Type 302: Solar Air Heater

Version 14.09.07

General Description

This component models the thermal performance and the friction losses of a variety of collector types using physical properties of the collector components. A 2-dimensional calculation scheme is used[1].

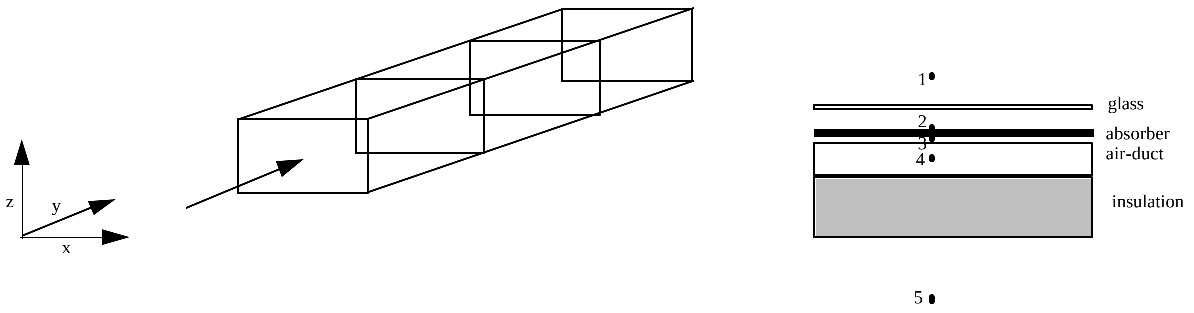
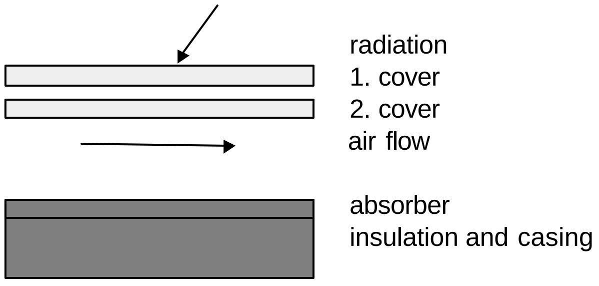
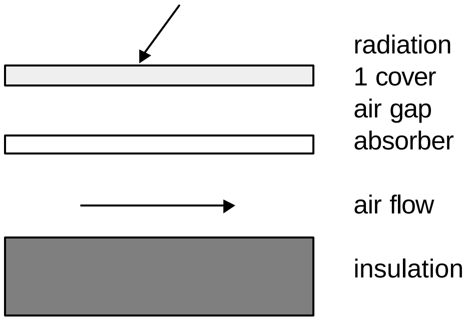


Fig.: Collector cells for calculation   Nodes inside each cell

Basic types of collectors:



Flow above absorber
Mode 1



Flow below absorber
Mode 0

The length of the collector is divided into small elements or increments (in direction of the flow) in which a thermal network for top losses, heat transfer and backside losses including the thermal capacity of the absorber is solved.

The total collector array may consist of collectors connected in series. For parallel arrays this type has to be used for each string. The following basic air collector types can be calculated:

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[1] The detailed model is used except for the calculation of a perforated absorber (SOLARWALL©). The calculation for this collector type is using an efficiency curve taking wind influence into account(see collector mode 2)

Collector mode:

1. flow between absorber and cover (collector mode 1)
2. flow below the absorber (collector mode 0)

The basic collector types can be calculated for different methods of heat transfer enhancement or absorber geometry:

Geometry mode:

1. surface roughness and ribs
2. finned absorbers making up rectangular or triangle ducts
3. displaced and continuous fins

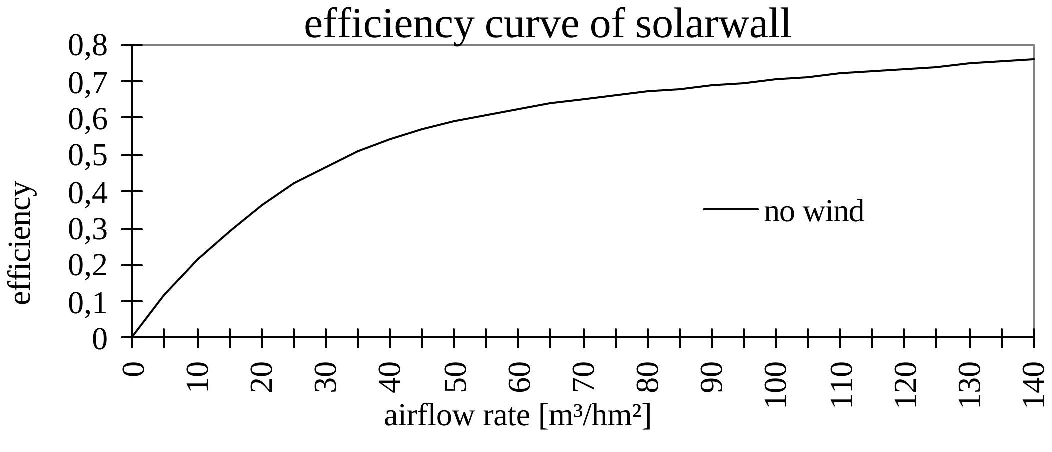
The thermal performance is determined for a eligible number of increments. In each element local values of heat transfer taken from Nusselt/Reynolds correlation are used. All properties of the air are depending on local temperature. Adjacent increments are coupled by the nodes of the air. Conduction in direction of the flow is neglected due to low temperature gradients. Leakage can optionally be taken into account. Edge losses are not taken into consideration.

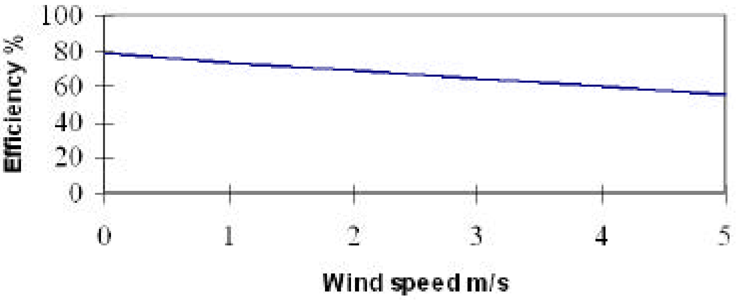
Perforated Absorbers

Perforated absorber known as the SOLARWALL©System are used to preheat ventilation air in a lot of applications. The system is consisting of a perforated aluminum wall or roof cladding with holes of small diameter covering a few percent of the surface area. Absorbed solar radiation is transferred to ambient air drawn through the holes into a cavity behind the absorber.

The efficiency of the system is only depending on air volume flow and slightly on wind speed. Results are documented and due to the fact that the system is produced industrially the results are consistent. The calculation of the efficiency therefore can be done easily by using efficiency curves taking wind influence into account, which is done when mode 2 is used.

no wind




Efficiency %
100
80
60
40
20
0
0
1
2
3
4
5
Wind speed m/s

Detailed Description of air collectors

Calculation method

The scheme of the calculation can be derived from Duffie, Beckman 'Solar engineering of thermal processes' chap.6. The resistances of the thermal network have been adapted to the requirements of the air collectors. In addition a capacity term at the absorber is used. The thermal network for case 0 (collector mode 0, flow below the absorber) consist of 5 resistances:

1. resistance from ambient to upper surface of the absorber
2. resistance of the absorber having a capacity
3. resistance from absorber to the fluid
4. resistance from the fluid to the backside insulation
5. resistance from backside insulation to backside ambient

For the calculation of resistance 1 two models can be chosen, the model of Klein (see Duffie/Beckman) or that of Malhotra (see Garg, 'The top loss calculation for flat plate solar collectors', Solar Energy 32, 141-143,1984).

The results from Malhotra Model are slightly more accurate compared to measurements done by Altfeld. Most resistances are combined resistances of convective and radiative heat transfer using linearized radiative terms (see Duffie/Beckman)

In case collector mode 1 is chosen (flow above the absorber) the thermal network is slightly different from that of case 0:

1. resistance from ambient to upper surface of first cover
2. resistance of first cover
3. resistance of air gap between covers
4. resistance of second cover
5. resistance from 2.cover to the fluid
6. resistance form fluid to the absorber
7. resistance of absorber having a capacity
8. resistance from absorber to ambient

For calculation the length of the collector is divided into small increments. The number of increments is chosen by the program dividing the length of the collector by 0.25. In each increment the thermal network is calculated by using local values of air properties and heat transfer.

Convective heat transfer

All heat transfer coefficients of the flow are calculated using Nusselt-Reynolds correlation.

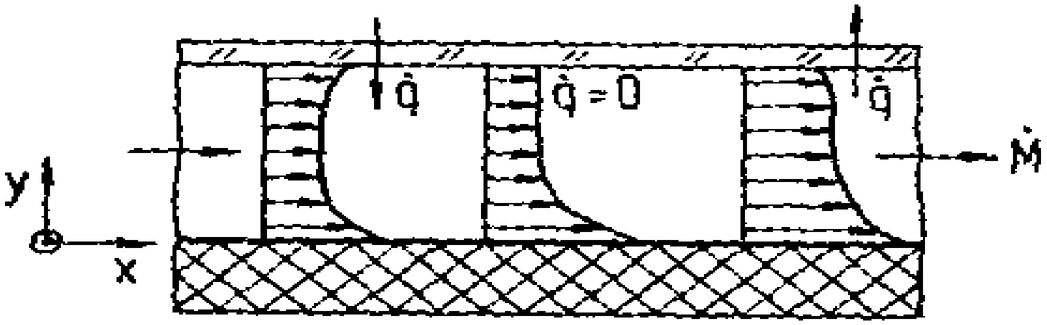
The following modes are available:

1. flow in a rectangular duct with heat flux from all sides (finned absorber)
2. flow in a triangular duct with heat flux from all sides (finned absorber)
3. flow in annular passages with heat flux from both sides or unsymmetrical heat flux
4. rib roughness (destroying air boundary)
5. developing flow

The models are described in Altfeld, Exergetische Optimierung flacher solarer Lufterhitzer, Düsseldorf 1985.

Used correlation in collector mode 1:

The heat transfer from 2. to the cover and from the absorber to the fluid is unsymmetrical. The different possible temperature profiles in the air gap are shown by the following figure.



Due to the unsymmetrical heat fluxes a correlation from Kays for annular passages using a superposition principle for the different cases of the heat flux is used:

$$Nu_i = Nu_{wi} / (1-q_o/q_i)*Zi$$

$$Nu_o = Nu_{wo} / (1-q_i/q_o)*Zo$$

q = heat flux

Z = correction factors for laminar flow from Heaton et al

for tubulent flow from Kays et al.

i = inner surface

o = outer surface

w = wall

Used correlations in collector mode 0:

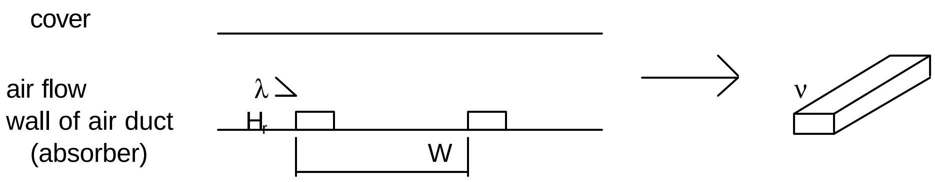
Developing laminar flow: Shah and London

Correlations used in all cases:

Change from laminar to turbulent flow in an air gap

Re =1800 (due to turbulent inlet flow)

For the calculation of the heat transfer from wind to the cover a correlation from McAdams is used (Duffie/Beckman). For ribbed surfaces the following graph shows the parameters:



H_r height of rip
λ angle of rib cross section to the flow
W spacing of rips
ν angle of attack

Friction losses

Friction is calculated depending on the heat transfer problem. The correlation for the different cases can be taken form Altfeld.

Leakage

Leakage is modeled similar to the infiltration of windows. The resulting mass flow is depending on static pressure in the component. The surrounding pressure is set to be constant. Input pressure is the static pressure at the entrance of the collector minus surrounding pressure 10^5 Pa . The calculated pressure drop is reducing the pressure in the collector. The leakage of each collector is calculated by using the entrance pressure. In case the pressure is below surrounding pressure i.m. negative the air flow by leakage is mixed with the collector flow rate at the outlet. The volume flow is increased and the temperature is calculated by balancing the different energy flows. Positive static pressure in the system is just reducing the flow rate.

Leakage flow rate:

$$m_L = a*F*\Delta P^{2/3}$$

Temperature at outlet:

$$T_o = (m_e T_e + m_L T_a)/(m_e + m_L)$$

Literature

Altfeld, K.: Exergetische Optimierung flacher solarer Lufterhitzer, Düsseldorf 1985.
Garg, A.P.: The top loss calculation for flat plate solar collectors', Solar Energy 32, 141-143,1984).
Heaton, H.S. et al: Heat transfer in annular passages. Simulation developement of velocity and temperature fields in laminar flows. Int. J. Heat Transfer, Vol.7.(1964) pp.763-781
Kays, W.M.: Convective heat and mass transfer . McGraw Hill New York 1966
Kays, W.M.; Perkin, H.: Forced convection, internal flow in ducts. In Handbook of heat transfer, Ed. W.M. Rohsenow and I.V. Hartnett; McGraw Hill, New York 1973.
McAdams, N.: Heat transmission. McGraw Hill, New York ,1954
McClenahan, D.: Performance of the perforated plate/canopy solarwall at GM Canada, Oshawa. Energy Technology Branch/CANMET. Dep. of Nat. Resources Canada, Ottawa 1994

Collector Mode =0

Parameter No.

1	calculation mode		0 => not used
2	collector mode		0 => Air Flow below the absorber
3	geometry mode		0- gap 1- displaced fins 2- continuous fins
4	heat transfer mode		0-smooth 1-surface roughness 2-rib roughness (ribs destroying boundary layer)
5	leakage		0-off 1-calculated
6	top losses model		1-Klein 2-Malothra
7	Nc	-	Number of collectors in series (max. 10)
8	Ak	m^2	Area of collector
9	Mac	kJ/K	capacity of collector
10	L	m	length of collector
11	H		height of air gap inside the collector for air flow
12	U_b	kJ/m^2hK	backside heat loss coefficient of casing,
13	N		number of covers
14	RI		Index of refraction of single cover
15	KL		extinction coefficient*thickness of single cover
16	H_o	m	height of air gap between cover and absorber
17	Da	m	thickness of absorber
18	h_l	kJ/mhK	conductivity of absorber
19	α		absorption of absorber coating
20	ε_a		emissivity of absorber coating
21	ε_w		emissivity of heat transferring walls
22	ε_c		emissivity of cover

Geometry mode=0

23	developing flow		no. of boundary developments

Heat transfer mode =1 (surface roughness)

24	K_s	m	roughness height

Heat transfer mode = 2 (ribs)

24	W	m	spacing of adjacent ribs
25	H_r	m	height of ribs
26	υ	degree	angle of attack
27	λ	degree	angle of rib cross section

Geometry mode = 1 (displaced fins)

For geometry mode = 1 or 2 heat transfer mode has to be 0

23			conduction transverse to flow 1= yes 2= No
24	H_f	m	height of fin
25	h_f	kJ/mhK	conduction of fin
26	W_f	m	fin spacing
27			ratio of fin length to fin height
28	d_f	m	thickness of fin

Geometry mode = 2 (continuous fins)

23	h_f	kJ/mhK	conduction of fin
24	W_f	m	fin spacing
25	d_f	m	thickness of fin

For leakage mode = 1 two additional parameter need to be specified at the end of the parameter list. The parameter list will extend depending to the geometry mode and the heat transfer mode.

Leakage mode =1 (optional)

x+1	a	$m^3/mhPa^{2/3}$	permeability of joints
x+2	F	m	length of joints

Inputs

1	-	T_i	°C	temperature of air entering cold side
2	-	M	kg/h	collector mass flow rate to use const. volume flow rate give XIN(13) a negative value V=M/abs(xin(13)
3	-	T_a	°C	ambient temperature
4	-	I_T	kJ/m^2h	incident radiation
5	-	I	kJ/m^2h	incident radiation on a horizontal plane
6	-	I_d	kJ/m^2h	diffuse radiation
7	-	rg		ground reflectance
8	-	θ	degree	incidence angle
9	-	β	degree	slope of collector
10	-	u	m/s	wind speed
11	-	ϕ	%	rel. humidity of the air
12	-	ΔP	Pa	stat. pressure diff. at col. entrance to surrounding
13	ρ	kg/m^3		density of the air (if negative density values are given the volume flow rate is kept constant and the mass flow is calculated depending on inlet temperature. In this case give values of design for density and mass flow as const. values)

Outputs

1	-	T_o	°C	temperature at the collector outlet
2	-	m	kg/h	mass flow at outlet
3	-	Qt	kJ/h	rate of energy gain
4	-	ΔP	Pa	stat. pressure difference at the outlet
5	-	Vo	m^3/h	volume flow at outlet
				individual collectors (i....nc=number of collectors)
1+5i	-	T	°C	outlet temperature
2+5i	-	m	kg/h	mass flow
3+5i	-	Qt	kJ/h	rate of energy gain
4+5i	-	ΔP	Pa	pressure drop
5+5i	-	V	m^3/h	volume flow

Collector Mode =1

Parameter No.

1	calculation mode		0 => not used
2	collector mode		1 => Air Flow above the absorber
3	geometry mode		0- gap
4	heat transfer mode		0-smooth 1-surface roughness 2-rib roughness (ribs destroying boundary layer)
5	leakage		0-off 1-calculated
6	top losses model		1-Klein 2-Malothra
7	Nc	-	Number of collectors in serie (max. 10)
8	Ak	m^2	Area of collector
9	Mac	kJ/K	capacity of collector
10	L	m	length of collector
11	H		height of air gap inside the collector for air flow
12	U_b	kJ/m^2hK	backside heat loss coefficient of casing,
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19	α		absorption of absorber coating
20	ε_a		emissivity of absorber coating
21	ε_w		emissivity of heat transferring walls
22	ε_c		emissivity of cover
23	H_c	m	height of gap between covers
24	h_c	kJ/mhK	conductivity of cover
25	d_c	m	thickness of cover

Geometry mode=0

26	-	developing flow		no. of boundary developments 1-with

Heat transfer mode =1 (surface roughness)

27	-	K_s	m	roughness height

Heat transfer mode = 2 (ribs)

27	-	W	m	spacing of adjacent ribs
28	-	H_r	m	height of ribs
29	-	υ	degree	angle of attack
30	-	λ	degree	angle of rib cross section

For leakage mode = 1 two additional parameter need to be specified at the end of the parameter list.

Leakage mode =1 (optional)

x+1	a	$m^3/mhPa^{2/3}$	permeability of joints
x+2	F	m	length of joints

Inputs

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4	-	ΔP	Pa	stat. pressure difference at the outlet
5	-	Vo	m^3/h	volume flow at outlet
				individual collectors (i....nc=number of collectors)
1+5i	-	T	^{o}C	outlet temperature
2+5i	-	m	kg/h	mass flow
3+5i	-	Qt	kJ/h	rate of energy gain
4+5i	-	ΔP	Pa	pressure drop
5+5i	-	V	m^3/h	volume flow

Possible data of air collectors

		Standard	Double	Optimized
L	M	2	2	2
Ub	kJ/m²hK	3.2	3.2	2.8
N		1	2	1
RI		1.53	1.53	1.53
kl		0.032	0.016	0.016
Ho	M	0.03	0.03	0.03
Da	M	0.0006	0.0006	0.0006
hi	kJ/mhK	540	540	540

Collector Mode = 2 (SOLARWALL$^{\tilde{a}}$ absorber)

Parameter No.

1			calculation mode - specify 0
2			collector mode - specify 2
3	Ac	m^2	collector area

Inputs

1	-	T_i	^{o}C	temperature of air entering
2	-	M	kg/h	collector mass flow rate to use const. volume flow rate give XIN(7) a negative value V=M/abs(xin(7)
3	-	T_a	^{o}C	ambient temperature
4	-	I_T	kJ/m^{2}h	incident radiation
5	-	u	m/s	wind speed
6	-	ϕ	%	rel. humidity of the air
7		ρ	kg/m^3	density of the air (if negative density values are given the volume flow rate is kept constant and the mass flow is calculated depending on inlet temperature. In this case give values of design for density and mass flow as const. values)

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