Solar Heater the principle and the design— 2011/2/4

Solar Heater(SH) is the very best performance in energy technology. Below are the physics basis and some design example. You could invent better SH.

http://solarcooking.org/

Author is not actual expert on SH, but had been "B wave generator" in energy technology. Also you could see SH is the kernel technology against the Climate Change Crisis. Above all, those are the best cost and CO2 performance than any other else. If you could save foods and energy, you could conqure any threatenning.

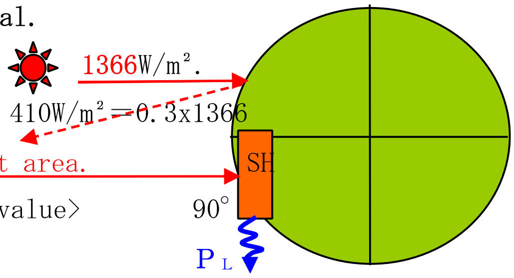
［1］: Solar Heater the physics fundamental.

❶(1)Solar constant＝1366W/m².

(2)reflection rate(albedo)≡a≒0.3.

(3)direct effective heat input(≡P_S)/unit area.

＝1366W/m²×(1−0.3)＝**956**W/m²... <best value>

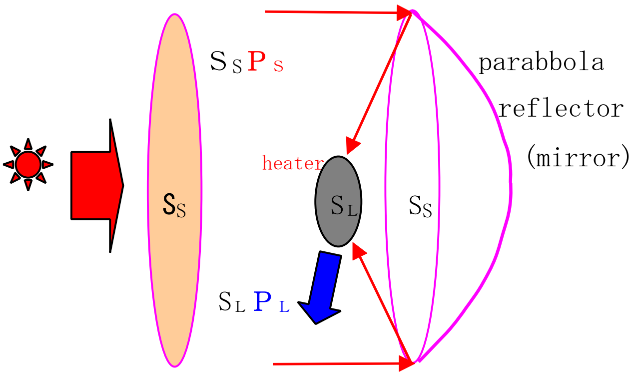


(4)SH light reciever surface is setted perpendicular to incoming beem, so heat amount depend fundamentally not seasonal !!, however **seasonal penetrating length of solar ray in atomosphere** would attenuate P_S by vapor density, etc.

❷solar heat input and dissipated heat output from heater of temperature T.

(1)actual heat input in SH ≡P_H=$S_S P_S$(956W/m²)－$S_L P_L$.
Effective heat input≡Q_S=$S_S P_S$ is uniquely determined by S_S. Heat loss Q_L=$S_L P_L$ depend on thermodynamic design of SH and its thermal enviroment.

(2)$S_S P_S$ is proportional to perpendicular **recieving area** S_S of incoming solar beam. Similary $S_L P_L$ is too. S_L is total **surface area** of heat container of T. Dissipated radiataion thermal loss ≡P_L/unit area might depend material of heater and the enviromental temperature, wind, etc.



Note that incoming sun beam are almost visible ray and some infrared one(IR).
While dissipated heat output are infrared ray to space, and conductive and covection heat flow in air and insulator.

Hence **larger** S_S and **smaller** S_L are preferable for gettimg larger effective heat.

(3)Heat Loss Estimation=dissipated thermal loss by radiation≡$Q_L=S_L@\sigma T^4$.

In SH design, P_L is called Blackbody Radiation(=σT^4)and is serious important.

Example-1)

$\sigma T^4=5.67\text{x}10^{-8}\times(273+40℃)^4=544W/m^2$. <<bath water temperature>>

$\sigma T^4=5.67\text{x}10^{-8}\times(273+100℃)^4=1100W/m^2$. <<boiling water temperature>>

Boilling pan & kettle of "unit area" has larger heat loss as shown in above.

(4)Countermesure for heat loss:

(a)making smaller heating surface area S_L.→ spherical surface is the best.

Example-2)

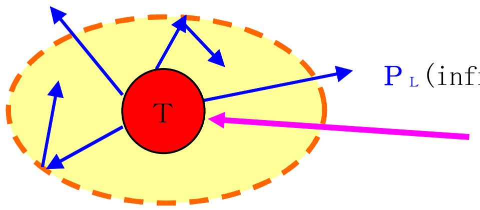
2.2 liter kettle has $0.12m^2$ surface area=S_L.→

$S_L\sigma T^4=0.12\times5.67\times\text{x}10^{-8}\times(273+100℃)^4=132W/m^2$. (@=1 of blackbody).

$@S_L\sigma T^4=0.5\times0.12\times5.67\times\text{x}10^{-8}\times(273+100℃)^4=62W/m^2$. (@=0.5 of graybody).

(b)green house method of @<heat(infrared ray)reflecting wall≡HW>.

$P_L=@\sigma T^4$.



P_L(infrared ray output)

P_S(visible ray input)

HW allow passing of visible ray P_S,while,HW can reduce passing probability @ of infrared ray(IR) from heating kernel T,which can rise temperature T.

(c)maximum temperature rise realizing by @ of HW. 0<@<1.

In heat flow balanced state,$S_S P_S=S_L P_L$.

$S_S P_S=S_L@\sigma T^4$. →$P'_S\equiv(S_S/S_L)P_S/@=\sigma T^4\geqq(S_S/S_L)P_S$.

→ $T_{Max}=[(S_S/S_L)P_S/@\sigma]^{1/4}$.

Example-3) ＊ $\sigma=5.67\text{x}10^{-8}W/m^2K^4$. (Stefan Boltzman constant).

@=1.0、→$P_S(956W/m^2)=@\sigma T^4$.→$T=(P_S/\sigma)^{1/4}$ =360K=(273+87℃).

@=0.5、→$P_S(956W/m^2)=@\sigma T^4$.→$T=(P_S/@\sigma)^{1/4}$=429K=(273+156℃).

☞:T=150℃ is told sufficient for slow mode cooking.

http://solarcooking.wikia.com/wiki/Minimum_Solar_Box_Cooker

http://solarcooking.org/

(5)realizing green house by insulators{glass,vinyl,....,paper board}.

Those materials have @<1 against infrared ray.

(6)heat insulator materials.

air,glass wool,paper board,alminium foil,...

(7)heat absorber by black paint.

Heat container surface must be black coulor for enhansing heat input.

❸On the global green house effect and P_G≡1566W/m²..

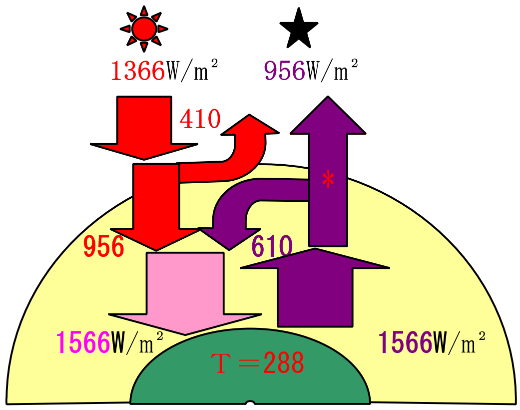
(1)The emergent crisis of the global warming(Climate Change Crisis≡CCC) is caused by Heat Trapping Gas(Green House effect Gas≡GHG＊) in atmosphere. See below figure.

P_s(956W/m²)＝@σT⁴........[1]❷(4)(b)

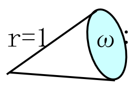
@＝(956W/m²)/(1566W/m²)＝0.61.<<passing probability of IR from earth>>.

$\sigma T^4 = 5.67\text{x}10^{-8} \times (273+15℃)^4 = 1566$W/m².<<Black body radiation from T＝288>>.

(2)Heat input on globe is not only direct solar ray (DS＝956W/m²), but also infrared ray reradiation from GHG＝heat trapping gas(RG＝610W/m²)in atmosphere. Then DS is one directional beam, while RG is isotropical one(visible sky solid angle=ω from SH reciever surface). If ω could be 2π, heat input＝610W/m², if ω=π/8, input＝40W/m²?.



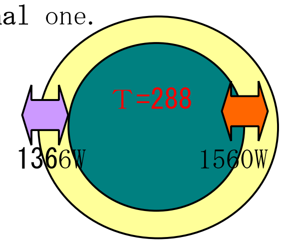
(3)Conclusion on 610W/m² heat input:



: solid angle.

1566W/m²＝956W/m²＋610W/m².

610W/m² is a big heat amount, but substantially not available for SH. Because SH is an antenna of uni-directional, while RG needs all-directional one.



(4)Heat account at earth surface and stratsphere boundary.

(a)earth surface:1566W/m²＝956W/m²＋610W/m².

(b)stratsphere boundary:1366W/m²＝956W/m²＋410W/m².

(c)The real cause of CCC is caused from Heat Passing Rate≡@ decreasing by GHG.

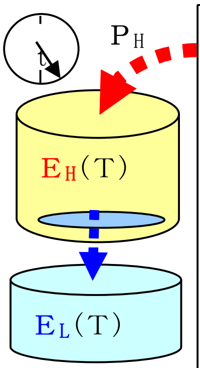
$\pi R_E^2 P_s(1-a) = 4\pi R_E^2 @\sigma T_E^4$. → $T_E = [P_s(1-a)/4@\sigma]^{1/4}$.
If @ decreased, T becomes higher.<<R_E＝earth radius, T_E＝global temperature>>

(d)The real cause of global warming is caused from Heat Debt.

surplus heat(radiative forcing≡RF＝1.6W/m²)＝heat input－heat output.
By decreasing @, cooling radiation from earth is more trapped to increase 1560W.

Strictly to tell on heat balance (4)(a)(b), those have deficit RF＝1.6W/m², which has been reseved in ocean heat(99.9% heat capacity of earth!!) and cause global warming(turbulence energy of ocean and atmosphere causing climate disasters, such as big floods, big draught, extreme weather, strong hurricane,...).

[2] : How much heat amount $\equiv E_H$ and boiling time $\equiv$ " t_H " does SH take ??.



$E_H = C_H(T_M - T_0)$ = Heat capacity × Temperature rise = necessary energy

$P_H = Q_S - Q_L = S_S P_S - S_L P_L = E_H / \langle t_H \rangle$. ⟨heat input/unit time⟩

$E_S - E_L = E_H = P_H \langle t_H \rangle = \int_0^{tH} dt\, P_H(t)$. ⟨heating up time⟩

$E_H + E_L = E_S = Q_S \langle t_H \rangle$. ⟨ t_H = time for getting max temperature = T_M ⟩

$Q_S = S_S P_S$. ⟨solar heat input per unit time⟩.

$Q_L = S_L @ \sigma T^4$. ⟨heat loss per unit time at temperature T⟩.

(Total heat for boiling E_H + Total heat loss E_L)/heat input(watt) Q_S = heating time t_H.

❶bath(the maximum heat consumer in home living!!!)。

Take caution on loss heat by cooling radiation accompanied with T rise.

(1)unit T rise heat/unit weight = water specific heat = 4.178KJ/℃Kg.

(2)bath water weight = 0.8m × 0.6m × 0.3m × 1000kg/m^3 = 150kg.

(3)Q_B = heat capacity/1℃ = 4.178KJ/Kg℃ × 150kg = 630KJ/℃.

(4)Total heat = Q_B × (40−10℃) = 30℃ × 630KJ/℃ = 18900KJ. ?!

<<☞:24 times of 781K=2.2ℓ boling kettle heat amount!!!>>.

(5)dissipated radiation heat loss in heat input = 364(10℃), 544(40℃)W/m².

(6)warm up time ≒ 18900KJ/<(956W/m^2 × 1.5m^2 − 544W/m^2) × 3600> = 5.9h

☞:Solar ray recieving area S_S = 1.5m^2。 equivalent dissipated area = 1m^2.

Commercial product has almost 2m^2、water temperature gradient automatically circulate wamer water to heat reserver tank, which finally supply bath water.

❷kettle(2.2liter=2.2Kg, heat capacity ≡ C = (4.178KJ/Kg℃ × 2.2Kg)

(1)Q_K necessary heat = C × (100−15)℃ = (4.178KJ/Kg℃ × 2.2Kg) × (100−15)℃ = 781KJ.

(2)heat loss : $L = \sigma T^4 = 5.67 \times 10^{-8} \times (283)^4 = 364$ W/m².

$L = \sigma T^4 = 5.67 \times 10^{-8} \times (373)^4 = 1100$ W/m².

☞:In air, heat loss by condution and covection is so small and neglegible.

(3)cooling radiation area $S_L = 4\pi R^2 = 4\pi (0.15\text{m})^2 = 0.3\text{m}^2$. → < L > ≒ 300W/m².

(4)Q_K = 781KJ/0.5h(boiling time) × 3600s/h ≒ 400W、+300W. 700W→ S_S ≒ 1m²。

☞:Heat loss is almost same as net heat, so loss must be decreased. Boling time is a criterion of SH performance. Note heat loss increases as T gose higher.

(5)Strict solution of temperature rise process:

: $P_H = Q_S - @ S_L \sigma T^4 = C\, dT/dt$.

= 700W − 100W(283) ≒ C<dT/dt>. <<T = 0.36h>>

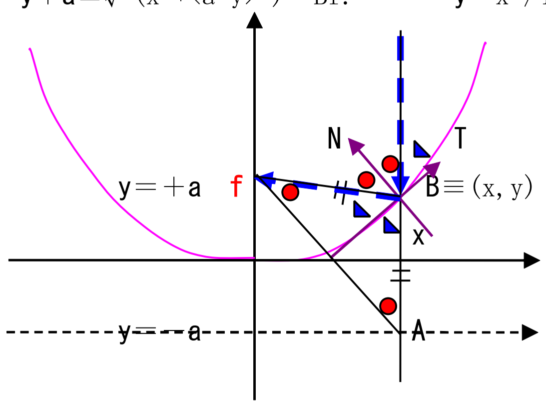
= 700W − 300W(373) ≒ C<dT/dt>. <<T = 0.54h>>

[2]: Principle of parabola solar ray collector.

Commercial SH bath wamer has not ray collector, but those has wider ray reciver area of water circulating pipe line within heat insulator box and with heat reserver tank. Pipe line and insulator box become high cost. Below technique are simple for mono heater tank(smaller S_L with rather high temperature), but accurate parabola antenna(wider S_S) is rather difficult for amateure fabrication.

(1)Parabola surface and focus coordinate f.

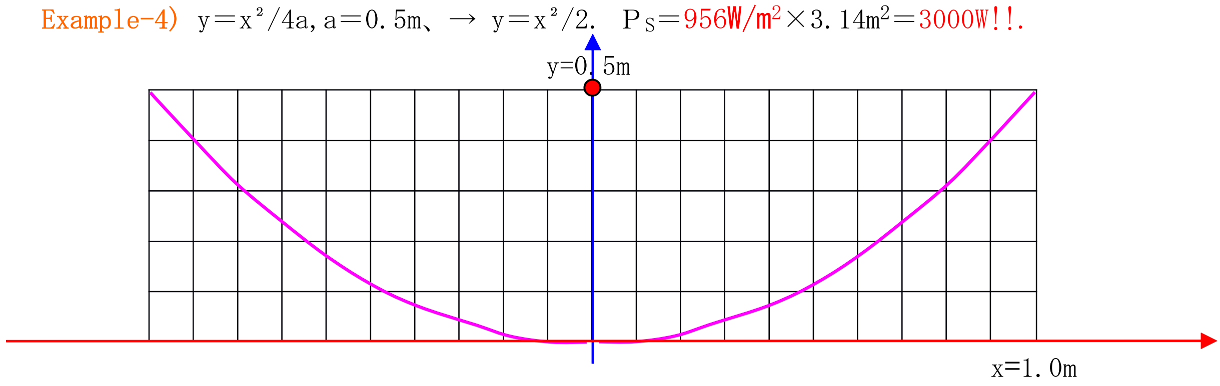
$AB = y + a \equiv \sqrt{(x^2 + \langle a-y \rangle^2)} = Bf.$ → $y = x^2/4a.$



T and N are tangential and normal line at $B \equiv (x, y = x^2/4a)$。 Then all incoming_light_beam being pararell with y axis is to be focused at f(0, a). Thus higher temperature can be gotten.

(2)Parabolar of commercial goods has opening radius=0.8(P_S=1900W)～1.5m(P_S=6700W)、and forcus point is about 0.5m from bottom。

Example-4) $y = x^2/4a$, a=0.5m、 → $y = x^2/2$. P_S=956W/m^2×3.14m^2=3000W!!.



x=0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
y=0	.005	0.02	.045	0.08	.125	0.18	.245	0.32	.405	0.5

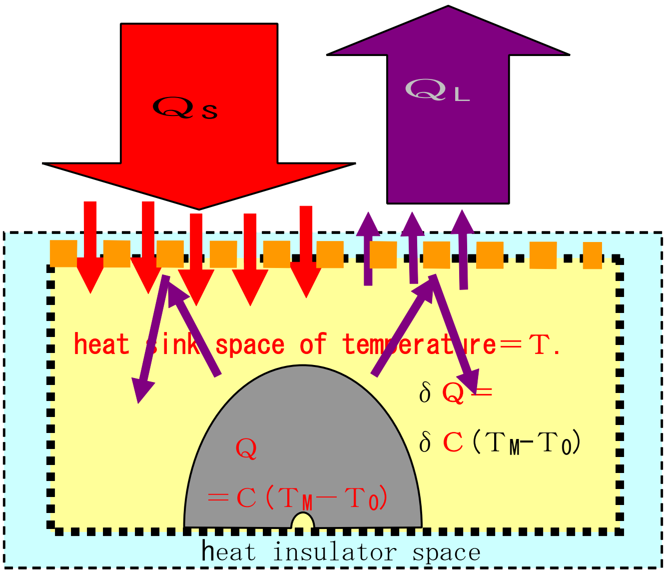
Parabola	r =0.50m、 → $S = \pi r^2 = 0.78m^2$ → P =956W/m^2×0.78m^2=745W.
	r =0.75m、 → $S = \pi r^2 = 1.77m^2$ → P =956W/m^2×1.77m^2=1689W.

Boiling time is 30 minutes for 2.2liter kettle of <10℃→100℃(781KJ)>.

T =781KJ/(745W−300W)×3600=0.5h.

[３]：Green House Effect Box without solar ray focusing。

In a temperature equibrium space, heat tend to be collected in larger heat capacity portion. This could be replaceable with heat beam focusing method for getting higher temperature T.



Gray part C is heating target, Inner yellow box(IB) has heat insulationg wall. Heat capacity of wall and space is $\delta C \ll C$, so also

$\delta C(T_M - T_0) \ll C(T_M - T_0) \fallingdotseq E_H$.

Note top surface of IB allow passing visible solar ray, while not for infrared one, which is called green house effect mesured by @.

In a thermal equibrium state, incoming and outgoing heat are balanced.

Conductive and covection heat flow loss are almost neglegible.

(1) $Q_s = P_s S_s = 956\mathrm{W/m^2} \times S_s$.

(2) $Q_s = Q_L = S_L @ \sigma T^4$. → (3) $T_M = [Q_s / S_L @ \sigma]^{1/4}$. <equilibrium max temperature>>

(4) $E_H = C_H (T_M - T_0)$.

{(5) $Q_L(T_0) = S_L @ \sigma T_0^4$; (6) $Q_L(T_M) = S_L @ \sigma T_M^4$}.

(7) $t_H \fallingdotseq E_H / (Q_s - \langle Q_L(T_0) + Q_L(T_M) \rangle / 2)$. <<coarse estimation>>

To gain higher temperature in (3), $S_L @$ should be smaller in SH design.

To gain short taking time t_H, Q_s should be larger.

Example-5)

inner blackbody box size＝0.46m×0.36m×0.18m; opening area $S_s = 0.46 \times 0.36 = 0.16\mathrm{m^2}$.

input heat amount $Q_s = 900\mathrm{W/m^2} \times 0.16\mathrm{m^2} = 150\mathrm{W}$. →80℃<observing 2011/2/3 in Japan>.

cooling radiation area $S_L = 2(0.46 \times 0.36) + 2(0.46 \times 0.18) + 2(0.18 \times 0.36) = 0.312\mathrm{m^2}$.

(1) covection heat flow into exterior air $Q_{LC} = S_L J = 0.312\mathrm{m^2} \times 7\mathrm{W/m^2K}$. <neglegible>

(2) radiation rate of material surface $@ \fallingdotseq 0.5$?.

Max cooling radiation amount $Q_s = Q_L = S_L @ \sigma T^4$. → $T \fallingdotseq 87$℃、observing＝80℃、

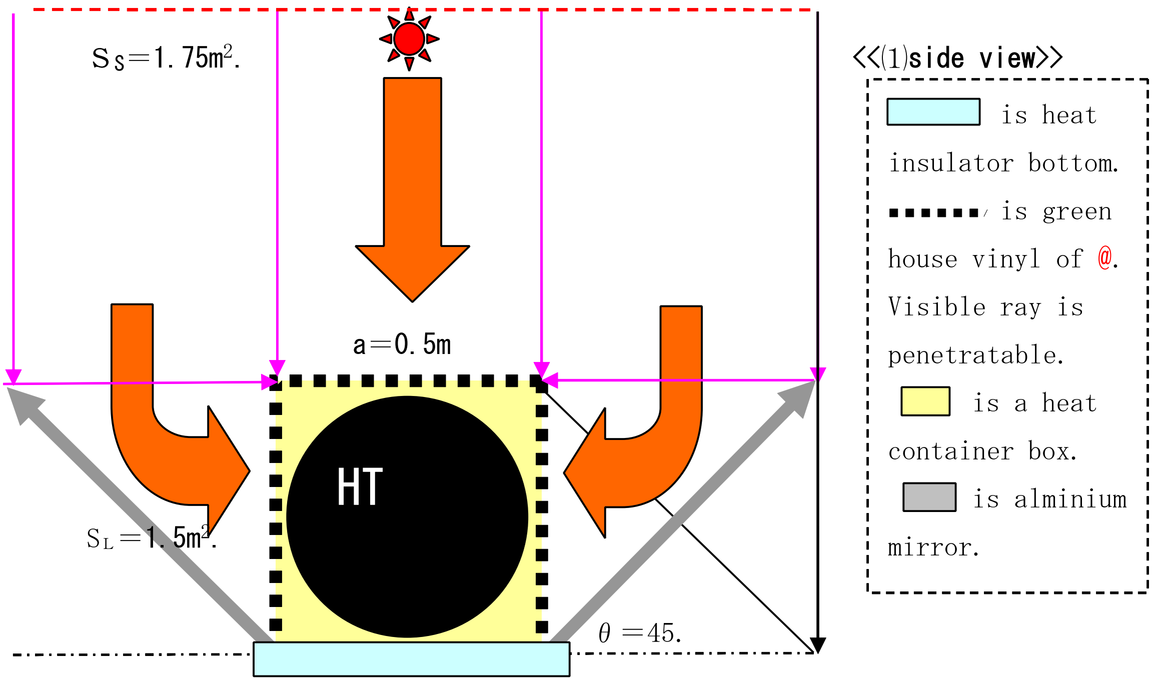
＊reference site on heat calculation.

http://www.hakko.co.jp/qa/qakit/html/s01050.htm

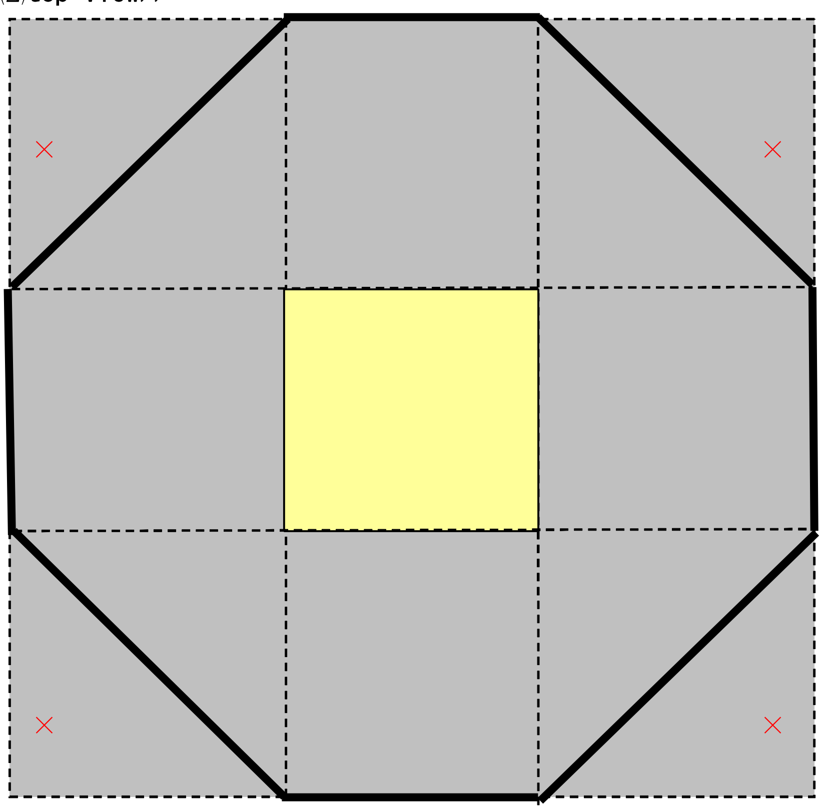
[4]: **Method of {pseudo parabola+green house≡PPGH}.** Opening area $S_S=1.75m^2$.

{$Q_S=956W/m^2\times0.25m^2\times7=1673W$; $S_L=1.5mm^2$; @=0.5}. → $T_M=[Q_s/S_L@\sigma]^{1/4}=170℃$

<u>{S_L,@} are green house material of vinyl, or glass(IR heat shutter)</u>. Heating target(HT=●) must be blackbody.



<<(2)top view>>



× triangle must be cutted off.

(3)The feature of PPGH:

PPGH is to take both merits of parabola antenna and green house box with easy fabrication by flat reflector panels.

$P_H = Q_S - Q_L = S_S P_S (956W/m^2) - S_L @\sigma T^4 = E_H/<t_H>$.
$Q_S = S_S P_S (956W/m^2)$. <solar heat input>.
$Q_L = S_L @\sigma T^4$. <dissipated heat loss>.
$t_H = E_H/<P_H>$. <heating up time=total heat amount/effective heat input/sec>.
$T_M = [Q_S/S_L @\sigma]^{1/4}$. <max temperature at heat input=heat loss>.

Parabola anntena (larger S_S, @=1)		Green house(smller S_S, @<1))	
merit	demerit	merit	demerit
higher temperature by beam collection	sensitive for solar direction	de-sensitive?? for solar direction,	lower power input, lower temperature
	smaller volume of heat target (cooking)	larger volume of heat target (cooking)	
	fabrication difficulty	easy fabrication?	green house box fabrication, etc

(4)Maximum green house equibrium temperature in $S_S = S_L$.

solar heat=$956W/m^2$	$=\sigma T^4 =$ ((@=1.0, max temp)	$=(273+87℃)^4$.
solar heat=$956W/m^2$	$=@\sigma T^4 =$ (@=0.8, max temp)	$=(273+108℃)^4$.
solar heat=$956W/m^2$	$=@\sigma T^4 =$ (@=0.7, max temp)	$=(273+121℃)^4$.
solar heat=$956W/m^2$	$=@\sigma T^4 =$ (@=0.6, max temp)	$=(273+136℃)^4$.
solar heat=$956W/m^2$	$=@\sigma T^4 =$ (@=0.5, max temp)	$=(273+156℃)^4$.
solar heat=$956W/m^2$	$=@\sigma T^4 =$ (@=0.4, max temp)	$=(273+180℃)^4$.

(5)variety of SH in the world.

http://www.google.com/images?hl=en&sugexp=ldymls&xhr=t&q=solar+cooker&cp=9&rlz=1R2GZAZ_jaJP409&wrapid=tljp1296792789015014&um=1&ie=UTF-8&source=univ&ei=5HxLTd_3IsiHcc6z1NUL&sa=X&oi=image_result_group&ct=title&resnum=2&sqi=2&ved=0CEUQsAQwAQ&biw=955&bih=794

postscript:

Note author had not used and made SH before, so he wish to try it from just now. It's terrible mistake not having the experience. 80% CO2 reduction is possible !.