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Solar Water Heating Theory

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The
Objective
of this talk is to present the
basic theory
on which solar water heaters work.

We will consider
flat plate solar water heaters
(both thermosyphon and pumped)
as well as
evacuated tube solar water heaters





Contents

How do we?:

- Collect the heat
- Transport the heat
- Store the transferred heat





A little about myself

1970-1980 Nuclear Energy
1980-1985 Solar Energy
1985-1988 Missile Manufacture Management
1988-2008 Heat Transfer Lecturer

My research philosophy is:

Adaptive engineering

where we try and engineer our heat transfer systems to make
exclusive use of
natural forces

such as gravity, surface tension density gradients and buoyancy
to do the job for us

without the use of any mechanically moving parts such as pumps
and mechanical activators and active electronic and mechanical
controls and switches

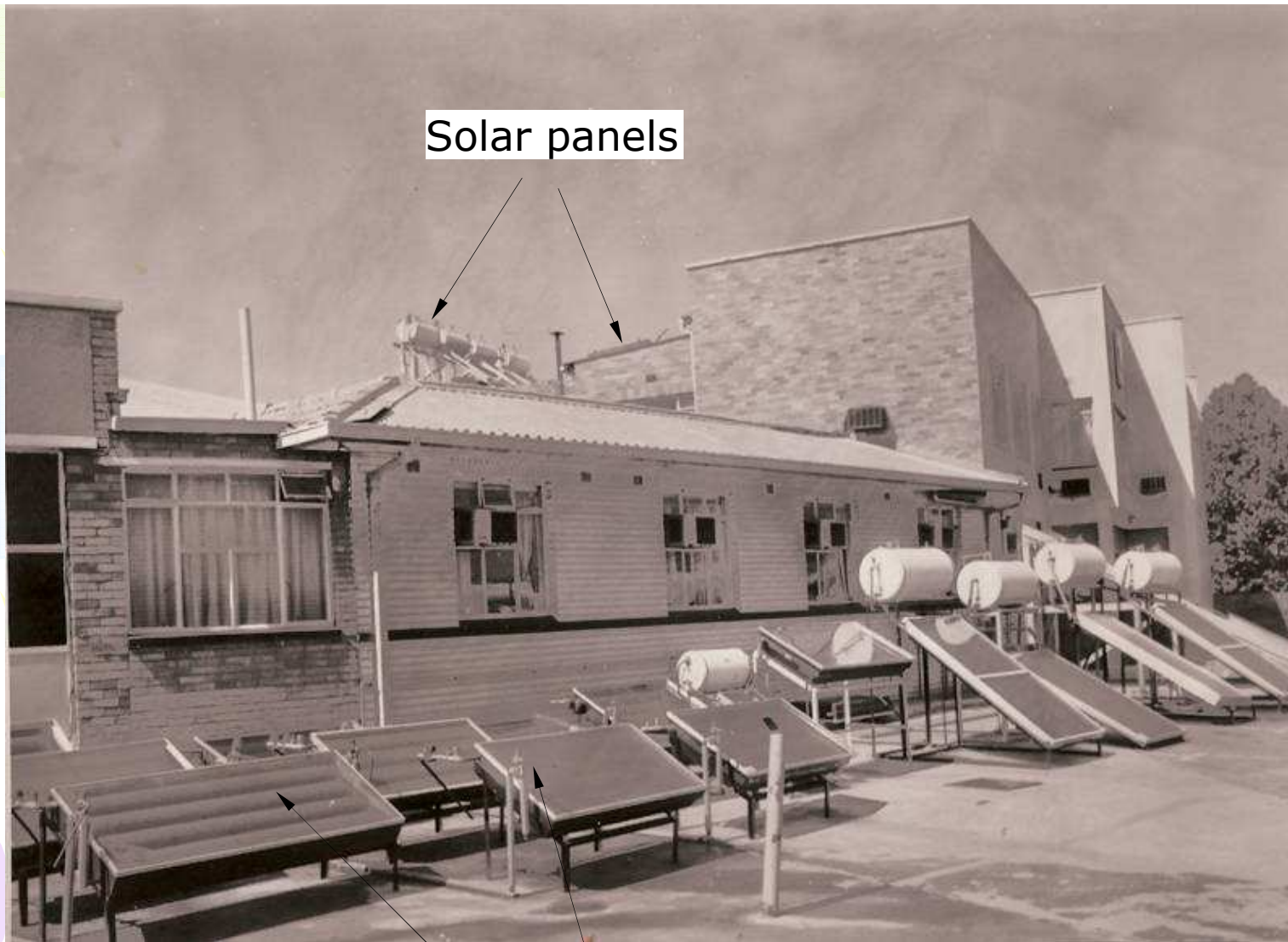
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We used the roof and the car park as our solar water heater test laboratory at Kwikot LTD, Edinburg Road, Benoni



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Solar panels

Integral Solar water heaters

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Thelma (Kwikot Factory Personal manager) cooking pap along side Benoni Lake in 1983



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Front and back-page of our "Frost Resistance" Panel



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KWIKOT

SOLAR

WATER HEATING SYSTEMS
DOMESTIC

Specifika

Max Heating Full Heating 23,000 108 TL	Solar Heating Capacity/Heatable 108 TL
SPECIFIC SECTION No. 76	
Date August 1988	

Make friends with the sun and Kwikot

**THE NEW, RAPID HEATING, FULLY WETTED
SURFACE, FREEZE RESISTANT, 200 kPa TYPE 444
STAINLESS STEEL ENVELOPE SOLAR COLLECTOR.**

COLLECTOR SPECIFICATION

Absorber Plate - Type 444 Stainless Steel envelope
Absorber Coating - Matt black paint, absorb. 0.96 absorptivity 0.96.
Housing - Aluminium extrusion.
Glazing - 3mm heat strengthened, hail resistant glass.
Insulation - Back: Glass fibre (thermal conductivity 0.04 W/M²C). Side: Polyurethane (thermal conductivity 0.026 W/M²C).
Seals - E.P.D.M. gasket, heat and ultra-violet radiation resistant.
Freeze Protection - Does not require any freeze protection devices.
Working Pressure - 200 kPa Test Pressure - 500 kPa
Aperture Area - 2.7 m² Gross Area - 2.25 m²
Mass - 50 kg Fluid Capacity - 4.2 l
Total Energy Rating - 19 MJ Specific Energy Rating - 13 MJ.

VERSAMELAAR SPESIFIKASIE

Absorberplaat - Tipe 444 roestvry staal omhulsel
Absorberende Bedekking - dofswart verf (absorberingsvermoë - 0.96 absorptiwegvermoë - 0.96)
Huisel - aluminiumsteking
Glasing - 3mm hittebestandende, haalbestandende glas.
Isolering - Agorkaam, versigtig (waaiergeleidelingsvermoë 0.04 W/M²C).
Kant polystireen (waaiergeleidelingsvermoë 0.026 W/M²C).
Seëls - E.P.D.M. plastiek, hittebestandende en ultra-voelstraling
Waaierbeskerming - Beskerming teen waaierbeskerming nie.
Werkdruk - 200 kPa, Toetsdruk - 500 kPa
Groette van Opheping - 2.7 m³ Brukruim 2.25 m²
Massa - 50kg, Vloeistofkapasiteit - 4.2 l
Algehele Energievermoë - 19 MJ, Spesifieke Energievermoë - 13 MJ.

	A	B	C	Bar Hole Centre	E	Element Rating	Mass kg	No of Panels
150	1125	563	814	400	584	3kW	66	1
200	1425	563	1100	400	584	4kW	73	2
250	1700	563	1382	400	584	4kW	91	2

INCIDENT SOLAR RADIATION vs. INCIDENT ANGLE OF COLLECTOR

INSTANTANEOUS EFFICIENCY CURVE vs. HEAT PARAMETER (W/M²C)

PRESSURE DROP CURVE vs. FLOW RATE (l/min)

m ² AREA	A mm	B mm	C mm	NUMBER OF CONNECTIONS	CONN. SIZE mm	GLAZING DESC.	MASS kg
2.0	1195	64	1540	4	25	TEMP. GLASS	50

N.B. FOR INSTALLATION DETAIL REFER TO KWIKOT TECHNICAL DEPARTMENT OR KWIKOT INSTALLATION MANUAL.

KWIKOT LTD.
P.O. BOX 1046, HENDELSIG
KWIKOT (CAPE) LTD.
P.O. BOX 445, SPRINGBOEK, 7491
TEL. 021 885 1111

KWIKOT (E. CAPE) LTD.
P.O. BOX 463, PORT ELIZABETH
KWIKOT (NATAL) LTD.
P.O. BOX 4196, GRIFFINS 316-4525
TEL. 33-1701

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Solar water heater configurations

- Integral
- Thermosyphon
- Pumped
- Close-coupled
- Swimming pool



Integral solar water heater



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Solar collector and Water Storage all in one unit



Collector
Water storage

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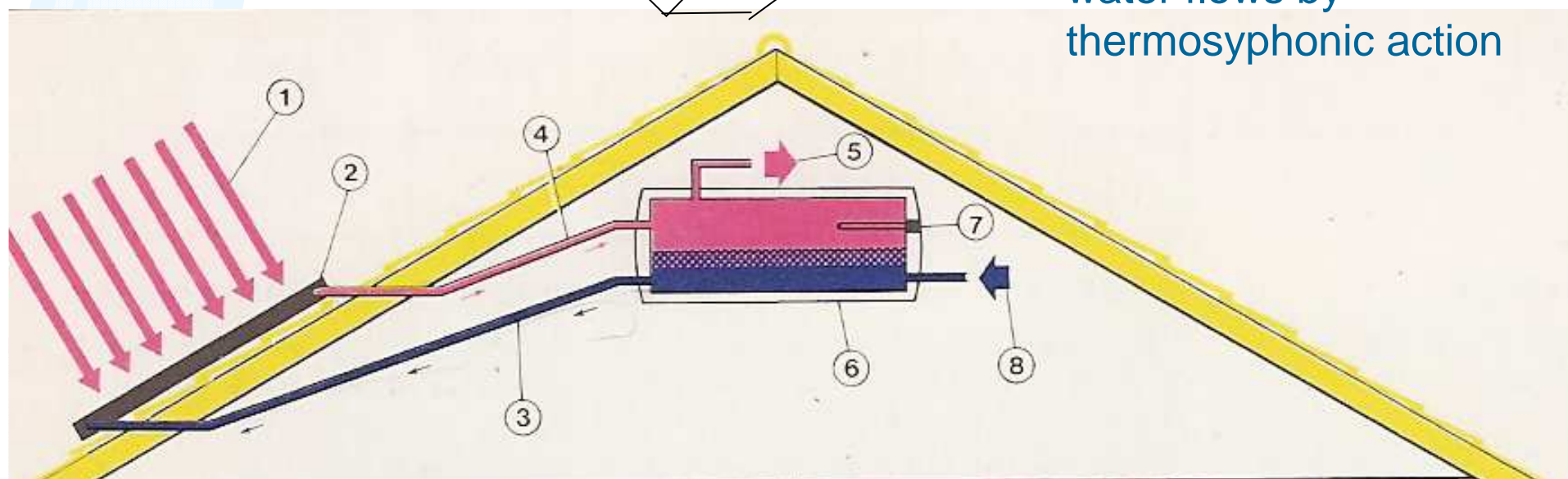


Thermosyphon solar water heater

Water
storage

Collector

Solar collector below
water Storage and
water flows by
thermosyphonic action

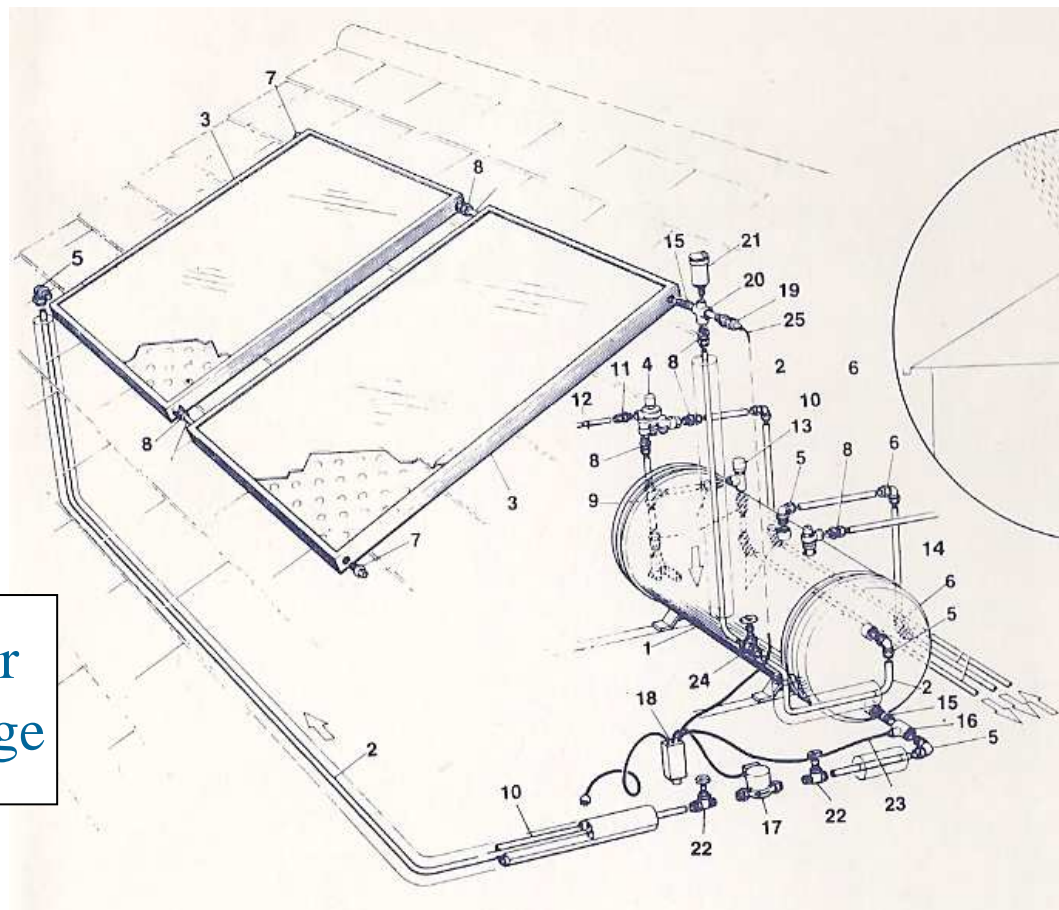
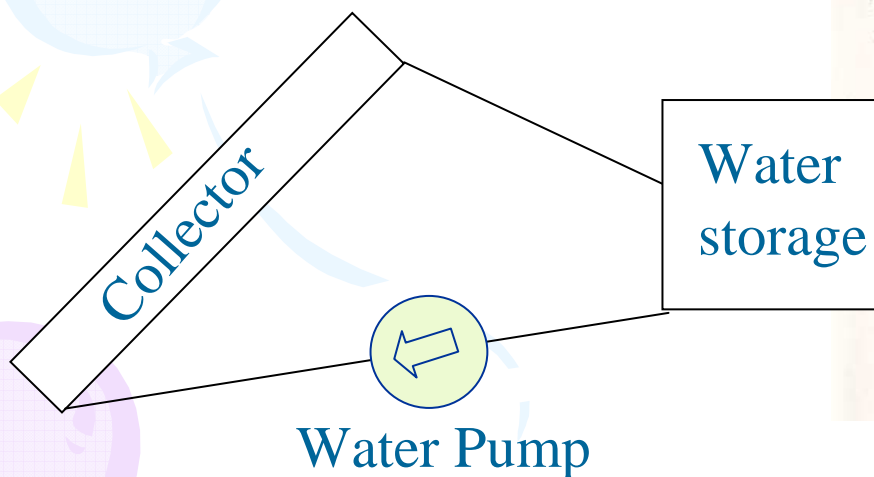


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Pumped solar water heater

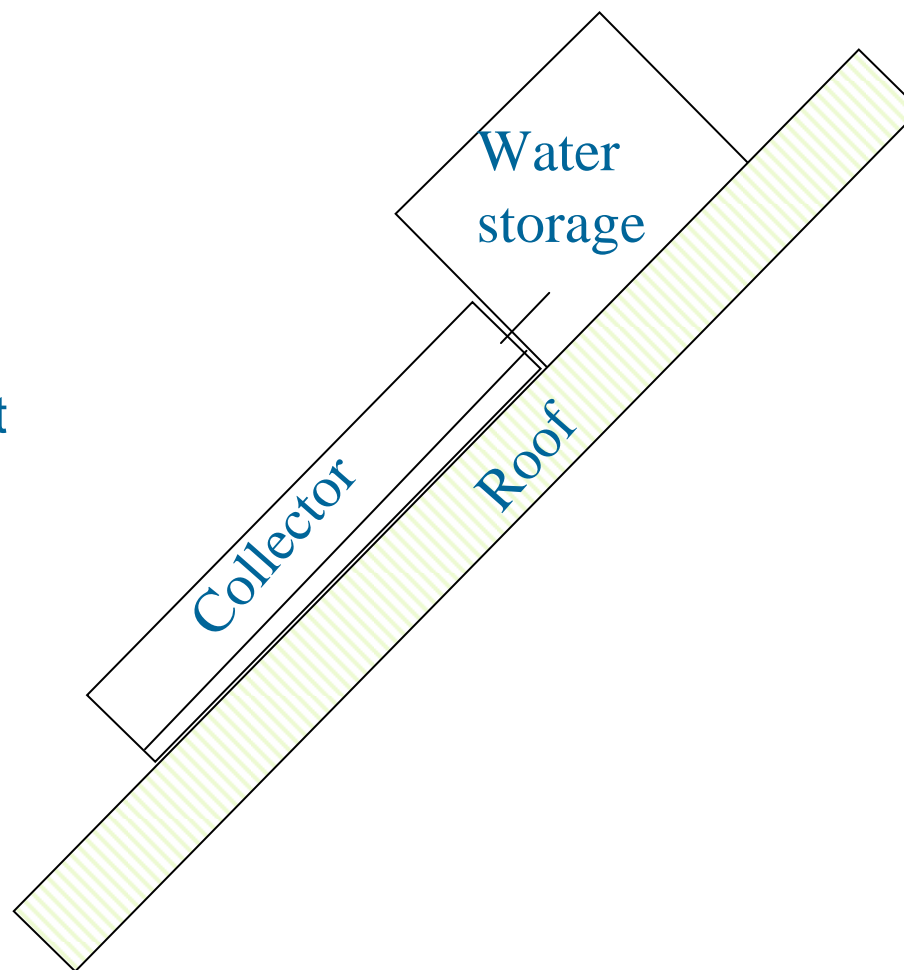
Solar collector
below water
storage. Water is
pumped





Close-coupled Thermosyphon solar water heater

Solar collector and
water storage
separated but on a
common integrated
support platform to
look like a single unit



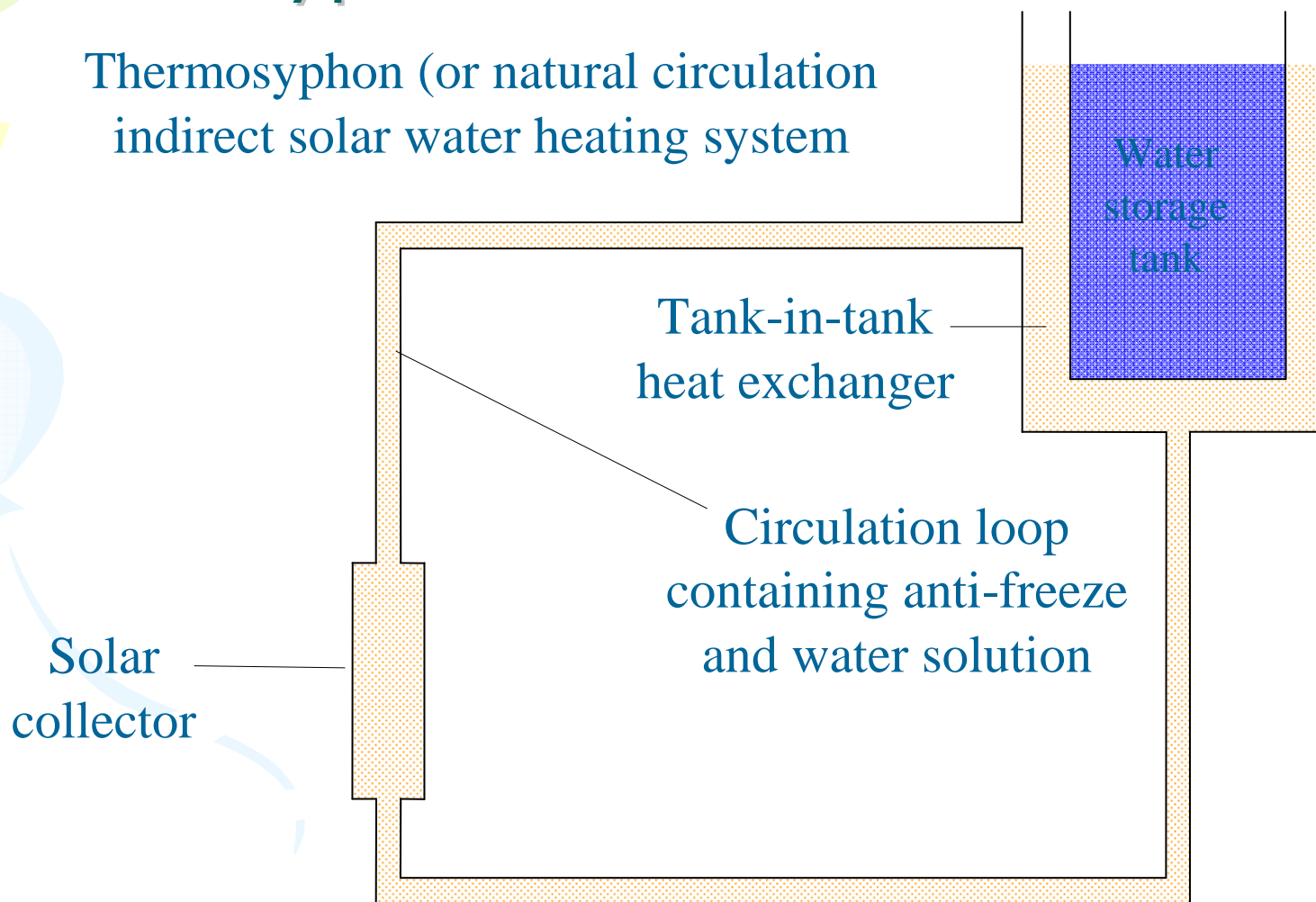
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Close-coupled Indirect Tank-in-Tank Thermosyphon solar water heater

Thermosyphon (or natural circulation
indirect solar water heating system

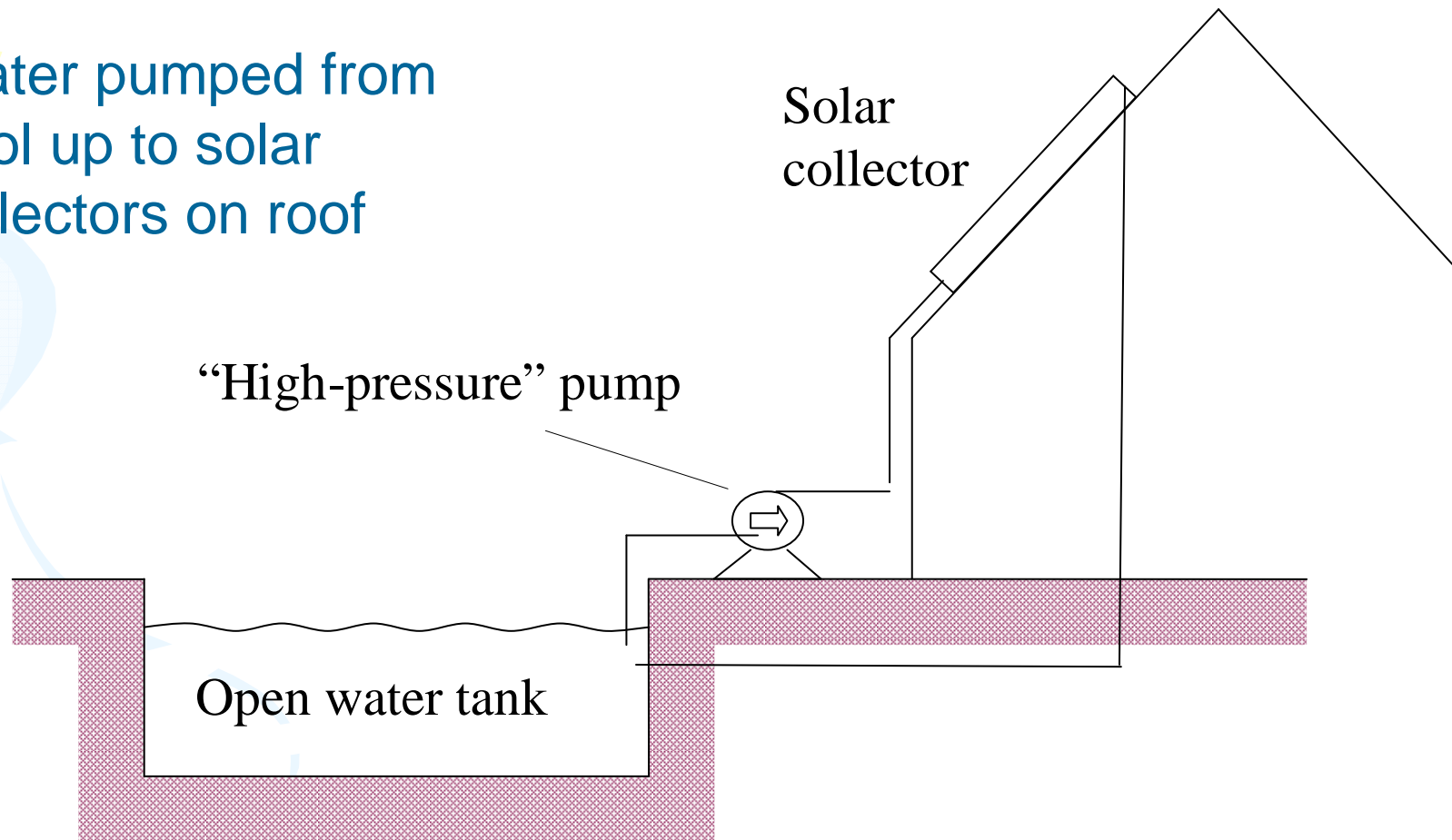


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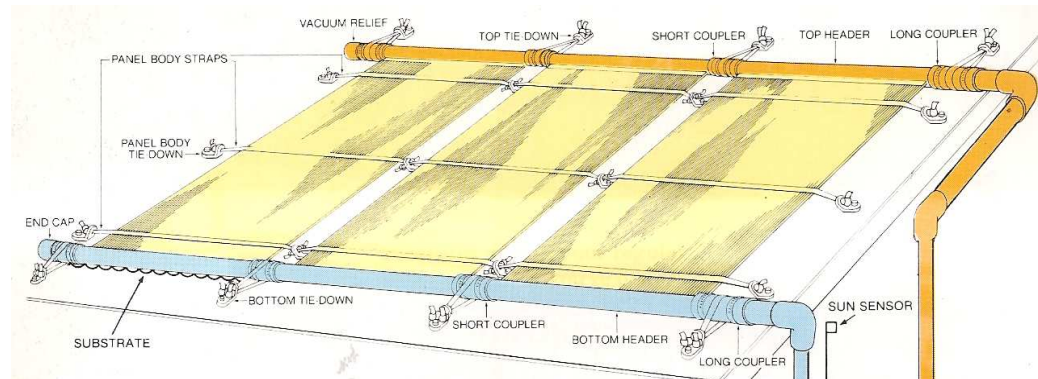
Swimming pool solar water heater

Water pumped from pool up to solar collectors on roof

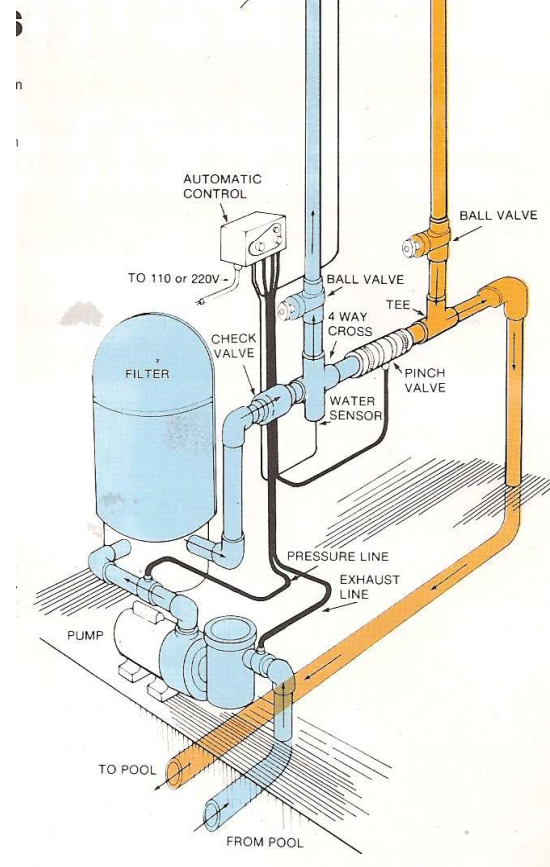


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Swimming pool solar water heating system

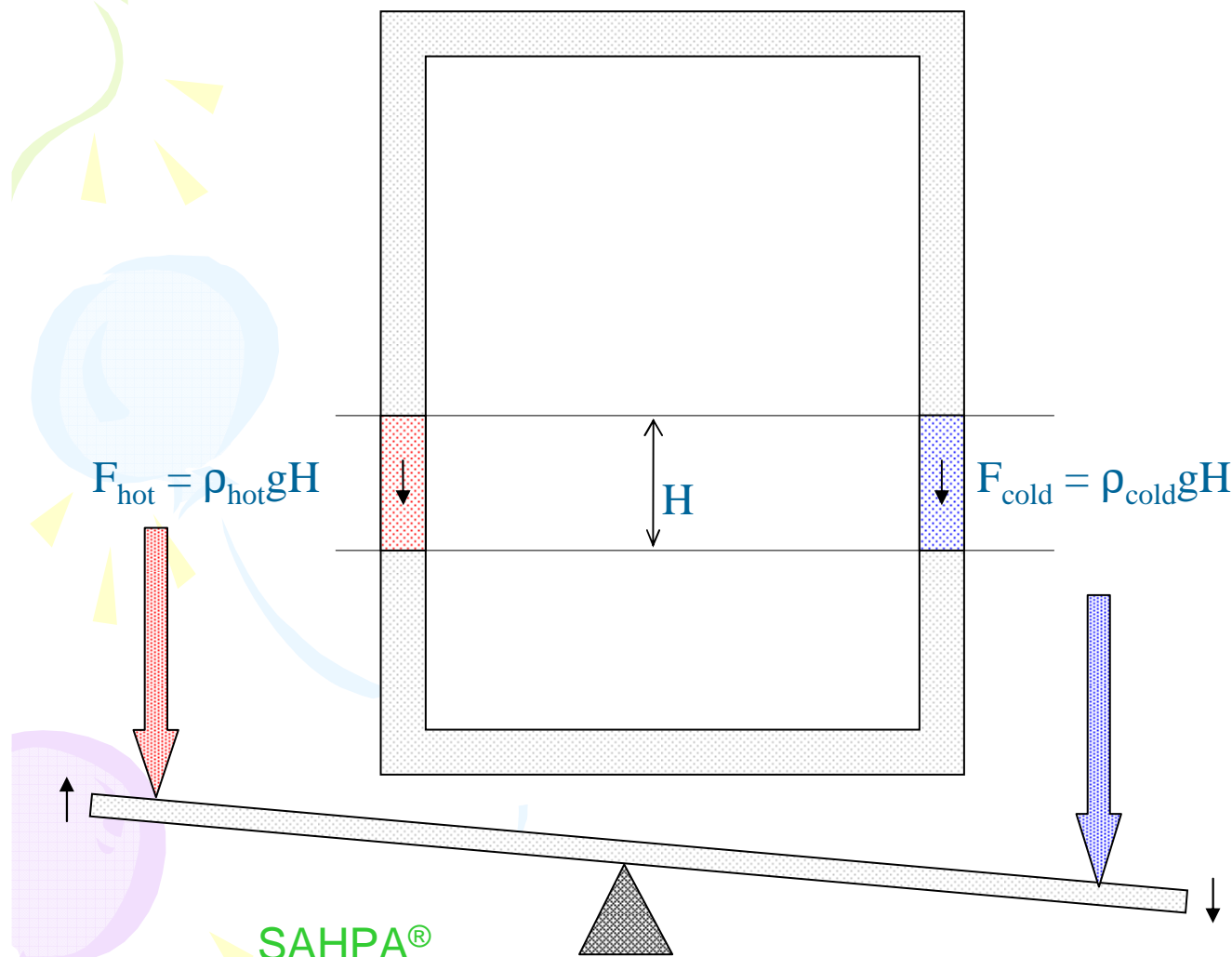


Thermosyphon solar water heating system

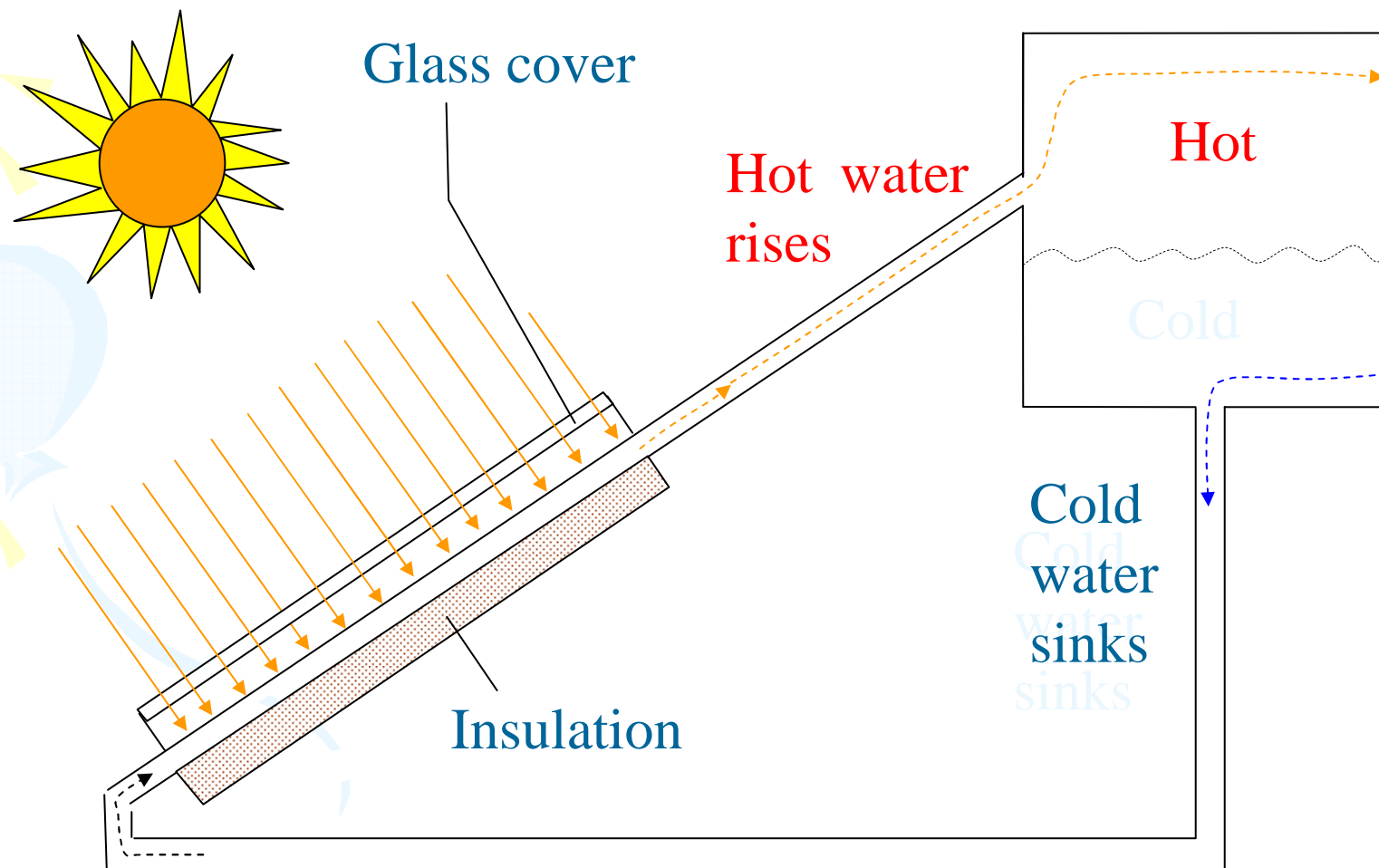
How does it work?



The density of the hot fluid is less than the density of the cold fluid. The force of attraction to the earth of the hot fluid is less than for the cold fluid. As a result of this force imbalance cold fluid sinks and the hot fluid rises and the fluid circulates around the loop. The denser or heavier fluid package will sink and pushes the less-dense or lighter fluid up



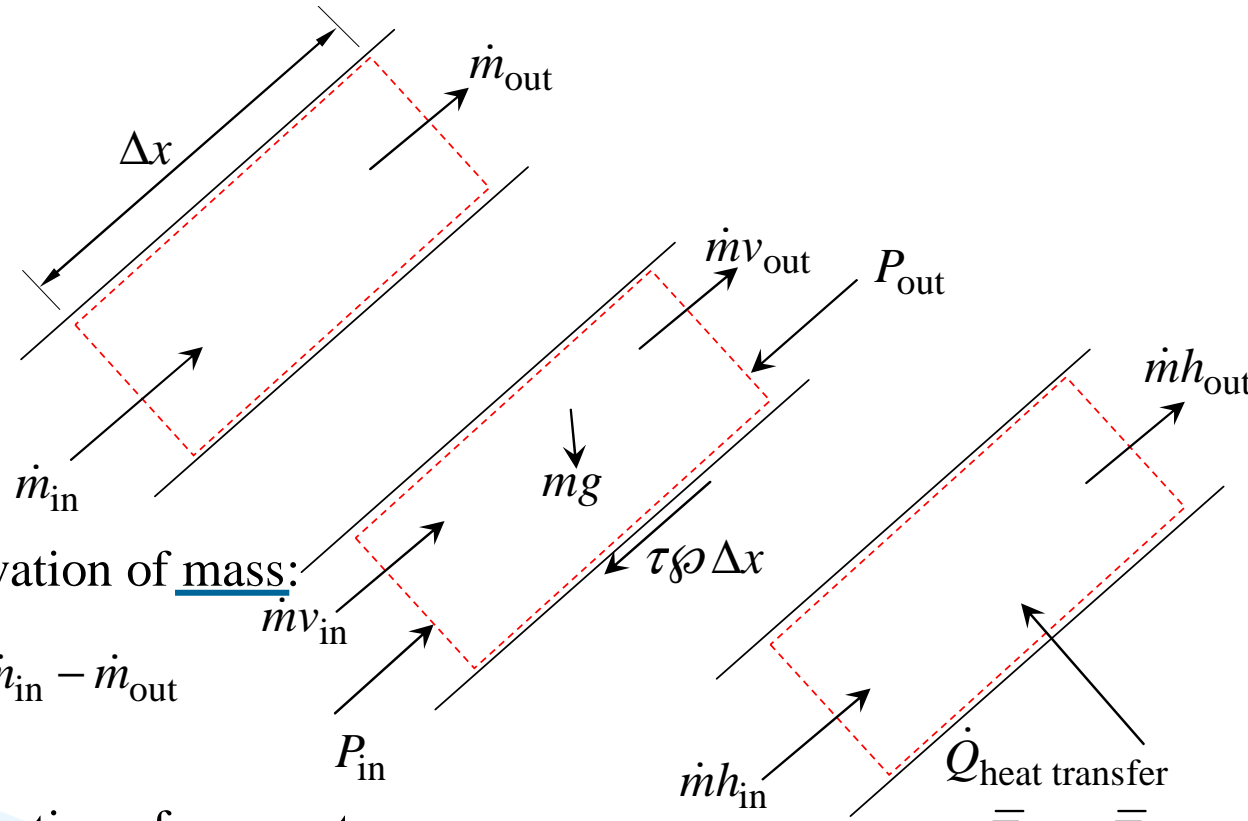
Thermosyphon solar water heating system



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Basic theory: Divide the system into control volumes and apply the conservation of mass, momentum and energy



Conservation of mass:

$$\frac{\Delta m}{\Delta t} = \dot{m}_{in} - \dot{m}_{out}$$

Conservation of momentum:

$$\frac{\Delta mv}{\Delta t} = \dot{m}v_{in} - \dot{m}v_{out} - mg - \tau\phi\Delta x - (P_{out} - P_{in})A$$

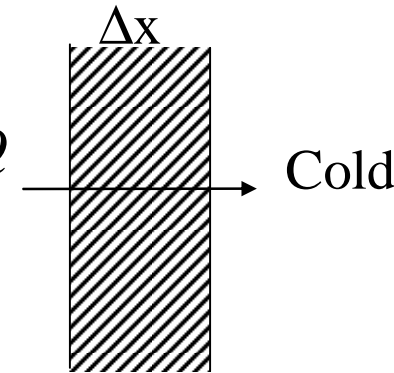
$$\dot{Q}_{\text{heat transfer}} = \frac{\bar{T}_{\text{hot}} - \bar{T}_{\text{cold}}}{R}$$

Conservation of energy and heat transfer: $\frac{\Delta U}{\Delta t} = \dot{m}h_{in} - \dot{m}h_{out} + \dot{Q}_{\text{heat transfer}}$

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Basic heat transfer theory:

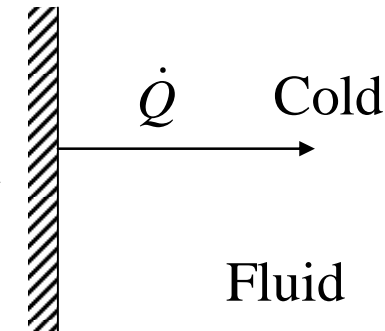
Heat transfer equation: $\dot{Q} = \frac{T_{\text{hot}} - T_{\text{cold}}}{R}$ [W]



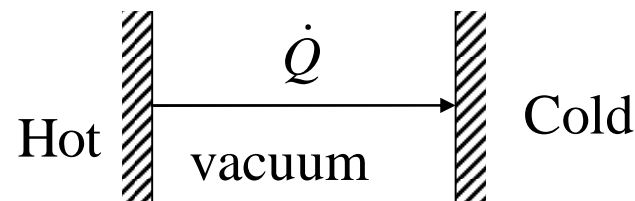
Conduction: $R = \frac{\Delta x}{kA}$ [$^{\circ}\text{C}/\text{W}$]



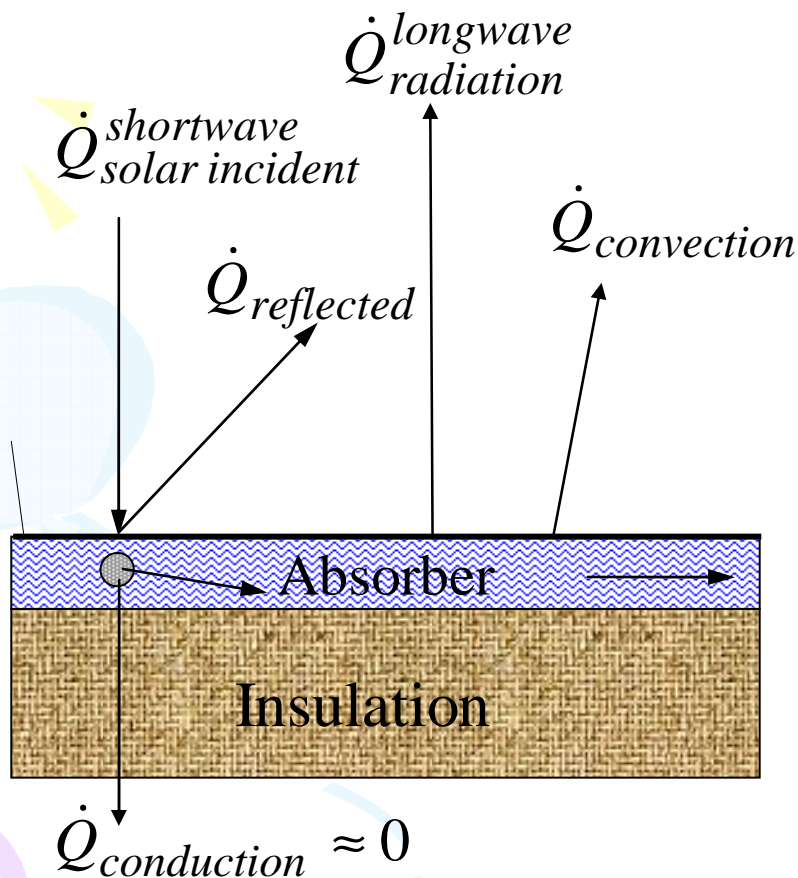
Convection: $R = \frac{1}{hA}$ [$^{\circ}\text{C}/\text{W}$]



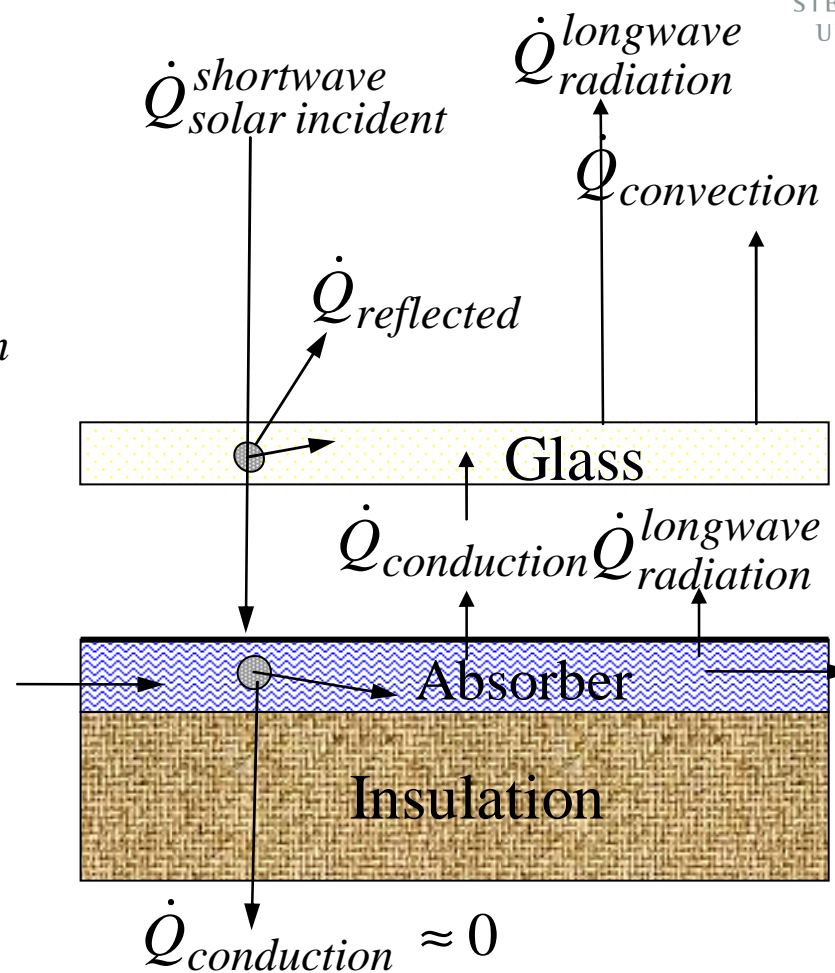
Radiation: $R = \frac{1}{\epsilon A \sigma \left((T_1 + 273)^2 + (T_2 + 273)^2 \right) \left((T_1 + 273) + (T_2 + 273) \right)}$ [



Basic theory: Effect of glazing (glass)



(a) No glass cover



(b) With glass cover plate

Evacuated-tube solar water heaters



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Hot
water

Vapour

Hot water

Cold water

glass

Condensate

Black paint

Evacuated
double walled
glass tube
+
heat pipe

Vacuum

Evacuated
double walled
glass tube

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Typical domestic evacuated-tube solar water heater installation



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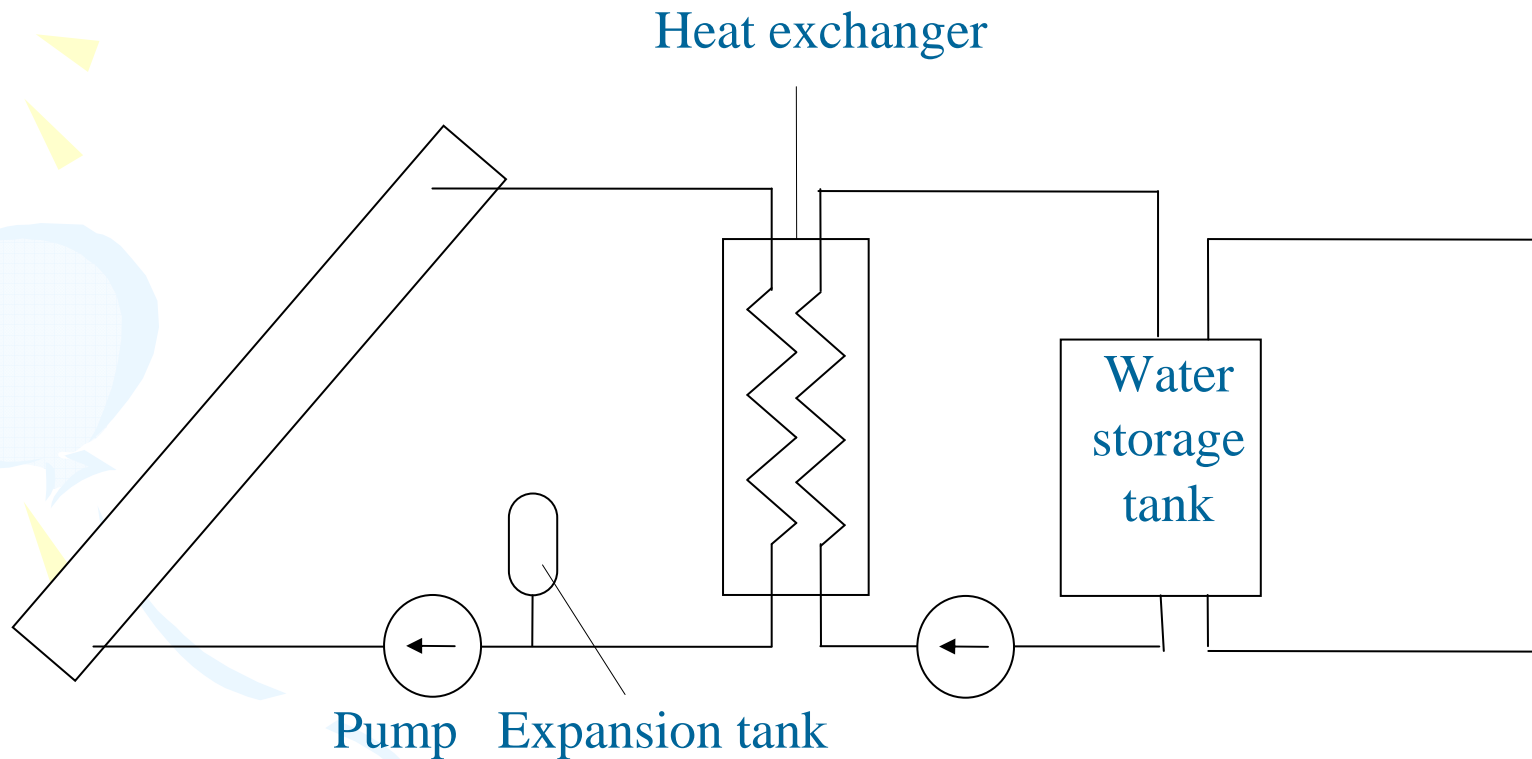
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Typical pumped indirect solar water heating system



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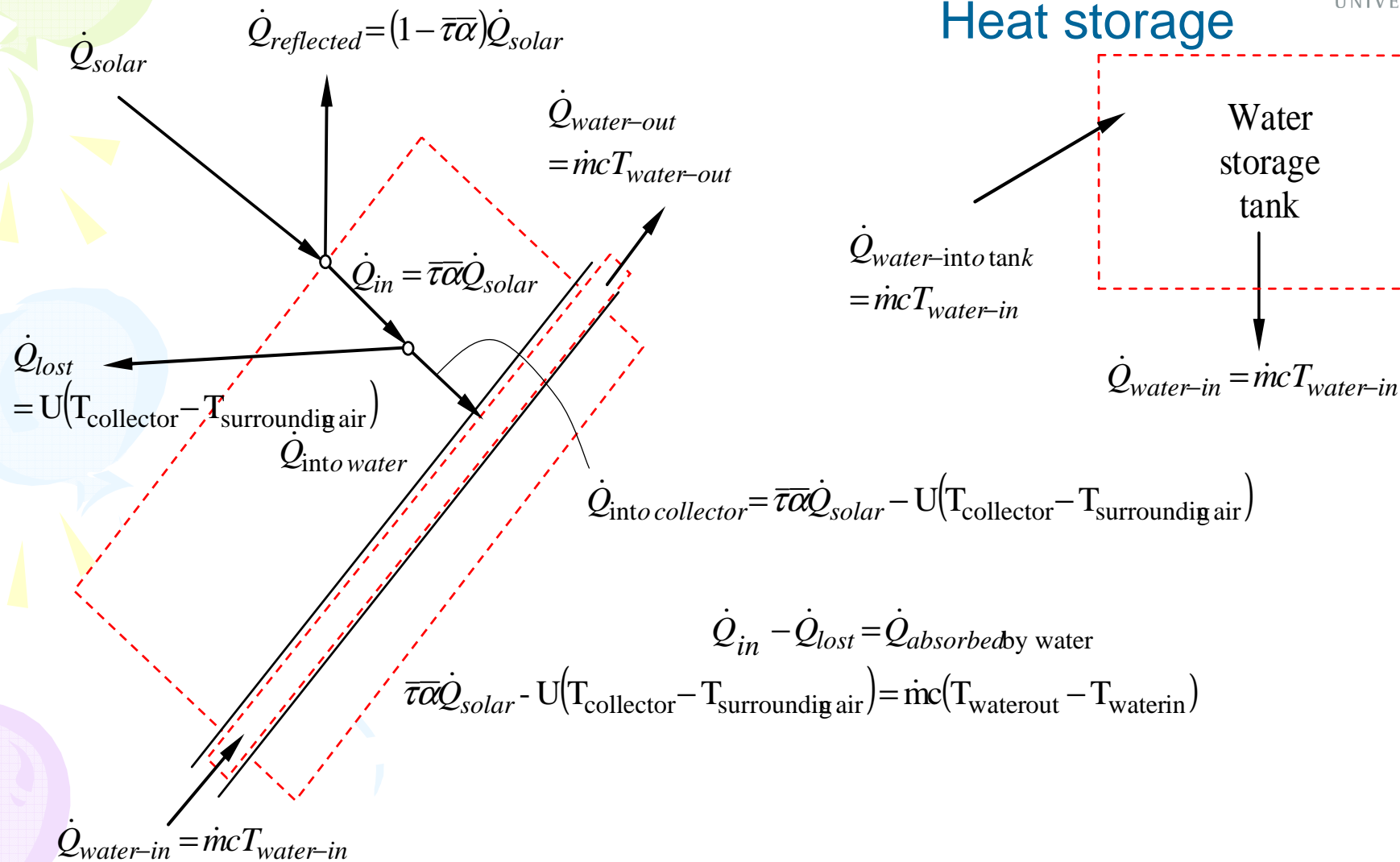


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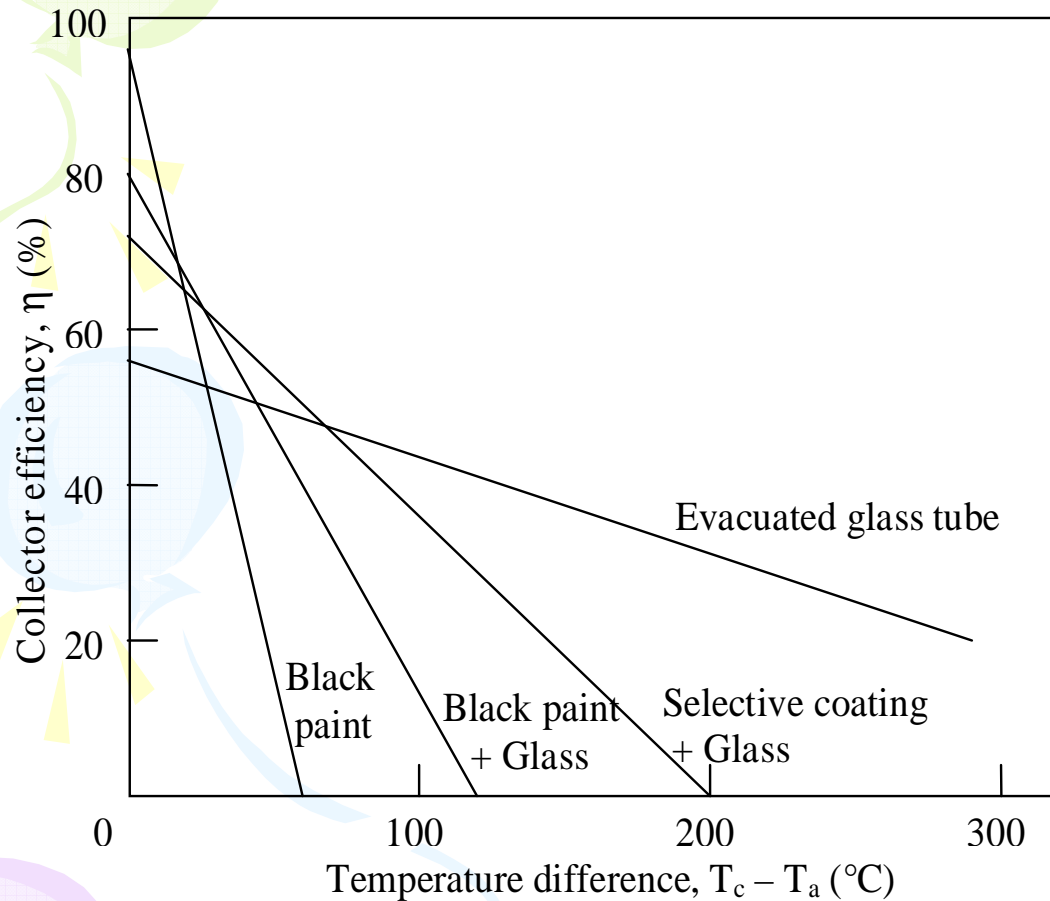
Basic theory: Heat collection

Heat storage



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Typical solar water heater collector characteristics



$$\text{where } T_c \approx \frac{T_{\text{water in}} + T_{\text{water out}}}{2}$$

Solar collector thermal performance characteristic is :

$$\eta = a + b(T_c - T_a)$$

where solar collector efficiency $\eta = \frac{\dot{Q}_{\text{collected}}}{\dot{Q}_{\text{input}}}$

heat input factor $a = \frac{\dot{Q}_{\text{input}}}{\dot{Q}_{\text{solar}}} = \frac{\bar{\tau}\bar{\alpha} \cdot \dot{Q}_{\text{solar}}}{\dot{Q}_{\text{solar}}} = \bar{\tau}\bar{\alpha}$, and

heat loss factor $b = \frac{\text{heat collected}}{\dot{Q}_{\text{solar}}} = \frac{\bar{\tau}\bar{\alpha} - U(T_{\text{collector}} - T_{\text{surrounding air}})}{\dot{Q}_{\text{solar}}}$
 $= \frac{\text{heat into water}}{\dot{Q}_{\text{solar}}} = \frac{\dot{m}c(T_{\text{water out}} - T_{\text{water in}})}{\dot{Q}_{\text{solar}}}$





My rules! @#\$%^&*()?:

Up to 40% electricity savings

50 % efficient

500 W/m² over an 8 hour period

Overheating??

Expansion relief??

Air bubbles??

Thanks

Automatic air relief??

Pressure??

Corrosion??

Freezing??

Gas loaded heat pipe
temperature control??

Reverse thermosyphoning??

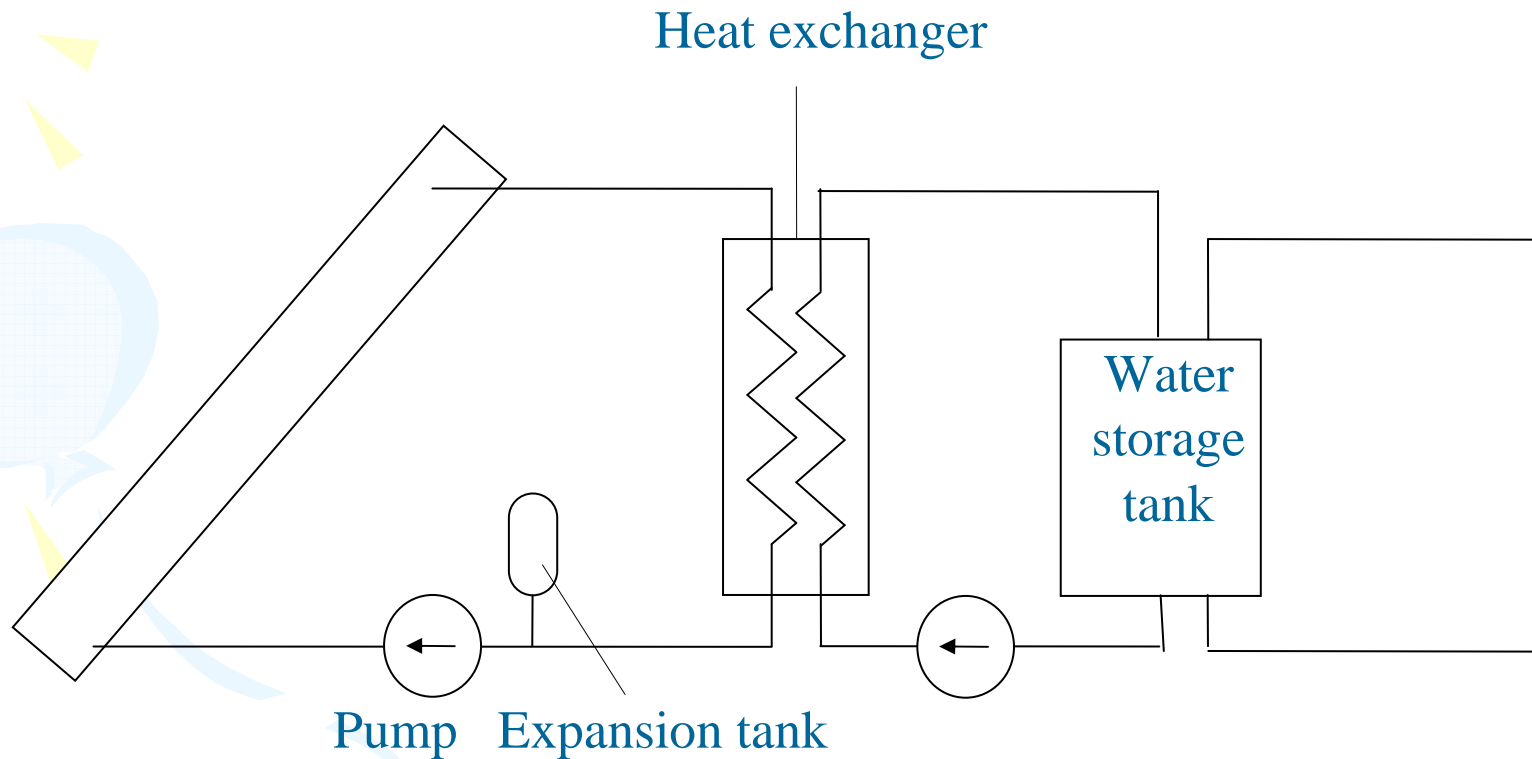
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Typical pumped indirect solar water heating system



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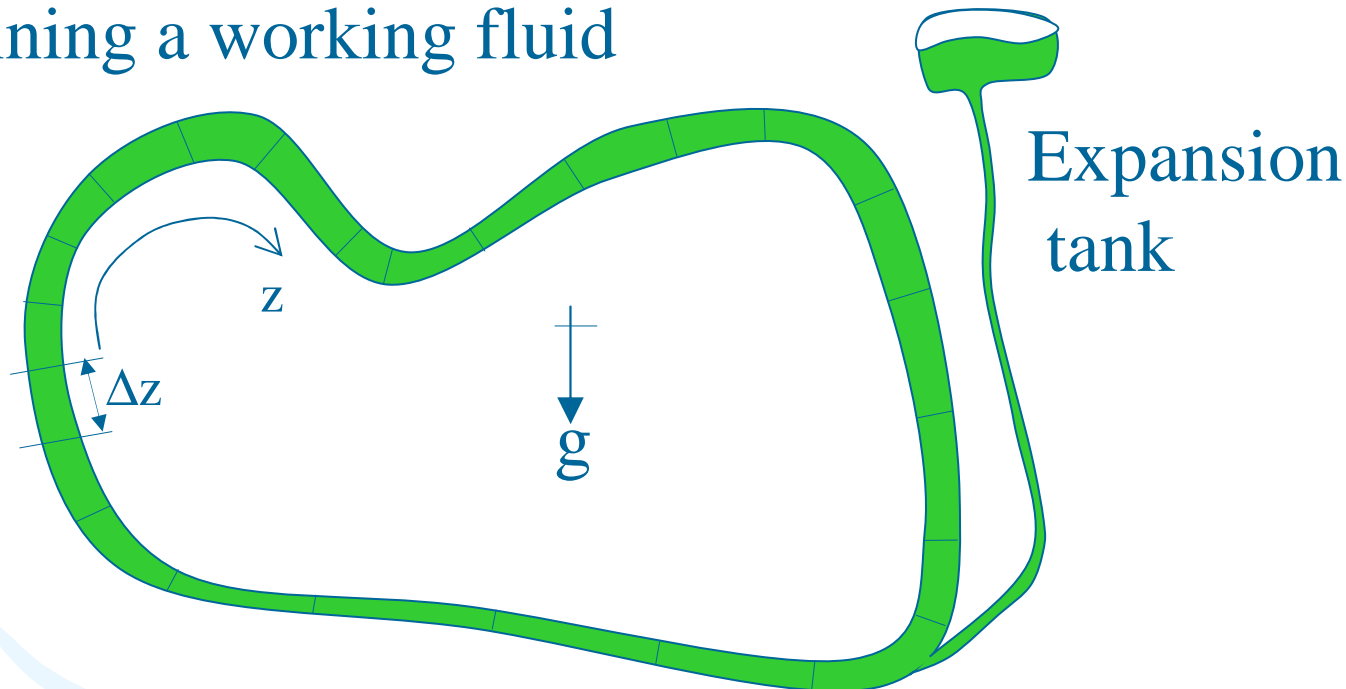


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Theoretical modeling

Consider a hollow pipe with a variable diameter and fashioned into a closed loop and also containing a working fluid



Divide the loop up into a number of smaller control volumes, apply the equations of change to each control volume, and integrate around the loop!

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Theoretical modeling (cont.)

Conservation of Mass

Single phase flow $\frac{\Delta m}{\Delta t} = 0 = \dot{m}_{\text{in}} - \dot{m}_{\text{out}}$

Two-phase flow $\frac{\Delta m}{\Delta t} \neq 0 = \dot{m}_{\text{in}} - \dot{m}_{\text{out}}$ but mass enters the expansion tank instantaneously

Assumptions:

- * One-dimensional flow $\dot{m} = \rho VA$
- * Both liquid and vapour phases are incompressible
- * Density (pressure) waves occur instantaneously, ie speed of sound $\gg \dot{m}$

Theoretical modeling (cont.)

Conservation of Energy

Single phase flow for the i^{th} control volume with the temperature T expressed explicitly:

$$T_i^{t+\Delta t} = T_i^t + \frac{\Delta t}{m_i^t c} \left(\dot{Q}_{\text{in,out}} + \dot{m}i_{\text{in}} - \dot{m}i_{\text{out}} \right)^t$$

Heat transfer rate

$i = \text{enthalpy}$

$c = \text{specific heat}$

$$m = \rho A \Delta z$$

Theoretical modeling (cont.)

Conservation of Energy

Two-phase flow for the i^{th} control volume with the temperature T expressed explicitly:

$$u_i^{t+\Delta t} = u_i^t + \frac{\Delta t}{m_i^t c} \left(\dot{Q}_{\text{in,out}} + \dot{m}i_{\text{in}} - \dot{m}i_{\text{out}} \right)$$

If $u^{t+\Delta t} < u_f$ then $T_{\text{hp}}^{t+\Delta t} = u^{t+\Delta t} / c_v$ and $x^{t+\Delta t} = 0$

If $u^{t+\Delta t} > u_f$ then $T_{\text{hp}}^{t+\Delta t} = T_{\text{sat}}$ and

$x^{t+\Delta t} = u^{t+\Delta t} - u_f^{t+\Delta t} / u_{fg}^{t+\Delta t}$, where $u_{\text{hp}} = u_f + x u_{fg}$,

$i = i_f + x i_{fg}$, $u_f = c_v T_{\text{hp}}$ and $i_f = c_p T_{\text{hp}}$.



Theoretical modeling (cont.)

Conservation of Momentum applied to heat pipe control volumes to determine the mass flow rate

Buoyancy driving term

Frictional-resistance term

$$\frac{d\dot{m}}{dt} = \frac{\sum_{k=1}^{N_k} \rho_k L_k g \sin \phi_k}{\sum_{k=1}^{N_k} \frac{L_k}{A_{x,k}}} - \frac{\sum_{k=1}^{N_k} \frac{C_{f,lo,k} \phi_{lo,k} L_k + L_{f,equiv,k}}{\rho_k r_{i,hp} A_{x,k}^2} \dot{m}^2}{\sum_{k=1}^{N_k} \frac{L_k}{A_{x,k}}}$$

Assumptions:

- * Quasi-equilibrium
- * Both liquid and vapour phases are incompressible
- * Homogeneous two-phase flow model
- * Hydrostatic pressure at a point (Archimedes and Boussinesq 's approximation)

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