Solar Energy Conversion Technology

Solar Air Heater

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Solar air heater and It's performance analysis

Solar Air Heater

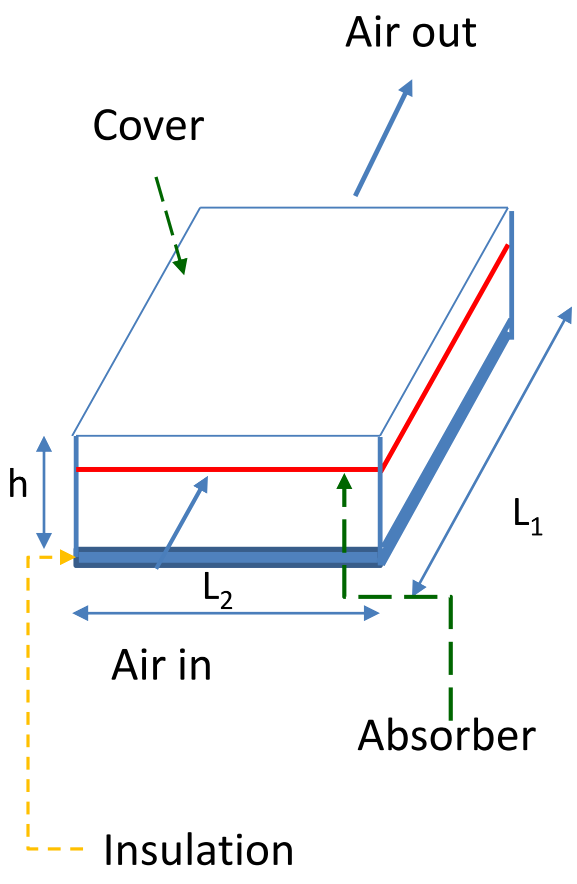
- **Solar air heater** is a thermal device in which the energy from the sun, is captured by an absorbing medium and is used to heat air.
- Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat applications.

Other applications

- ✓ Drying of agricultural products
- ✓ Industrial process heat
- ✓ Space heating

Solar Air Heaters

- ✓Eliminate the need to transfer heat from one fluid to another.
- ✓Consists of an absorber plate with a parallel plate below forming a small passage through which the air to be heated.
- ✓A transparent cover system is provided above the absorber plate.
- ✓A sheet metal container filled with insulation on the bottom and sides.



Solar Air Heaters

- ✓ Face areas of solar air heater range from 1 to 2 m^2.
- ✓ MOC and sizes are similar to those used in Liquid flat plate collectors.
- ✓ Absorber plate is a metal sheet of thickness 1 mm usually made of GI or steel.
- ✓ Glass thickness : 4-5 mm, plastics are also used.
- ✓ Mineral wool or glass wool of thickness 5 to 8 cm is used for the bottom and side insulation.
- ✓ Whole assembly is contained in a sheet metal box and inclined at a suitable angle.

Advantages and Disadvantages

Advantages:

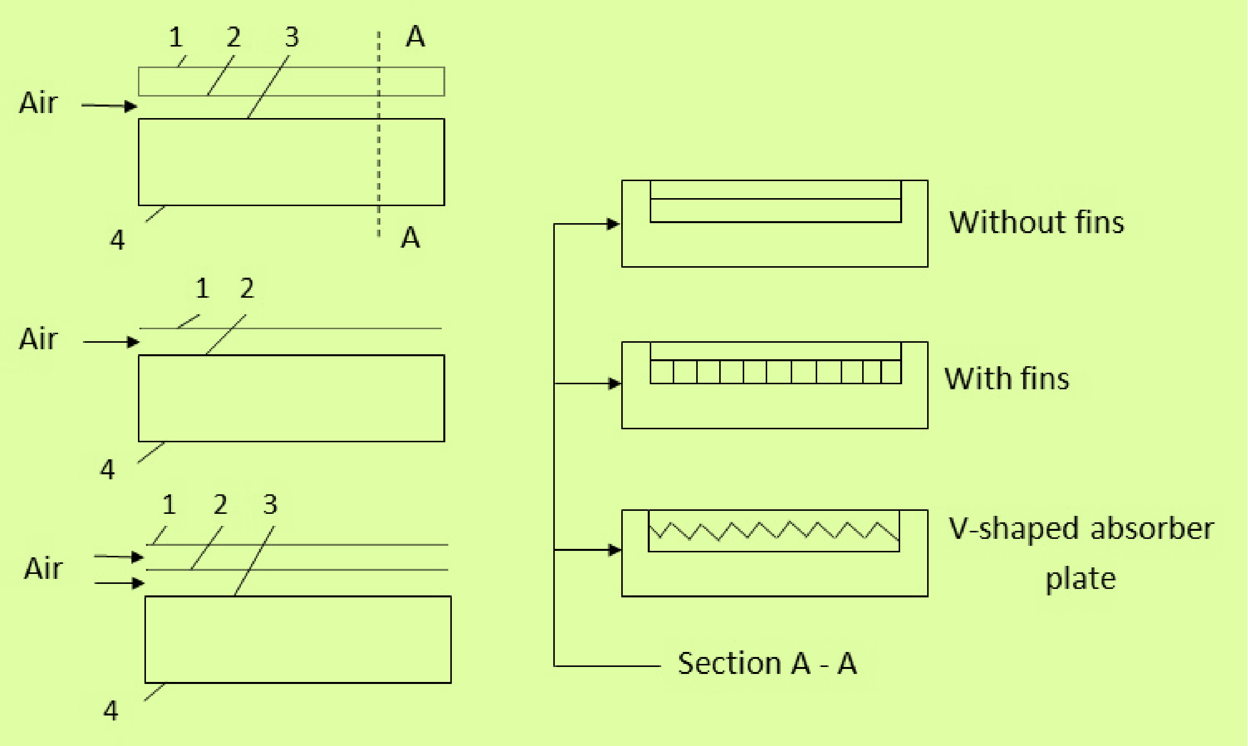
- Corrosion and leakage problems are less compared to LFPC
- Does not require any special attention at temperature below 0 °C

Disadvantages:

- ➢ Heat transfer coefficient between the absorber plate and the air is low – results in a lower efficiency.
- ➢ Large volume of fluid have to be handled – electrical power required is high if the pressure drop is not kept within prescribed limits.

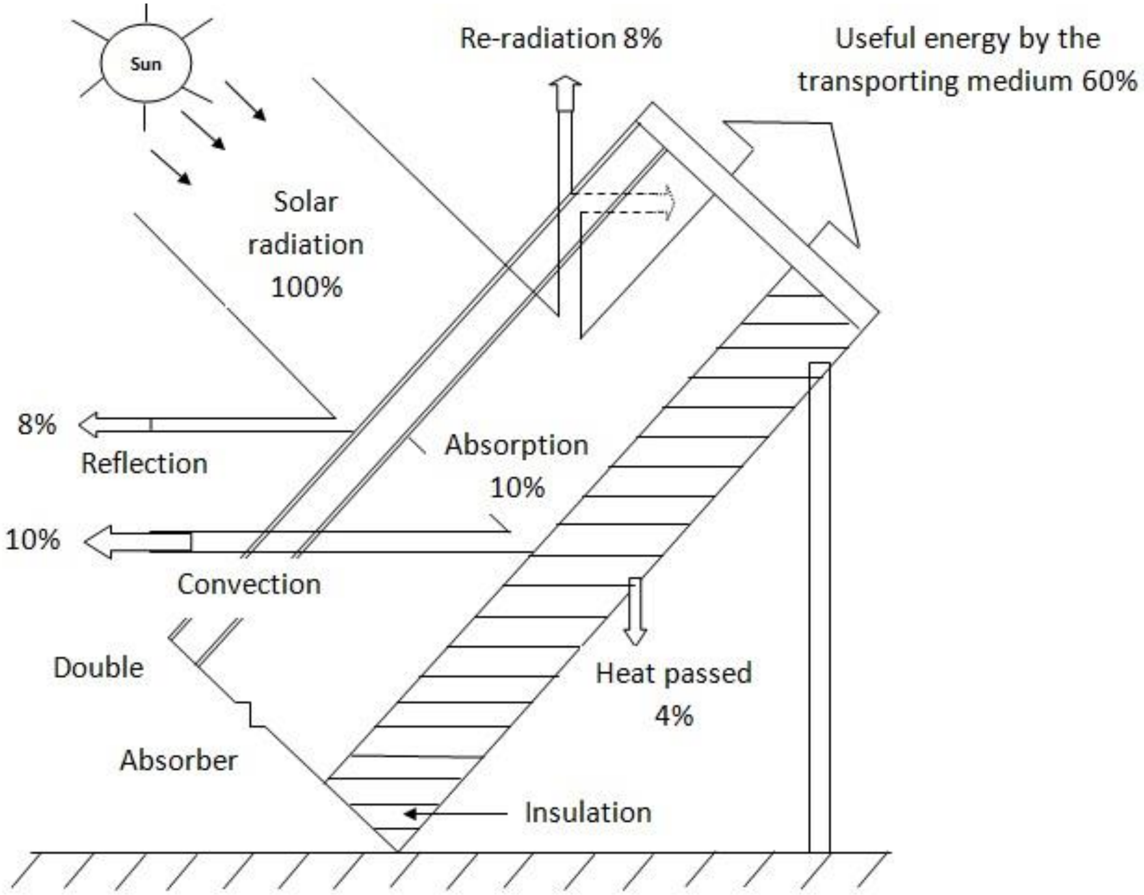
Roughened surface or longitudinal fins are provided in the air flow passes to increase the HTC

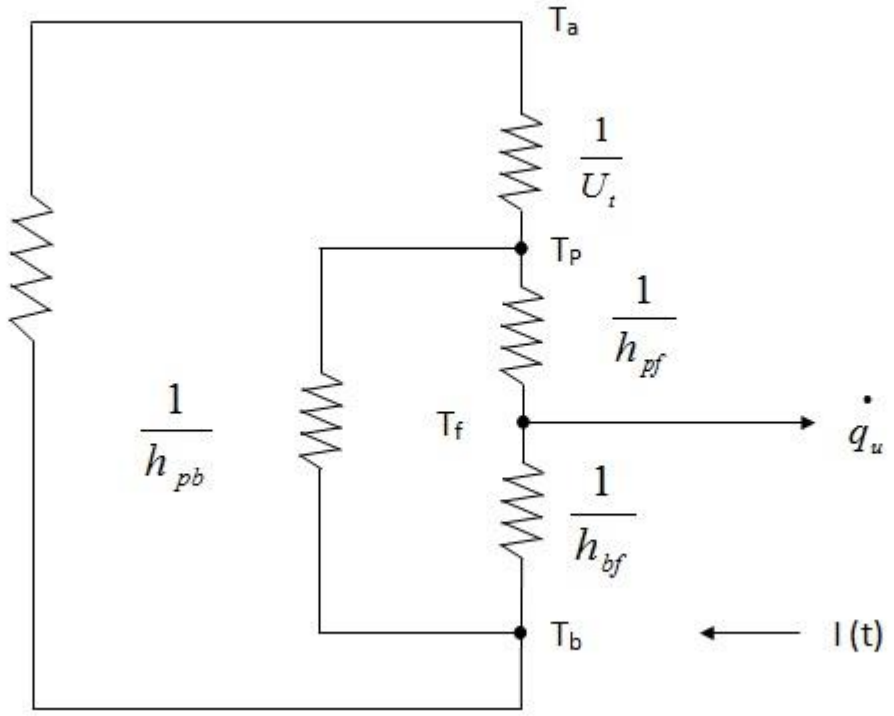
Various types of Solar Air Heaters



- ✓ ***Air flows between the cover and the absorber plate instead of through the separate passage.***
- ✓ ***Air flows between the cover and the absorber plate as well as through the passage below the absorber plate.***

Performance analysis of SAH





Performance analysis of solar air heater

Considering a slice of the solar air heater, width L_2 and thickness dx at a distance x from inlet

Assumptions:

i. Temperature changes from T_f to ($T_f + df$) in distance dx

ii. $\dot{m}$ = Air mass flow rate

iii. T_{pm} = Absorber plate temperature, T_{bm} = Bottom plate temperature

iv. Variations of T_{pm} & T_{bm} neglected

v. Side losses neglected

Now, Energy balance for Absorber plate:

$$SL_2dx = U_tL_2dx(T_{pm} - T_a) + h_{fp}L_2dx(T_{pm} - T_f) + \frac{\sigma L_2 dx}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)}\left(T_{pm}^4 - T_{bm}^4\right) \quad (1)$$

Energy balance for Bottom plate:

$$\frac{\sigma L_2 dx}{\left(\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_b}-1\right)}\left(T_{pm}^4-T_{bm}^4\right)=h_{fb}L_2dx\left(T_{bm}-T_f\right)+U_bL_2dx(T_{bm}-T_a) \longrightarrow (2)$$

Energy balance for Air stream:

$$\dot{m}C_p dT_f = h_{fp}L_2dx\left(T_{pm}-T_f\right)+h_{fb}L_2dx\left(T_{bm}-T_f\right) \longrightarrow (3)$$

Again, assuming negligible difference in heat transfer coefficients of both plates:

$$h_{fp}=h_{fb}$$

Introducing equivalent radiative heat transfer coefficient h_r ,

$$h_r\left(T_{pm}-T_{bm}\right)=\frac{\sigma}{\left(\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_b}-1\right)}\left(T_{pm}^4-T_{bm}^4\right) \longrightarrow (4)$$

For small temperature difference between absorber and bottom plates, $\left(T_{pm}^4-T_{bm}^4\right)$ can be approximated as $4T_{av}^3\left(T_{pm}-T_{bm}\right)$, where T_{av} is the average of two plate temperatures.

Then, eq. (4) becomes:

$$h_r=\frac{4\sigma T_{av}^3}{\left(\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_b}-1\right)} \longrightarrow (5)$$

Assuming U_b<<U_t, equations (1), (2) and (3) reduces to:

$$S = U_l(T_{pm} - T_a) + h_{fp}(T_{pm} - T_f) + h_r(T_{pm} - T_{bm}) \longrightarrow (6)$$

$$h_r(T_{pm} - T_{bm}) = h_{fb}(T_{bm} - T_f) \longrightarrow (7)$$

$$\frac{\dot{m}C_p dT_f}{L_2 dx} = h_{fp}(T_{pm} - T_f) + h_{fb}(T_{bm} - T_f) \longrightarrow (8)$$

From eq. (7),

$$T_{bm} = \frac{h_r T_{pm} + h_{fb} T_f}{h_r + h_{fb}} \longrightarrow (9)$$

Substituting (9) in (6),

$$T_{pm} = \frac{S + U_l T_a + h_e T_f}{U_l + h_e} \longrightarrow (10)$$

where, h_e is effective heat transfer coefficient between absorber plate and air given by:

$$h_e = \left[h_{fp} + \frac{h_r h_{fb}}{h_r + h_{fb}}\right] \longrightarrow (11)$$

Hence,

$$(T_{pm} - T_a) = \frac{S + h_e(T_f - T_a)}{U_l + h_e} \longrightarrow (12)$$

From eq. (6) to (8), we have:

$$\frac{\dot{m}C_p dT_f}{L_2 dx} = S - U_l\left(T_{pm} - T_a\right) \longrightarrow (13)$$

Substituting (12) in (13),

$$\frac{\dot{m}C_p dT_f}{L_2 dx} = \frac{1}{\left(1 + \frac{U_l}{h_e}\right)}\left\{S - U_l\left(T_f - T_a\right)\right\} \longrightarrow (14)$$

Now, defining collector efficiency factor *F´* as:

$$F' = \left(1 + \frac{U_l}{h_e}\right)^{-1} \longrightarrow (15)$$

Thus, eq. (14) becomes the following differential equation:

$$\frac{\dot{m}C_p dT_f}{L_2 dx} = F'\left\{S - U_l\left(T_f - T_a\right)\right\} \longrightarrow (16)$$

Integrating eq. (16) and applying boundary conditions $T_f = T_{fi}$ at $x = 0$,

$$\frac{\left(\frac{S}{U_l} + T_a\right) - T_f}{\left[\frac{S}{U_l} + T_a\right] - T_{fi}} = \exp\left[-\frac{L_2 F' U_l x}{\dot{m}C_p}\right] \longrightarrow (17)$$

Similarly, useful heat gain rate from the collector can be obtained as:

$$q_u = F_R A_p \left[S - U_l\left(T_{fi} - T_{fo}\right)\right] \qquad (18)$$

where, F_R is the collector heat removal factor given as:

$$F_R = \frac{\dot{m}C_p}{U_l A_p}\left[1 - \exp\left\{-\frac{F' U_l A_p}{\dot{m}C_p}\right\}\right] \qquad (19)$$

If the assumption $U_b << U_t$ was not considered, eq. (16) would have been:

$$\frac{\dot{m}C_p dT_f}{L_2 dx} = F'\left\{S - U_l''\left(T_f - T_a\right)\right\} \qquad (20)$$

where, U_l'' is the equivalent overall loss coefficient and F' & U_l'' are given as:

$$F' = \left(1 + \frac{U_l'}{h_e}\right)^{-1} \qquad (21)$$

$$U_l'' = U_l' + \frac{U_b h_{fb}}{F'\left(h_r + h_{fb} + U_b\right)} \qquad (22)$$

where,

$$U_l' = U_t + \frac{h_r U_b}{\left(h_r + h_{fb} + U_b\right)} \qquad (23)$$

and,

$$h_e = h_{fp} + \frac{h_r h_{fb}}{\left(h_r + h_{fb} + U_b\right)} \qquad (24)$$

The useful heat gain for the collector is then given by:

$$q_u = F_R A_p \left[S - U_l'' \left(T_{fi} - T_{fo} \right) \right] \qquad \longrightarrow (25)$$

and F_R here is given as:

$$F_R = \frac{\dot{m} C_p}{U_l'' A_p} \left[1 - \exp\left\{ -\frac{F' U_l'' A_p}{\dot{m} C_p} \right\} \right] \qquad \longrightarrow (26)$$

Heat Transfer and Pressure Drop in parallel duct

Considering fully developed flow when length to equivalent diameter ratio exceeds 30 and surfaces to be smooth, the correlations are:

$$Nu = 0.0158\, Re^{0.8} \qquad \text{(Kays)} \qquad \longrightarrow (27)$$

$$Nu = \frac{0.01344 Re^{0.75}}{1 - 1.586 Re^{-0.125}} \qquad \text{(Malik \& Buelow)} \qquad \longrightarrow (28)$$

The equivalent diameter to be used in above equations is given by:

d_e *= (4 × Cross-sectional area of duct)/Wetted Perimeter*

Nu values calculated from eq. (27) and (28) agree within 10% for *Re* = 10,000 to 20,000

The dimensionless pressure drop in duct is given by Blasius equation as:

$$f = 0.079 Re^{-0.25} \qquad \longrightarrow (29)$$

where, f is the friction factor.

- If Reynolds No. is 5515, f = 0.009167

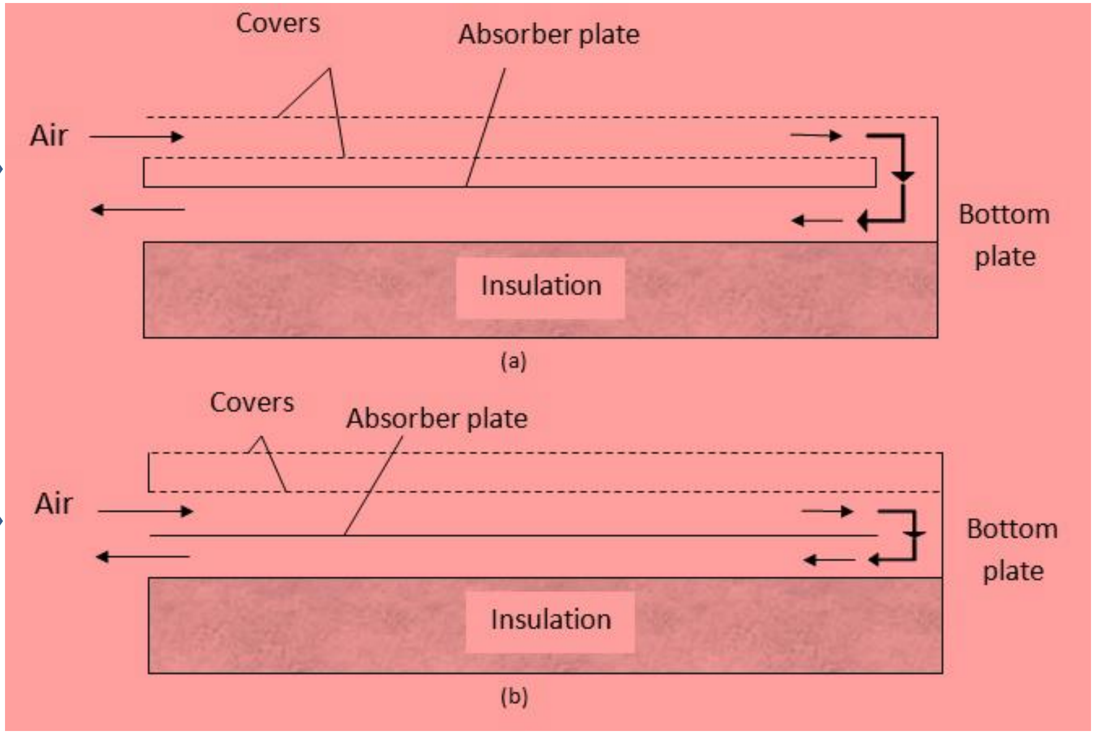
- Pressure drop = $\frac{4fL\rho V^2}{2d_e}$

Two-pass air heater

- Outer glass cover temperature lowered by 2 to 5 ^{o}C
- Efficiency of this type of collector is measured to be 10-15% higher than a conventional air heaters.

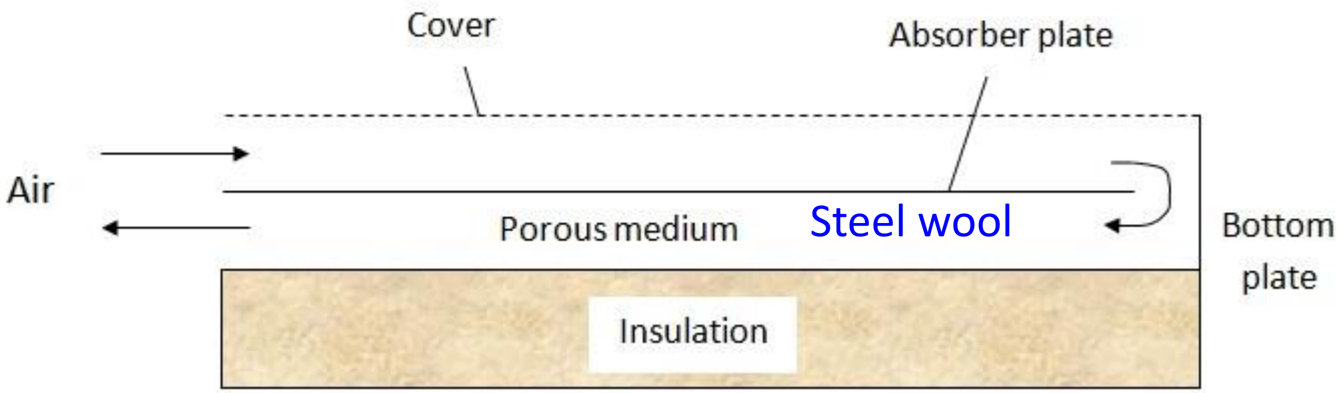
Better up to an inlet air temperature difference of 20 ^{o}C

Better up to an inlet air temperature difference of 50 ^{o}C



Two-pass air heater with porous medium

- Solar radiation and width of the flow channels are varied. Efficiency: 70% (10-20 % higher than that for the collector without porous medium)
- An outlet temperature of 90 °C at a solar radiation of 900-1000 W/m² can be achieved at a flow rate of 0.0995 kg/s.



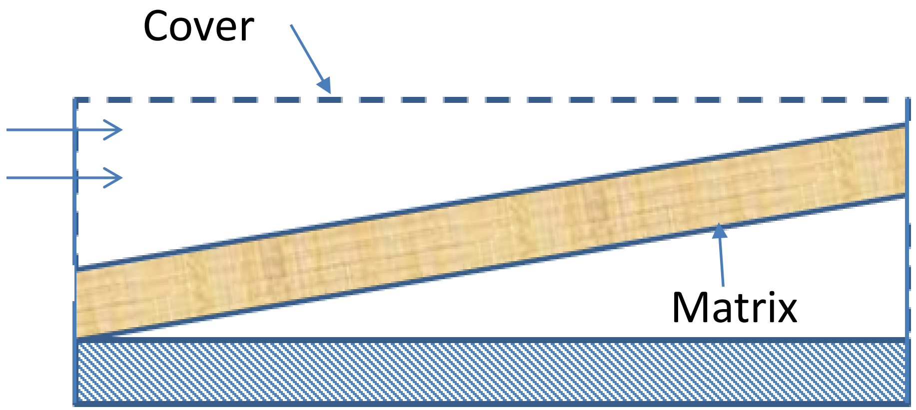
Other SAH design

- The matrix air heater
- The plastic air heater
- Transpired air heater

✓ Collector with porous absorber
✓ Yield higher efficiencies than conventional design
✓ Because of large flow areas these designs have small pressure drops

Matrix air heater

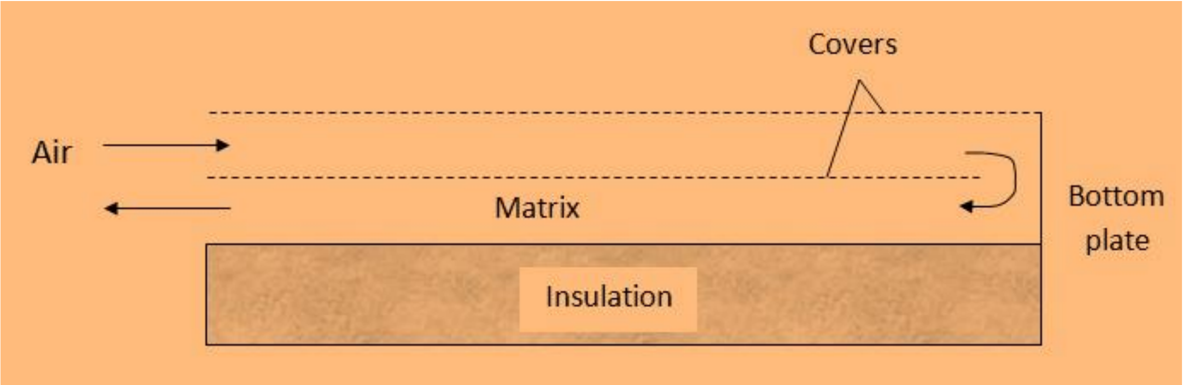
- Top loss is reduced
- Matrix provide large heat transfer area to volume ratios
- Higher HTC DUE TO INCREASED TURBULENCE of air flowing through the matrix
- Higher collector efficiency
- With an air inlet temperature of 21 °C, the efficiency is reported to be 75 %.



- ✓ Matrix is made by stacking wire screen meshes or slit–expanded metallic foils.
- ✓ Low cost material like glass bids, crushed glass wool etc. are used.

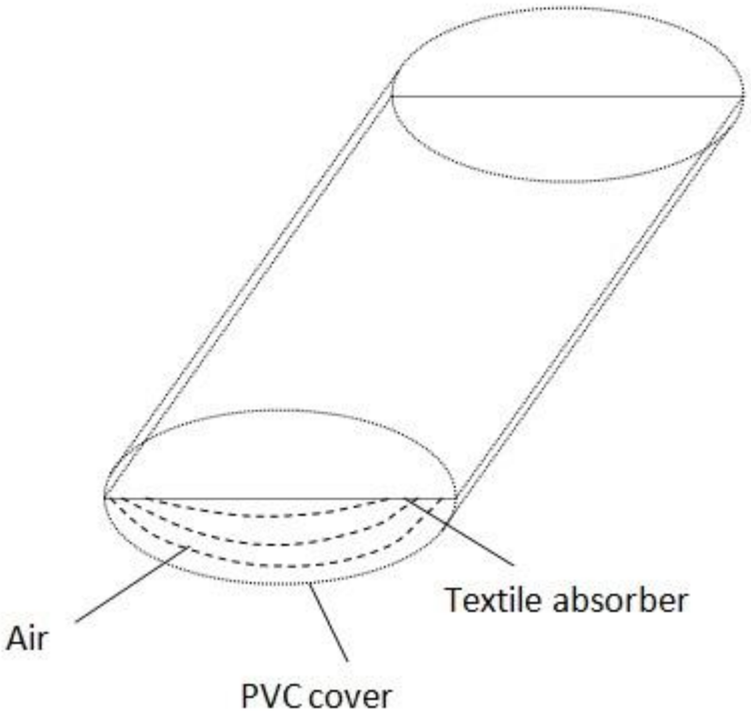
Two-pass air heater with matrix

- Much higher efficiency than conventional air heater
- Pressure drop is high compared to conventional air heaters



Plastic air heater

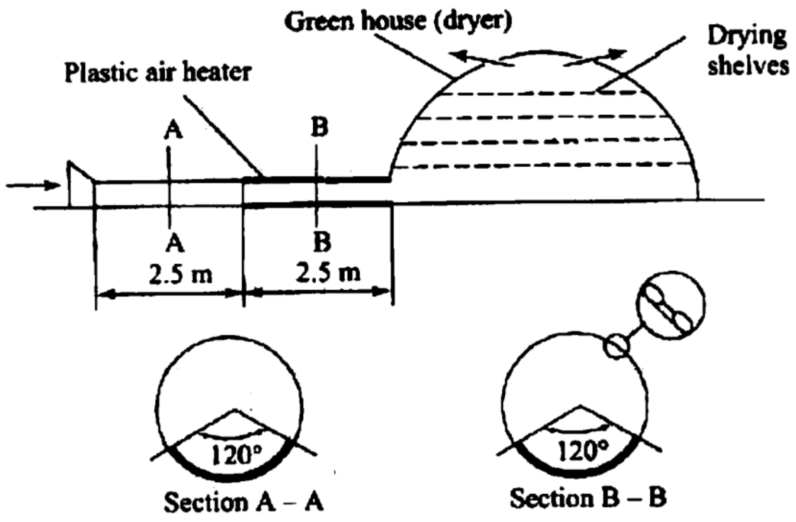
- Flexible plastic sheet is used
- 10 m^2 – 20 m^2, 1 m wide
- Best 6 cm thick polyethylene
- Efficiency of 67.9 %
- 770 m^3/h, 759 w/m^2



- ✓ **Absorber: Porous black textile of polyester**
- ✓ **Transparent sheet: Polyvinyl chloride**

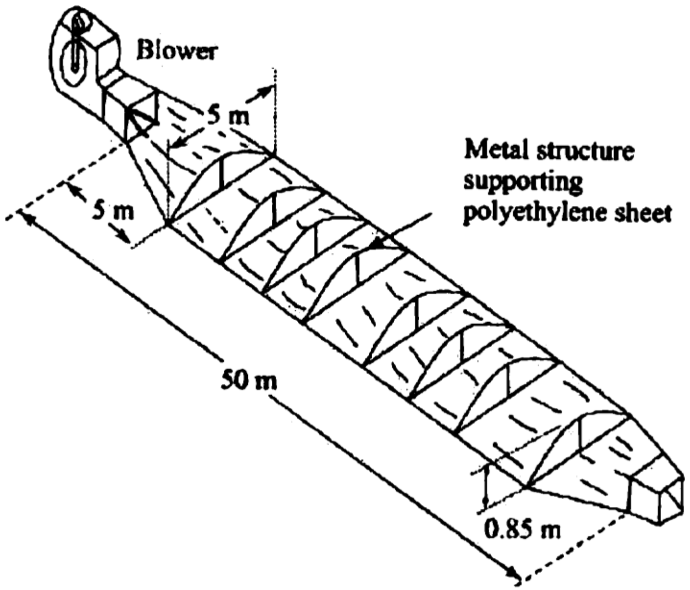
Plastic air heater connected to green house

- 5 m long , 0.36 m dia
- Suitable for agricultural drying operations
- Collector is divided into two halves (1st half only polyethylene sheet, 2nd half another layer of plastic wrapping film with air bubble to reduce the convection heat loss)



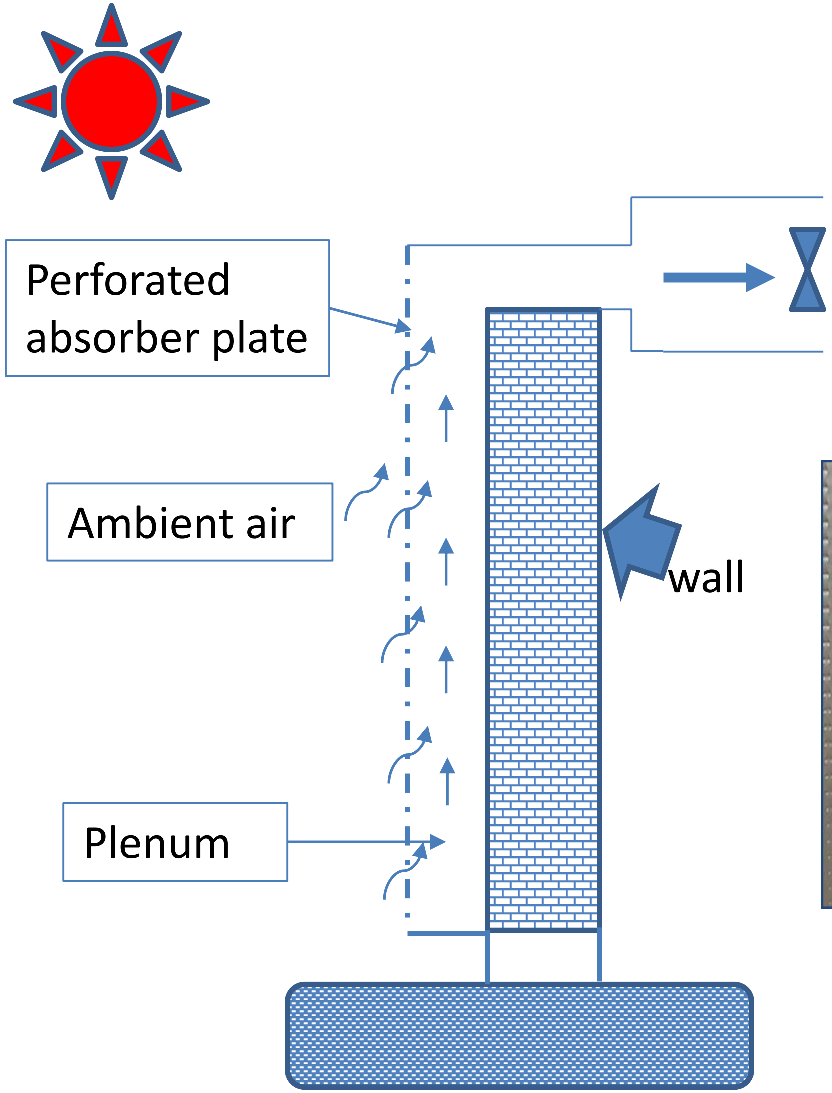
Inflatable-tunnel plastic solar air heater

- Absorber is a layer of pebble (5.5 cm thick) and is painted black
- The cover is a UV stabilized polyethylene sheet (178 μm thick)
- After an exposure of 6.5 h, Outlet temperature of 53 ^{o}C has been achieved at an air flow of 4.36 kg/s, and I=850 W/sq.m.



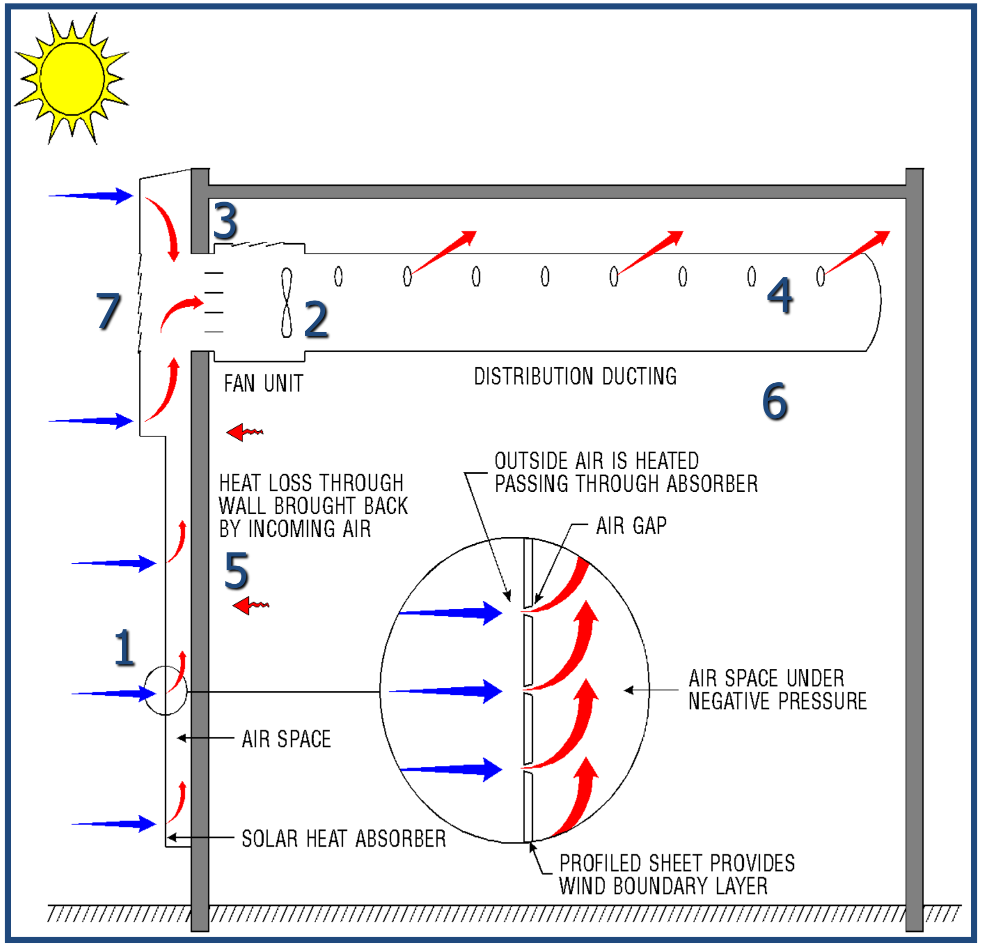
Unglazed transpired collector on a vertical wall

- Cold countries for space heating applications
- Crop drying
- Porosity is about 0.5%
- Mass flow rate : 0.01-0.05 kg/s-sq. m
- Planum depth range: 5-30 cm



SAH System Operation

1. Dark perforated absorber captures solar energy
2. Fan draws air through collector & canopy
3. Controls regulate temperature
   - Dampers
   - Auxiliary heating
4. Air is distributed through building
5. Wall heat loss recovered



Ex.1: The temperature rise ΔT of air through a vertical south-facing unglazed transpired collector (UTC) is found to satisfy the following empirical relation:

$$\Delta T = 0.03 I_T + 3.0$$

For an air flow rate of 36 $m^3/h\text{-}m^2$ of UTC. I_T is the total solar radiation incident on UTC in W/m^2; ΔT is in ^oC. Assuming this relation to be valid, calculate the efficiency of a vertical south facing UTC for the following data:

- Location: $28^o35^/N$, $77^o12^/$ E;
- Date: December 10;
- Hour angle: 15^o
- Air flow rate: 36 $m^3/h\text{-}m^2$ of UTC;
- Global solar radiation on horizontal surface: 543 W/m^2;
- Diffuse solar radiation on horizontal surface: 144 W/m^2;
- Reflectivity of the surrounding surface: 0.2.

Summary

- Fundamentals of solar air heaters.
- Performance analysis of SAH.
- Different types of solar air heaters.