the temperature level below 250°C
- This heat could be entirely produced by thermal solar systems. This are systems that convert, store and delivery heat to the user when the heat is needed.
- Thermal solar collectors as heat generators will be discussed in this lecture.



Black dots represent area needed for current energy demand (including heat, fossil fuels, nuclear energy, electricity) by today available technologies.



Most of the heat demand at temperature level below 250°C could be covered with utilization of solar energy.

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Thermal solar collectors (SC) – types regarding to the heat transfer media

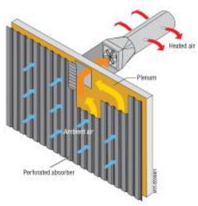
- Thermal solar collectors are devices that convert solar radiation into the heat and transfer heat to the heat transfer fluid.
- Transfer fluid could be water, mixture of water and antifreeze solution or high thermal resistant oil in case of liquid solar collectors (LSC) or air in case of air solar collectors (ASC).

Liquide thermal solar collectors

Air solar collector. Solar cell (PV module) is integrated in the casing at the top for providing electicity to run ventilator.

Thermal solar collectors (SC) – open and close loop systems

- Thermal solar collectors can operate in close or open system. In close systems heat transfer fluid flows in pipes or channels into heat storage or into the building, cool down and return to SC.
- In open cycle systems heat transfer fluid is taken from surroundings and heat up in SC. Mainly ASC operates in such a way as preheated for ventilation air.



When operate in closed system, SC heat up transfer fluid circulating in pipes or channels. In open systems, heat transfer fluid entrance into SC directly from ambient. Such kind of operation is not common for LSC, but is widely used then ASC is used for preheating of ventilation air or for drying crops.

Source: James&James

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Thermal solar collectors (SC) –operation temperature

Low temperature: air/unglazed	Mid-temperature: Flat plate/vacuum	High temperature concentrators



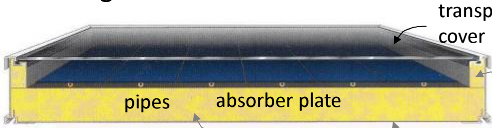


Air preheating, space heating, drying, pool heating	Domestic hot water heating, space heating, drying, solar cooling	Solar cooling, process heat

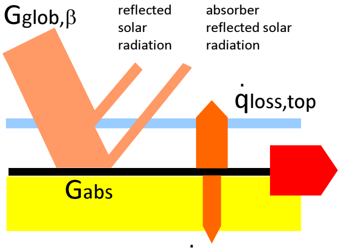
35°C — 90°C — 250°C

Heat transfer in thermal solar collectors

- Thermal solar collector consist of absorber with pipes or channels where heat transfer fluid flows, transparent cover, back and edge thermal insulation and casing.



- Heat flux balance in SSE



$G_{glob,\beta}$	solar radiation on the SC cover
G_{abs}	absorbed solar radiation
$\dot{q}_{loss,top}$	heat flux form the absorber to environment through the cover
$\dot{q}_{oss,bottom}$	heat flux thought bottom and edge thermal insulation
$\dot{q}_{usefull}$	heat transferred by heat transfer fluid out of the 1 m^2 of SC

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Efficiency of thermal solar collectors

- Absorbed solar radiation per 1 m² SC is equal to:

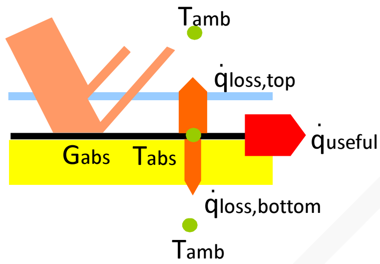
$$G_{abs} = G_{glob,\beta} \cdot \tau_{cover} \cdot \alpha_{absorber} \quad \left[\frac{W}{m^2}\right]$$

τcover	solar radiation transmition of the cover (-)
αabs	solar radiation absorption of the absorber (-)

- Heat losses are equal to:

$$\dot{q}_{loss} = \dot{q}_{loss,bottom} + \dot{q}_{loss,top} \approx U_{SC} \cdot (T_{abs} - T_{amb}) \quad \left[\frac{W}{m^2}\right]$$

Usc	overall thermal transmitance of the SC (W/m²K)
Tabs	absorber temperature (°C, K)
Tamb	ambient temperature (°C,K)



Efficiency of thermal solar collectors

- Specific useful heat flux produced by 1 m² of SC is equal to:

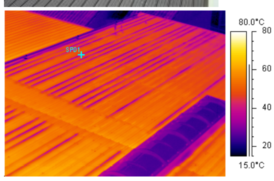
$$\dot{q}_{useful} = G_{abs} - \dot{Q}_{loss}$$

$$\dot{q}_{useful} = G_{glob,\beta} \cdot \tau_{cover} \cdot \alpha_{absorber} - U_{SC} \cdot (T_{abs} - T_{amb}) \quad \left[\frac{W}{m^2}\right]$$

- Two problems:

? How to calculate overall thermal transmittance U_{SC}

? How to calculate T_{abs} since it defers from point to point on the absorber



Thermal image of the unglazed SC: big difference between the temperatures of fins and pipes on absorber can be seen

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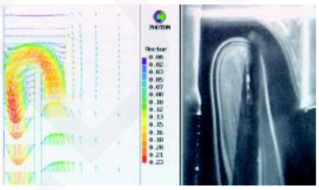
Overall thermal transmittance U_{SC}

- Using Fourier law, Newton cooling law and Stefan-Boltzman law, conduction, convection and radiation heat fluxes as boundary conditions or heat sources are integrated in solution of Navier-Stoke Equations (NES)
- Using numerical methods and Computer Fluid Dynamic (CFD) tools, NES can be solved for temperature, velocity and pressure for all differential small points (x,y,z) of SC (glass, air gap, absorber, thermal insulation, casing).
- With known temperatures, local heat losses as well as U_{SC} can be determinate and integrated (when Q_{loss} is calculated) or averaged (when U_{SC} is calculated) over the aperture whole area of SC.

Temperature, velocity and pressure fields are calculated for differential each point of SC using CFD computer tools



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Overall thermal transmittance U_{SC}

- Using empirical formulas which were developed using (combination of) analytical, numerical or experimental methods. This is an example of such empirical formula:

$$U_{SC} = \left[\frac{N}{\frac{A}{T_{abs}}\left(\frac{T_{abs}-T_{amb}}{N+B}\right)^{0,33}} + \frac{1}{\alpha_w} \right]^{-1} + \frac{\sigma \cdot (T_{abs}+T_{amb})(T^2_{abs}+T^2_{amb})}{\left[\varepsilon_{IR,abs}+0,05N(1-\varepsilon_{IR,abs})\right]^{-1} + \left(\frac{2N+B-1}{\varepsilon_s}\right) - N} \quad \left[\frac{W}{m^2K}\right]$$

$$A = 250[1-0,0044(\beta-90)]$$

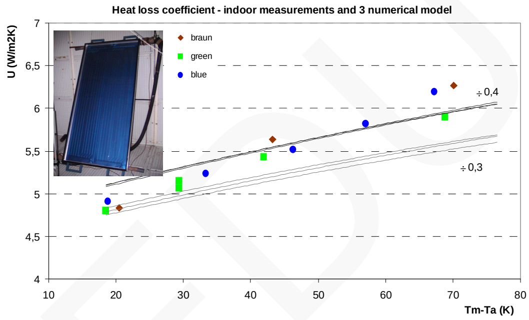
$$B = (1-0,04\alpha_w + 0,0005\alpha_w^2)(1+0,091N)$$

$$\alpha_w = 8,6+2,7v_w$$

N	number of cover layers (-)
T_{abs}	absorber temperature (K)
T_{amb}	ambient temperature (K)
$\varepsilon_{IR,abs}$	thermal emissivity of absorber (-)
ε_g	cover thermal emissivity (-)
α_w	convection heat transfer coefficient between cover
and	ambient (W/m²K)
σ	Stefan-Boltzman constant (5,67*10^{-8} W/m²K⁴)
β	SC tilt angle (°)
v_w	wind velocity over SC cover (m/s)

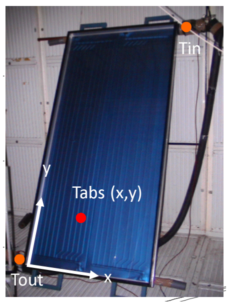
Overall thermal transmittance Usc

- Usc can be determinate experimentally by measuring heat losses without presents of solar radiation when externally heated heat transfer fluid is circulating through SC. In this case heat losses can be calculated regarding to mass flow rate of heat transfer fluid and temperature difference between inlet and outlet (which is lower of two) temperatures of heat transfer fluid.
- Picture presents results of experiments and comparison with empirical results for two SC with different thermal emissivity of absorber $\varepsilon_{IR,abs}$ 0,3 and 0,4. Note that Tabs are replaces by average temperature of heat transfer unit Tm. This temperature is calculated as average value of inlet and outlet temperature of heat transfer fluid.



Efficiency of thermal solar collectors

- Even if Usc is know, there is still question witch temperature of absorber (Tabs) is most representative for calculation of heat losses because every single point of the absorber has different temperature.
- The problem can be solved using so called Hottel-Whillier-Bliss approach. Regarding to this approach, unknown absorber temperatures are replaced by single temperature Tm which is average temperature between inlet and outlet temperature of heat transfer fluid.
- It is obvious that in this case, temperature of absorber will be lower that real one, therefore correction factor F' must be included in the calculation of useful heat flux (thermal power of SC with area A_{SC}) (Hottel-Whillier-Bliss equation):

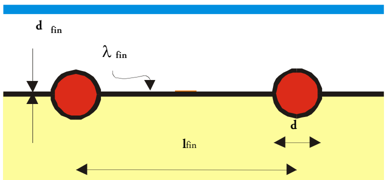


$$T_m = \frac{T_{in} + T_{out}}{2}$$

$$\dot{Q}_{useful} = A_{SC} \cdot F' \cdot \left(G_{glob,\beta} \cdot \tau_{cover} \cdot \alpha_{absorber} - U_{SC} \cdot \left(\frac{T_{out} + T_{in}}{2} - T_{amb} \right) \right) \quad [W]$$

Efficiency of thermal solar collectors

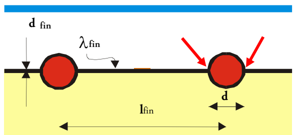
- In theory values of F' are between 0 and 1. It is obvious that F' should be close to the 1 to. How this can be achieved?
  - with high fin efficiency – tubs in LSC are bounded to heat conductive fin. In this way cost of absorber is lower. If fin has reasonable short length l_{fin} ~100 to 120 mm), good thermal conductivity (λ_{fin} > 150 W/mK) and thickness d_{fin} ~ 0,5 mm, the fin efficiency bill be above 0,97.

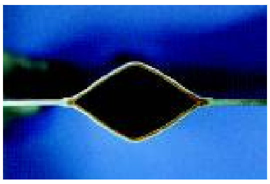


Rubber made unglazed SC absorber for low temperature applications (pool heating) shown on the picture must have very short fins, since rubber has low thermal conductivity; that's way rubber tubes are so close together

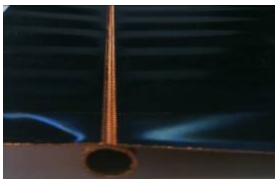
Efficiency of thermal solar collectors

- In theory values of F' are between 0 and 1. It is obvious that F' should be close to the 1 to. How this can be achieved?
  - by reducing bond conductance between absorber fin and tubes; several techniques can be used, like roll-bond, ultrasound or laser welding.

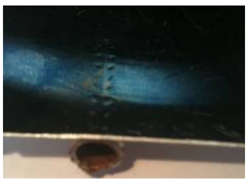




absorber made by roll-bond technique, two Al and two Cu ribbons are press together to ensure best possible contact between Al fin and Cu pipe



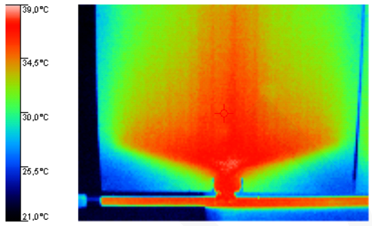
2 to 3 mm thick visible line at the top of the absorber is characteristic for ultrasound welding

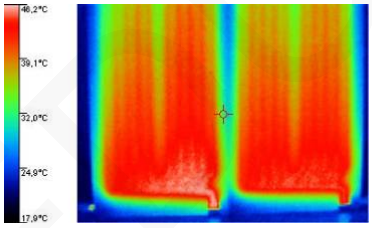


nearly invisible points at the top of the absorber indicate laser welding

Efficiency of thermal solar collectors

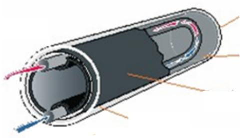
- In theory values of F’ are between 0 and 1. It is obvious that F’ should be close to the 1 to. How this can be achieved?
  - tubes inside absorber should be connected in such a way that ensures equal mass flow rate of heat transfer fluid thought each pipe.

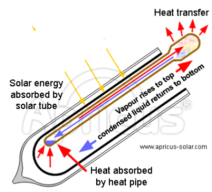




Efficiency of thermal solar collectors

- In theory values of F’ are between 0 and 1. It is obvious that F’ should be close to the 1 to. How this can be achieved?
  - Tubes in LSC could be in form of serpentine or parallel between two integrated collective tubes at the bottom and top of the SC
  - In case of vacuum SC heat transfer fluids flows either thought “U-shaped” pipe or heat pipe is used for transfer heat from SC to collective pipe at the top of SC.





Efficiency of thermal solar collectors

- For real products analytical models are to simple and efficiency of solar collectors is in most cased determinate by field measurements. The test procedure is standardized (EN ISO 9806 group standards).
- In this case calorimetric method is used for determination of Q_{useful} at different operating conditions. Heat flux (or SC thermal power) is calculated as average value in time interval between t1 and t2:

$$\dot{Q}_{useful} = \frac{1}{t_2 - t_1} \int_{t1}^{t2} \dot{m} \cdot c_p \cdot \left(T_{out} - T_{in}\right) \cdot dt \quad [W]$$

- Integral equation can be discredited in a form:

$$\dot{Q}_{useful} = \frac{1}{N} \sum_{1}^{N} \dot{m} \cdot c_p \cdot \left(T_{out,N} - T_{in,N}\right) \quad [W]$$

m	mass flow rate (kg/s)	t1	start time (s)
cp	heat capacity of heat transfer fluid (J/kgK)	T2	end time (s)
Tout	outlet heat transfer fluid temperature (K)	N	number of discrete measurements
T_{in}	inlet heat transfer fluid temperature (K)		

Efficiency of thermal solar collectors

- Efficiency of SC is then defined as:

$$\eta_{SC} = \frac{\dot{Q}_{useful}}{A_{SC} \cdot G_{glob,\beta}} \quad [1]$$

$$\eta_{SC} = \frac{\dot{Q}_{useful}}{A_{SC} \cdot G_{glob,\beta}} = \frac{A_{SC} \cdot F' \cdot \left(G_{glob,\beta} \cdot \tau_{cover} \cdot \alpha_{absorber} - U_{SC} \cdot \left(\frac{T_{out} + T_{in}}{2} - T_{amb}\right)\right)}{A_{SC} \cdot G_{glob,\beta}} \quad [1]$$

$$\eta_{SC} = \frac{\dot{Q}_{useful}}{A_{SC} \cdot G_{glob,\beta}} = F' \cdot \tau_{cover} \cdot \alpha_{absorber} - F' \cdot U_{SC} \cdot \left(\underbrace{\frac{\frac{T_{out} + T_{in}}{2} - T_{amb}}{G_{glob,\beta}}}_{\equiv T^*}\right) \quad [1]$$

- Linear fit to data ¨(see next page) can be used presenting temperature and solar radiation flux dependant SC efficiency:

$$\eta_{SC} = \eta_o - a_1 . T^* \quad [1]$$

T* reduced temperature difference (Km²/W)

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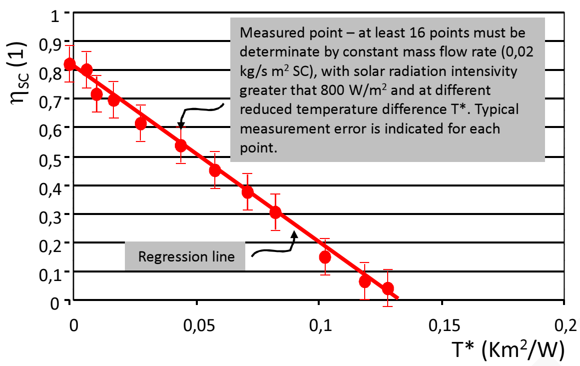
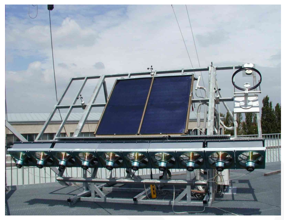
Efficiency of thermal solar collectors

- Efficiency of SC can be determinated by outdoor test or indoor test using solar simulator. In both cases, this is steady state efficiency – "instantaneous efficiency". Term η_o is "eta zero" or optical efficiency, constant a_1 is regression slope coefficient.



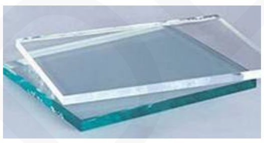


Field testing of solar collectors; ventilators in front of SC are used for simulation of wind

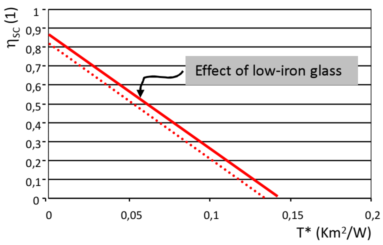
- Because area of SC (A_{SC}) is needed for calculation of efficiency, this can cause some obscurity; A_{SC} can be measures as absorber area, aperture area or gross area of SC. The differences between them are extreme in case of vacuum (tube) SC.

Efficiency of thermal solar collectors – how can be improved ?

- using low-iron glass transitivity of cover of solar radiation is enlarged



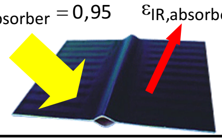
Ordinary window glass consist ferrous oxides. That's why edge colour of such glass is slightly green. SC glass cover without ferrous oxides (so called low-iron glass) is more transparent for solar radiation. This improves efficiency at all operating temperatures.



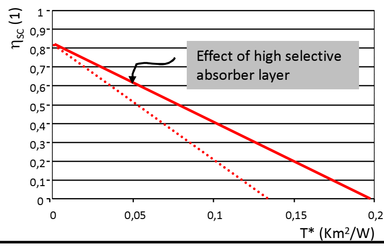
- with selective absorber layer, using coating or sputtering procedure, highly solar radiation (short wave) layer can have very low emissivity for thermal radiation (long wave). This property is measured by selectivity S:

$$S = \frac{\alpha_{S,absorber}}{\varepsilon_{IR,absorber}} \quad [1]$$

$\alpha_{S,absorber} = 0,95$ $\quad \varepsilon_{IR,absorber} = 0,05$



Ordinary bloc paint has S ~ 1, meanwhile S up to 20 is characteristic for contemporary SC

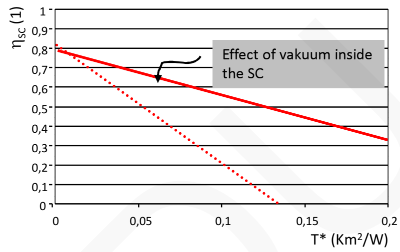


Efficiency of thermal solar collectors – how can be improved ?

- Selective layer reduce radiation heat losses between absorber and cover. Further improving of efficiency can be achieved if air is removed from interior of SC. If technical vacuum (absolute pressure is lower than 0,05 Pa) is reached, convection heat losses between absorber and cover are almost zero.

  Because high pressure difference between environment and interior of SC, casing must be inform of tube.

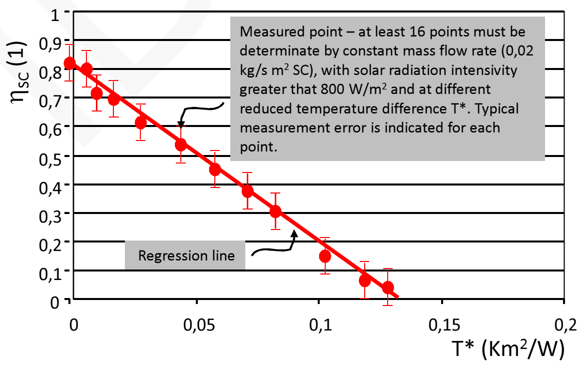
Two types of vakuum SC, single glass tube with flat absorber (top), double glass tube vakuum SC with round absorber.

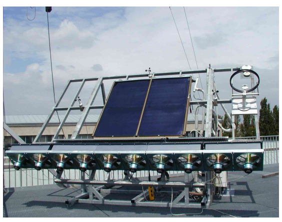


Vacuum SC has little lower optical efficiency (zero eta) η_o comparing to flat plate SC, because some spacing between tubes is necessary for avoiding shading effect.

Efficiency of thermal solar collectors

- Efficiency of SC can be determinated by outdoor test or indoor test using solar simulator. In both cases, this is steady state efficiency – “instantaneous efficiency”. Term η_o is “eta zero” or optical efficiency, constant a_1 is regression slope coefficient.

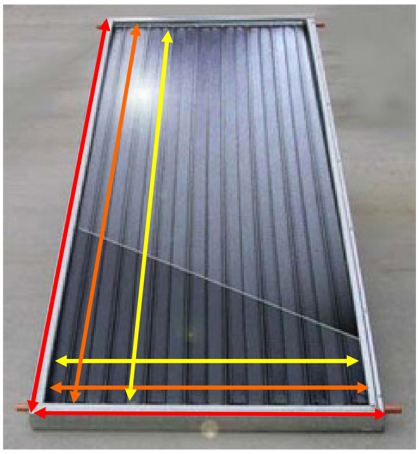




Field testing of solar collectors; ventilators in front of SC are used for simulation of wind

- Because area of SC (A_{SC}) is needed for calculation of efficiency, this can cause some obscurity; ASC can be measures as absorber area, aperture area or gross area of SC.

Efficiency of thermal solar collectors – presentation of A_{SC}



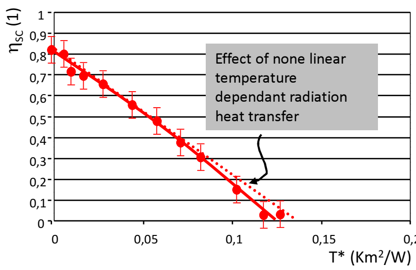
absorber area (A_A)
aperture area (A_a)
gross area of collector (A_g)

Efficiency of thermal solar collectors

- Conduction and convection heat losses are proportional to linear temperature difference between absorber and environment, meanwhile radiation heat losses are proportional to temperature on power of 4. This mean that efficiency of SC will decrease more that linear at higher reduced temperature T*. Therefore second-order fit to data could be more appropriate:

$$\eta_{SC} = \eta_o - a_1 \cdot T^* - a_2 \cdot G_{glob,\beta} \cdot T^{*2} \quad [1]$$

$$\eta_{SC} = 0{,}717 - 1{,}52 \cdot T^* - 0{,}0085 \cdot G_{glob,\beta} \cdot T^{*2}$$



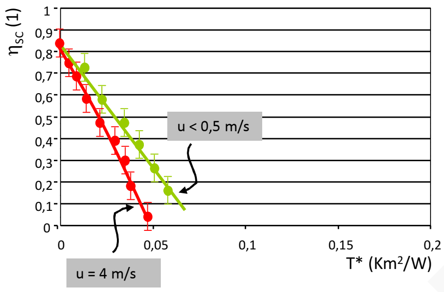
Second-order fit constants a_1 (W/m²K) and a_2 (W/m²K²) are determinated at reference solar irradiation on the aperture area of SC 800 W/m².

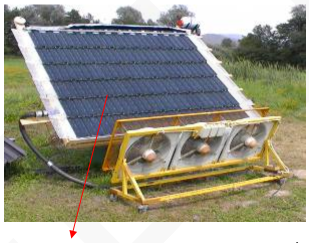
- Selection between first- and second-order fit must be made regarding to least squares regression or linear fit should be adopted if constant a_2 is negative.

Efficiency of thermal solar collectors

- Wind has very small effect on efficiency of flat or vacuum SC, but huge effect in case of unglazed SC. Therefore slope angle of linear-fit line must be determinated for different wind velocities and constant a_1 should be established as linear function of wind velocity u with two additional constants b_1 and b_2. Regarding to standardized method, wind effect is simulated by ventilators.

$$\eta_{SC} = \eta_o - a_1(u).T^* = \eta_o - (b_1 + b2 \cdot u).T^* \quad [1]$$



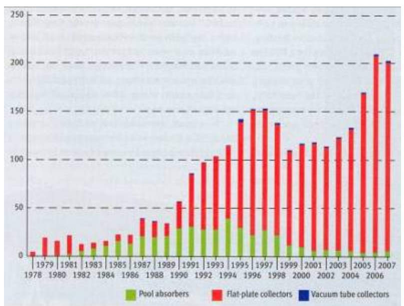


$$\eta_{SC} = 0,75 - (11,2 + 3,9 \cdot u).T^*$$

Efficiency of thermal solar collectors

Type of SC	η_o (-)	a_1 (W/m²K)
Unglased	**0,85**	**20**
Flat, black painted absorber	**0,80-0,82**	**7-9**
Selective	**0,75-0,80**	**4-5**
Selective with low-iron glass	**0,82-0,85**	**4-5**
Vakuum	**0.70-0,75**	**1,5-2,5**

Share of different technologies of SC on Austrian market..



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Durability tests of thermal solar collectors

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PRESKUS NA ZUNANJEM PRESKUŠEVALIŠČU

PREGLED DOKUMENTACIJE

- TEHNIČNA DOKUMENTACIJA
- RISBE IN SKICE
- PROSPEKTNI MATERIAL

MEHANSKI IN HIDRAVLIČNI PRESKUSI

- KONTROLA MATERIALOV, OZNAK IN DIMENZIJ
- DOLOČITEV HIDRAVLIČNE KARAKTERISTIKE
- TLAČNI PRESKUS ABSORBERJA
- PRESKUS TOGOSTI OHIŠJA

NOTRANJI TOPLOTNI PRESKUS

- MERITVE TOPLOTNE PREHODNOSTI V KOMORI

Durability tests of thermal solar collectors

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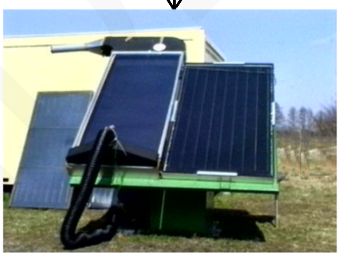


TOPLOTNI PRESKUSI

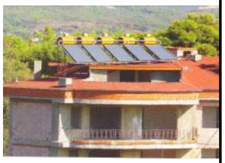
- PREDHODNO STARANJE
- MERITVE UČINKOVITOSTI
- DOLOČITEV FAKTORJA VPADNEGA KOTA
- DOLOČITEV ČASOVNE KONSTANTE
- DOLOČITEV TOPLOTNE VSEBNOSTI
- PRESKUS ODPORNOSTI NA VISOKE TEMPERATURE
- PRESKUS ODPORNOSTI NA ZUNANJE TEMPERATURNE ŠOKE
- PRESKUS ODPORNOSTI NA NOTRANJE TEMPERATURNE ŠOKE

ZUNANJI MEHANSKI PRESKUSI

- PRESKUS SSE NA VDOR VODE
- PRESKUS ODPORNOSTI NA TOČO
- KONČNA VIZUELNA KONTROLA

ntegration into the buildings

- Quite often installing of SC is not appreciated by architects or urban planers. In heritage cities SC are not allowed to be installed on visible parts of the facades or roofs.



- Several solutions are available to overcome this problems:

  Integration into the roof construction; beside good looking, such installing improve efficiency of SC, because back heat losses decreasing. In some countries such mounting is obligatory (ex. In Slovenia)

Source: James&James

ntegration into the buildings

- SC can be shape as ordinary building constructions.

"Solar tiles" are formed as ordinary roof brick. As they are made from transparent polycarbonate, heat transfer fluid can be in same colours (here, brick-red and dark blue) as remain roof.

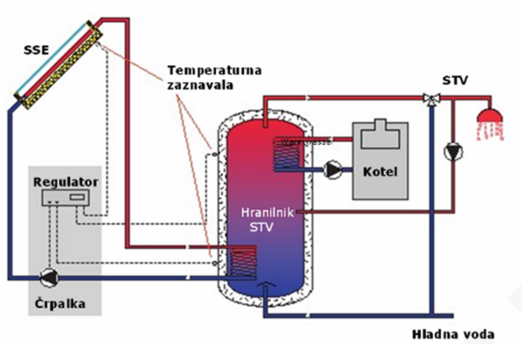
Solar collectors can be integrated in prefabricated thermal insulated envelop elements

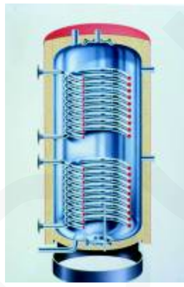
- Colour of Sc can be adjusted to architectural requirements

Solar collectors are made from semi-selective coloured absorbers; thanks to low emissivity ($\varepsilon_{IR,absorber}$ 0,3 to 0,4), lower solar absorptivity of none black paint ($\alpha_{s,absorber}$) can be companzate !

Most popular applications of thermal solar systems (TSS)

- Domestic tap water heating is most popular application of TSS. Beside SC, components like heat storage, piping, circulation pump, backup heating and regulation consist such systems. ! To 2 m^2 of SC per person and volume of heat storage 50 to 75 lit per 1 m^2 of SC is typical for this systems.

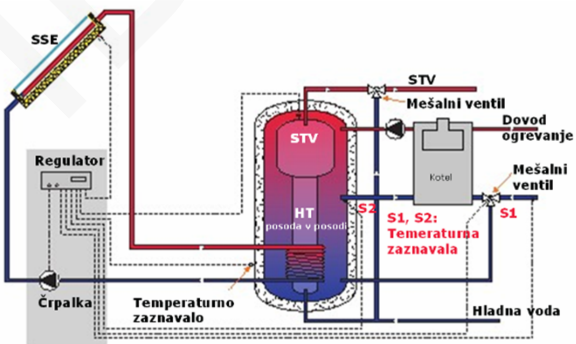


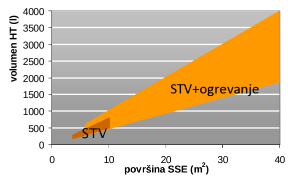


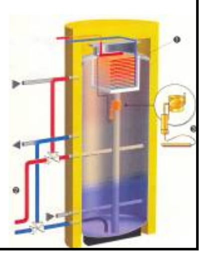
Heat storage with integrated tube heat exchangers. Bottom one is connected with SC, top one with backup heat generator.

Most popular applications of thermal solar systems (TSS)

- Space heating assisted TSS have larger solar collector area (up to 1/3 m^2 of SC per 1 m^2 heated area and larger heat storage - up to several m^3 in family house. Heat storage has integrated smaller heat storage for tap water heating. Important is temperature stratification inside heat storage. Adequate computer tool is needed for planning.







Heat storage with integrated heat exchanger or heat storage for tap water heating. Wirth intakes on different highs, thermal stratification can be achieved. This improves exergy balance of the system.

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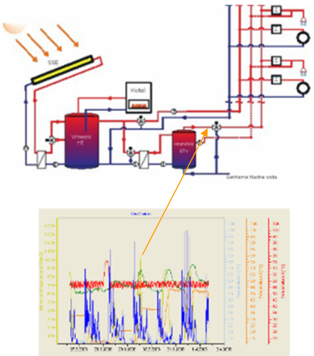
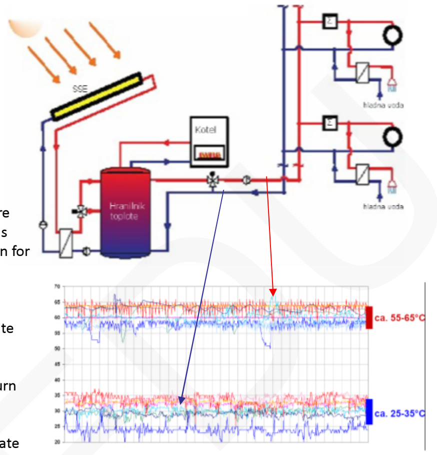
Most popular applications of thermal solar systems (TSS)

- TSS for multifamily building become very popular in recent years. Four pipes (left) or two pipes systems (right) are common.

In case of four pipes TSS, tap water system is divided from space heating. Backup heating is needed. Special care to avoiding growth of microorganisms is needed – such thermal shock, then whole system is heated up to 60°to 70°for several hours once per week..



Two pipes TSS are more advanced. Each flat has own heating substation for space and tap water heating. Tap water is heated on demand thought integrated plate heat exchanger. This prevent unhealthy tap water conditions. Return water has lower temperature. As consequence, SC operate with higher efficiency.



Heat production – calculation methods

Rule of thumb

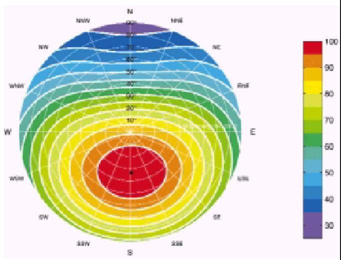
- Yearly production of heat (heat indicated per 1 m² of aperture area of SC for place having yearly solar irradiation ~ 1200 kWh/m²) differ a lot upon technology:

Unglassed SC ; 250 kWh/m²a

Flat, selective SC 500 kWh/m²a

Vacuum SC; 650 kWh/m²a

- If SC are not orientated optimal (due to SE-S-SW direction, with tilt angle between 25° to 45° , the reduction factor, shown on the figure, must be taken into account. Tilt angle should be decrease for 10°for summer-only operating systems, and increased for 10°for solar heating assisted systems. (Attention: chart is valid for latitudes between 30°and 50°)



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Heat production – calculation methods

EXAMPLE:

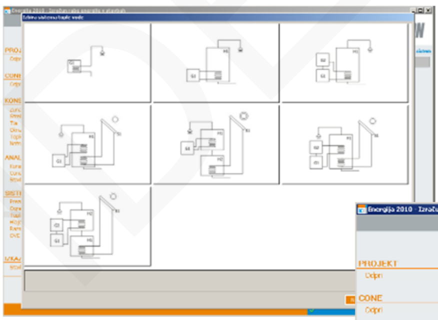
Flat, selective SC will be installed at optimal orientation in teh city having annual global solar irradiation 1000 kWh/m^2. SC will be used for domestic tap water heating in one family building. Useful area of building is 120 m^2. If 65% of tap water should be prepared by solar system, what will be required SC area ?

Average heat demand for tap water heating is 12 kWh to 16 kWh per year per 1 m^2 of house useful area:

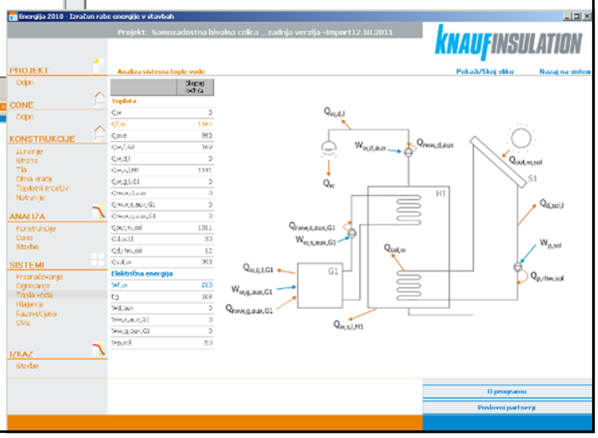
- Q_{tap} = 15 kWh/m^{2}a . 120 m^2 = 1800 kWh/a
- Asc = 0,65 . Q_{tap} /(500. 1000/1200) = 2,81 -> 3 m^2

Note: fraction 1000/1200 is correction factor of solar irradiation on the site

Heat production – calculation methods

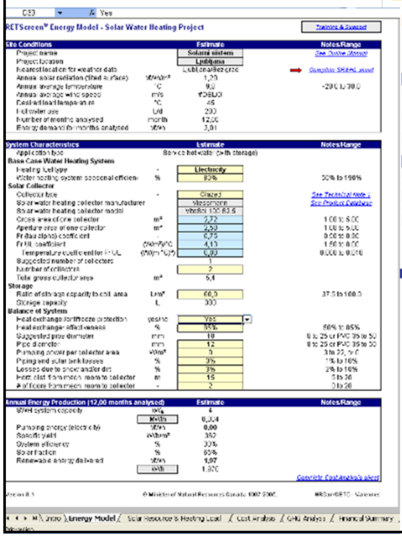


- Methodology EN ISO ; monthly method, often integrated in national regulation of building energy performance regulations.



Heat production – calculation tools

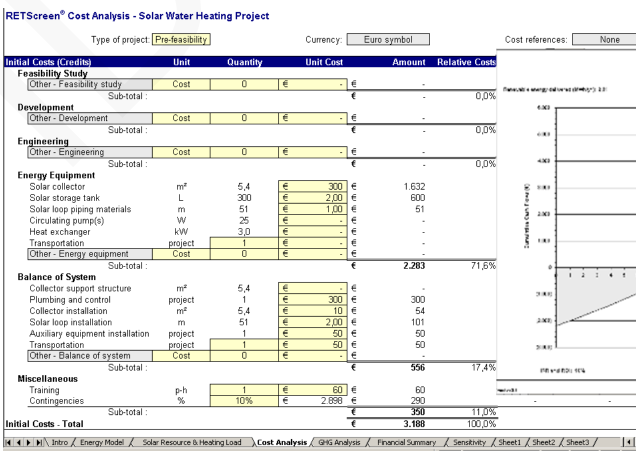
- Public available Excel based computer tool



- Site and system description; many market available products are included in database

Heat production – calculation tools

- Cost evaluation is integrated in computer tool

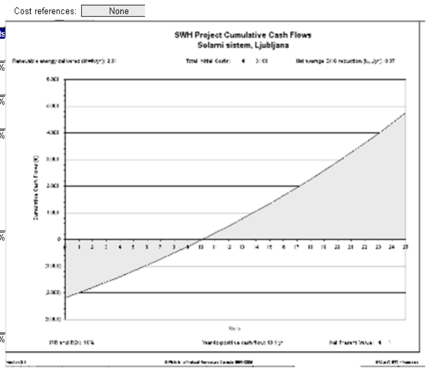


RETScreen® Cost Analysis - Solar Water Heating Project

Type of project: Pre-feasibility   Currency: Euro symbol   Cost references: None

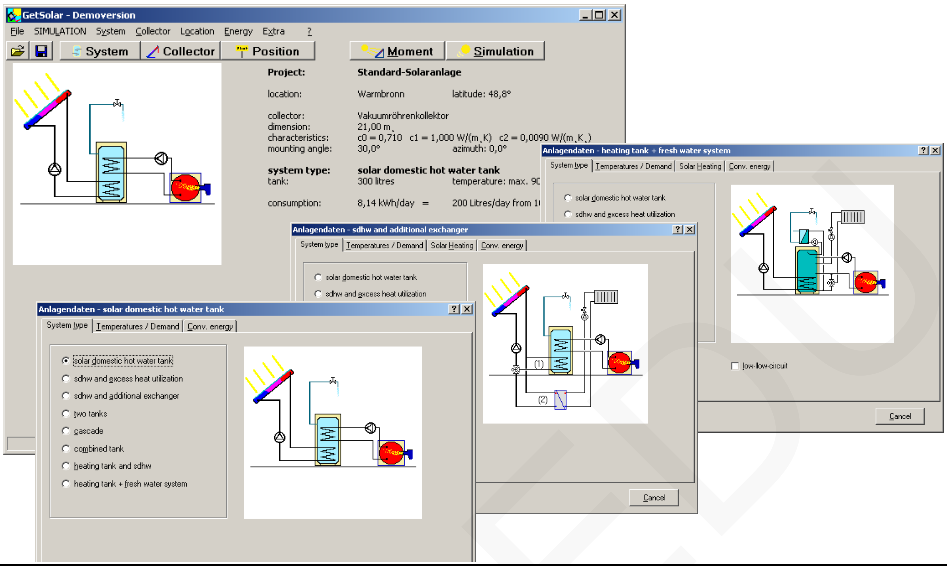
Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs
Feasibility Study					
Other - Feasibility study	Cost	0	€ -	€ -	
Sub-total :				€ -	0,0%
Development					
Other - Development	Cost	0	€ -	€ -	
Sub-total :				€ -	0,0%
Engineering					
Other - Engineering	Cost	0	€ -	€ -	
Sub-total :				€ -	0,0%
Energy Equipment					
Solar collector	m²	5,4	€ 300	€ 1.632	
Solar storage tank	L	300	€ 2,00	€ 600	
Solar loop piping materials	m	51	€ 1,00	€ 51	
Circulating pump(s)	W	25	€ -	€ -	
Heat exchanger	kW	3,0	€ -	€ -	
Transportation	project	1	€ -	€ -	
Other - Energy equipment	Cost	0	€ -	€ -	
Sub-total :				€ **2.283**	71,6%
Balance of System					
Collector support structure	m²	5,4	€ -	€ -	
Plumbing and control	project	1	€ 300	€ 300	
Collector installation	m²	5,4	€ 10	€ 54	
Solar loop installation	m	51	€ 2,00	€ 101	
Auxiliary equipment installation	project	1	€ 50	€ 50	
Transportation	project	1	€ 50	€ 50	
Other - Balance of system	Cost	0	€ -	€ -	
Sub-total :				€ **556**	17,4%
Miscellaneous					
Training	p-h	1	€ 60	€ 60	
Contingencies	%	10%	€ 2.898	€ 290	
Sub-total :				€ **350**	11,0%
Initial Costs - Total				€ **3.188**	100,0%

Intro / Energy Model / Solar Resource & Heating Load / **Cost Analysis** / GHG Analysis / Financial Summary / Sensitivity / Sheet1 / Sheet2 / Sheet3



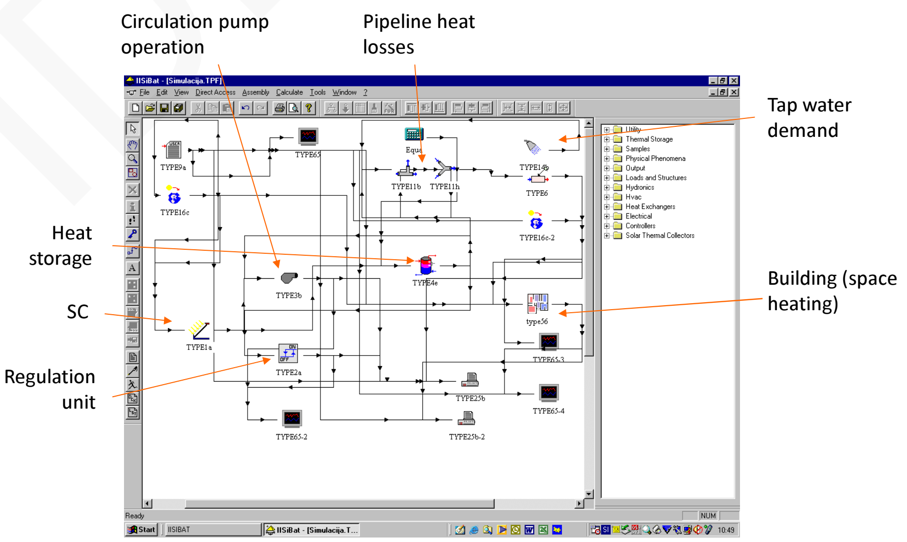
Heat production – calculation tools

- **GetSolar** (www.getsolar.de) – large number of preformed TSS configurations



Heat production – computer tools

- **TRNSYS** – detailed hour-by-hour simulations, very flexible for new deviced (TYPEs) and configurations of the systems.



The future of thermal solar systems (TSS)

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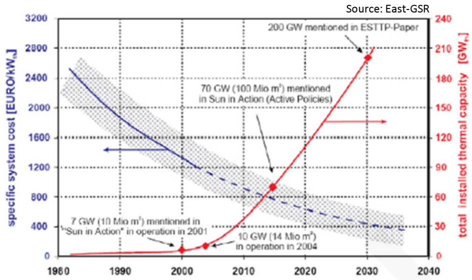
- Past market development and future plans for TSS in EU. For wider implementation of TSS, reduction of cost will be crucial, as well as improved confidence of investors. Methods, such as “Guarantied solar results contract” can play important role.

Source: East-GSR



- European Solar Thermal Technology Platform published ambition plans for the year 2030

- EPBD 2 -> all new buildings after 2018 (2020) must be “Near Zero Energy Houses”. TSS will have an important role if this goal will be achieved.

Self evaluation

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- Describe the types of solar collectors regarding to the heat carriers and solar thermal systems regarding to the operation temperature ?
- How overall thermal transmitance is defines and how can be calculated ?
- Explain Hottel-Whillier-Bliss approach in calculation of SC efficiency !
- What is the meaning of the F’ and how it can be improved ?
- How efficiency curve of the SC can be constructed ?
- What you know about the types of solar thermal systems ?
- State your vision about use of the SC in solar thermal systems in the future !

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Literature/References

Hsieh J.; Solar Energy Engineering, Prentice Hall, 1986

Duffie J., Beckman W.; Solar Engineering of Thermal Processes; Wiley, 1991

Werner W.; Solar Heating Systems for House; IEA 2003

Publications of SOLARGE project, 2008

Publications of EAST-GSR project, 2009

www.viesmann.de
www.sonnenkraft.at

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