Pergamon

PII: S0360-5442(97)00054-6

Energy Vol. 23, No. 1, pp. 11–16, 1998

Printed in Great Britain
0360-5442/98 $19.00 + 0.00

THE INFLUENCE OF COLLECTOR ASPECT RATIO ON THE COLLECTOR EFFICIENCY OF BAFFLED SOLAR AIR HEATERS

HO-MING YEH, CHII-DONG HO and CHI-YEN LIN
Department of Chemical Engineering, Tamkang University, Tamsui, Taipei 251, Taiwan

(Received 18 March 1997)

Abstract—The effect of collector aspect ratio on the collector efficiency of baffled solar air heaters has been investigated theoretically. With constant collector area, the collector efficiency increases when the collector aspect ratio increases. This is the same results as those obtained in the previous work for flat-plate solar air heaters without fins and baffles. Although the collector efficiency of baffled solar air heaters is larger than that of flat-plate heaters without fins and baffles, the improvement of collector efficiency by increasing the collector aspect ratio is reverse. © 1997 Elsevier Science Ltd.

1. INTRODUCTION

In its simplest form, a flat-plate solar-energy heater consists of a sheet of glass or transparent material situated above a flat plate so constructed that it acts as a blackbody to absorb heat. The sun's rays pass through the glass and are trapped in the space between the cover and plate or absorbed by the black body. The heat may then be utilized by passing a fluid through a conduit system located between the bottom and absorbing plates, the heated fluid subsequently being used to heat a home, water supply, or swimming pool.

The main applications of solar air heaters are space heating and drying. The solar air heater occupies an important place among solar heating systems because of minimal use of materials. Furthermore, direct use of air as the working substance reduces the number of components required in the system. The primary disadvantage of solar air heaters is the need for handling relatively large volumes of air with low thermal capacity as working fluid.

Our design of a solar air heater has an extended heat-transfer area [1], an arrangement for producing free convection [2,3], creation of air turbulence past the heating surface [4], and inclusion of important forced convection. Considerable improvement in the collector efficiency of a flat-plate solar air heaters is obtainable if the collectors are constructed with fins, and the improvement will be extended if the fins in the collectors have been attached by baffles to create air turbulence and an extended heat-transfer area [5,6].

It is well known that the collector configuration will influence the fluid velocity, as well as the strength of forced convection. A simple procedure for changing the fluid velocity and also the strength of forced convection involves adjusting the aspect ratio of a rectangular flat-plate collector with constant flow rate [7]. It is our purpose in the present studies to investigate theoretically the effect of aspect ratio on the collector efficiency of baffled solar air heaters for constant collector area and constant flow rate.

2. COLLECTOR EFFICIENCY

Although there are many different designs of flat-plate collectors available, the generalized representation of efficiency for all solar energy collectors is [8–11]

$$\eta = Q_u/A_c I_0 = F_R[\alpha_P \tau_g - U_L(T_{f,i} - T_a)/I_0], \tag{1}$$

in which the heat-removal factor is defined as

$$F_R = (mC_P/A_cU_L\{1 - \exp[-(U_LF'A_c/mC_p)]\}, \quad (2)$$

while the collector-efficiency factor for the baffled flat-plate solar energy collectors shown in Figs. 1. and 2 is [6,12]

$$F' = \{1 + U_L/\{h_1\phi + [(1/h_2) + (1/h_r)]^{-1}\}\}^{-1} \quad (3)$$

in which the dimensionless quantity ϕ is defined as

$$\phi = 1 + (A_f/A_c)\eta_f + (A_b/A_c)\eta_b, \quad (4)$$

where the baffle efficiency may be estimated with Chou's empirical equation [6,13]

$$\eta_b = 26.361(w/D_{e,b})^{-0.454}(L/\ell)^{-0.634}. \quad (5)$$

Note that $\phi = 1$ when there are neither fins nor baffles on the absorbing plate; $\phi = 1 + (A_f/A_c)\eta_f$ when fins are provided; $\phi = 1 + (A_f/A_c)\eta_f + (A_b/A_c)\eta_b$, when fins with baffles are attached on the absorbing plate.

3. THE EFFECT OF ASPECT RATIO ON COLLECTOR EFFICIENCY

As mentioned earlier, the collector configuration can influence the fluid velocity as well as the strength of forced convection. The simplest method for changing the fluid velocity and also the strength of forced convection involves adjusting the aspect ratio of a rectangular flat-plate collector of fixed collector area with constant flow rate. Here, we will investigate the effect of aspect ratio on the collector efficiency of rectangular flat-plate collectors with or without fins and baffles.

The effect of aspect ratio on the collector efficiency will be illustrated numerically. We assign numerical values for collector geometries, system properties and operating conditions as follows: $A_c = BL = 0.54\ m^2$; L = 1.8, 0.9, 0.6 and 0.3 m; B = 0.3, 0.6, 0.9 and 1.8 m; L/B = 6/1, 3/2, 2/3 and 1/6; H = 5.5 cm; w = 1, 2 and 3 cm; w_1 = 6 cm; w_2 = 5.5 cm; ℓ = 8, 16 and 24 cm; t = 0.1 cm; τ_g = 0.875;

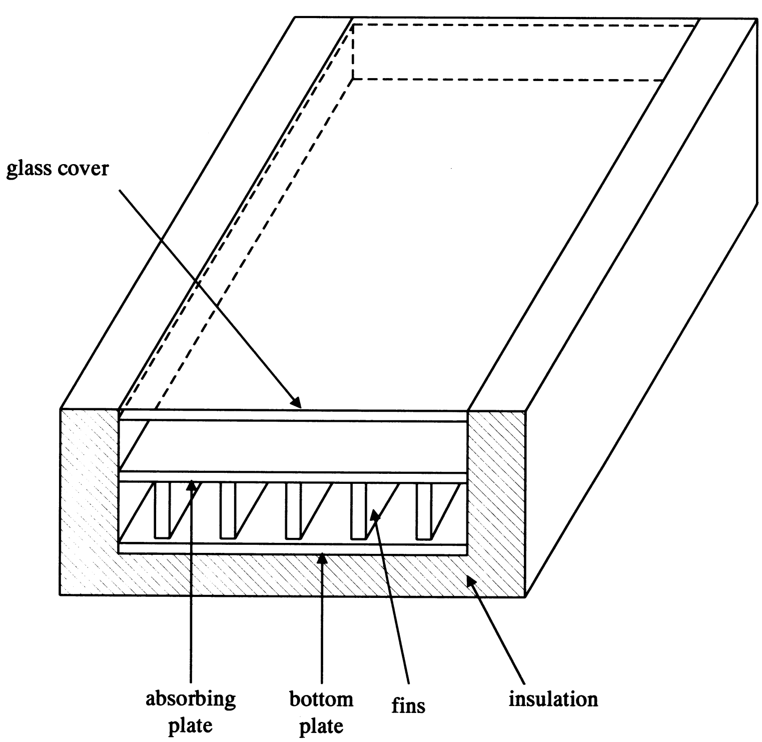

Fig. 1. Solar air heater with fins.

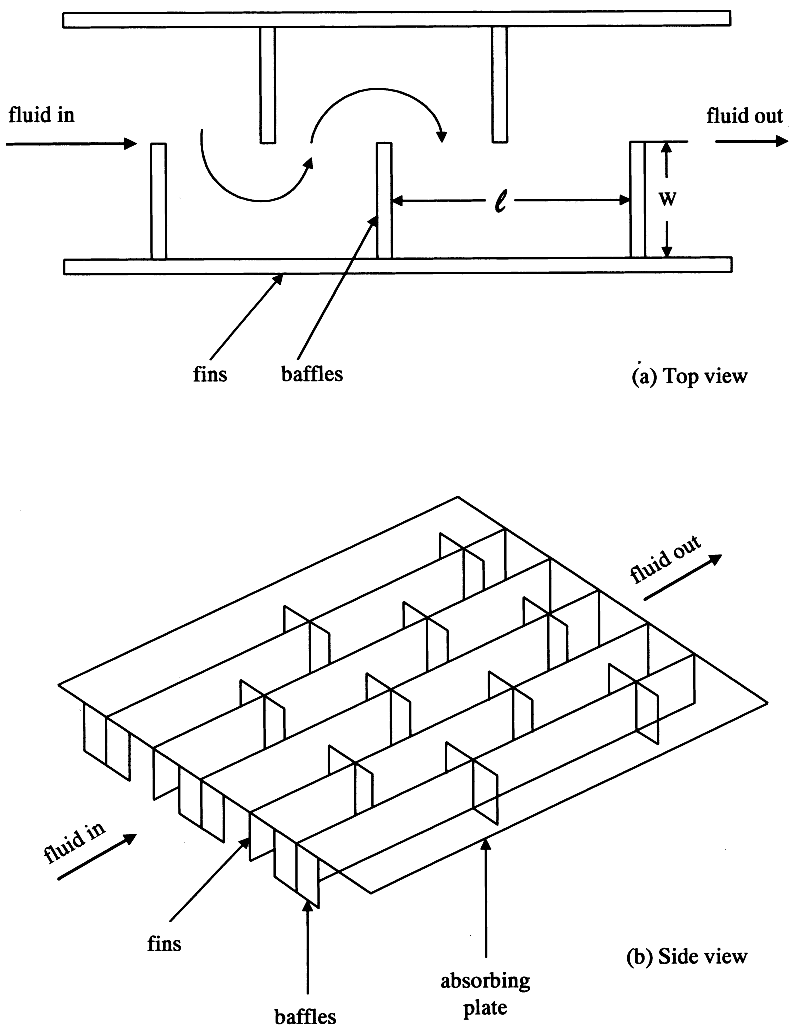

Fig. 2. Fins with attached baffles.

$\alpha_p = \epsilon_p = 0.95$; $\epsilon_R = 0.94$; $\epsilon_g = 0.94$; $U_b = k_s/\ell_s \approx 0$; $I_0 = 830$ and $1100\ \mathrm{W/m^2}$; $T_a = 30°C$; $T_{f,i} = 30°C$; $V = 1.0$ m/s.

The method for the theoretical prediction of the collector efficiencies as well as the heat-transfer coefficients was described in a previous paper [7] while the physical properties of air are listed in Table 1. By substituting the specified values into the four appropriate equations, theoretical predictions were obtained. The results are plotted in Figs. 3–7.

4. DISCUSSIONS AND CONCLUSION

We find from Figs. 3–5, as well as Figs. 6 and 7, that with constant collector area A_c, the collector efficiency increases when the collector aspect ratio increases. This result is obtained because increasing

Table 1. Physical properties of air at 1 atm [12].

T (°C)	ρ (kg/m^3)	C_p (KJ/kg-K)	k (w/m-K)	$\mu \times 10^5$ (kg/m-s)
0	1.292	1006	0.0242	1.72
20	1.204	1006	0.0257	1.81
40	1.127	1007	0.0272	1.90
60	1.059	1008	0.0287	1.99
80	0.999	1010	0.0302	2.09

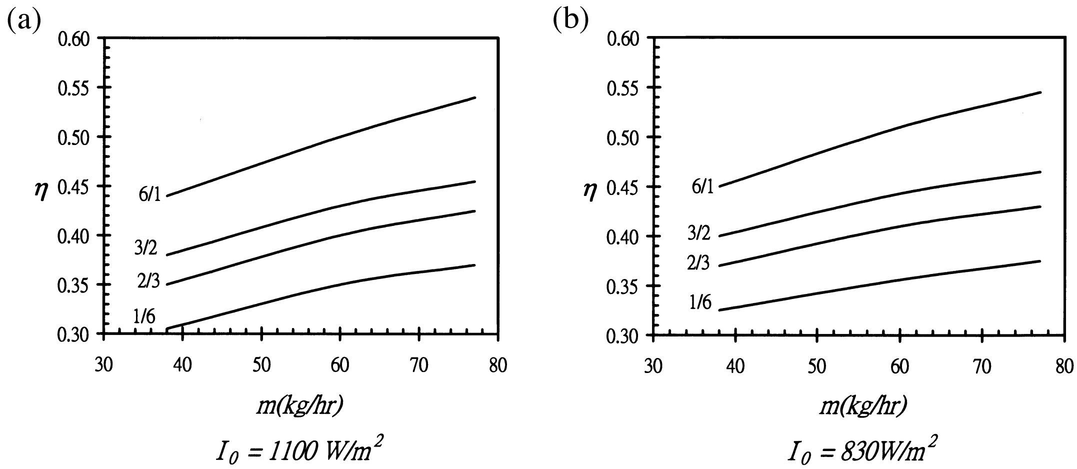

Fig. 3. Effect of collector aspect ratio on collector efficiency in flat-plate solar air heaters.

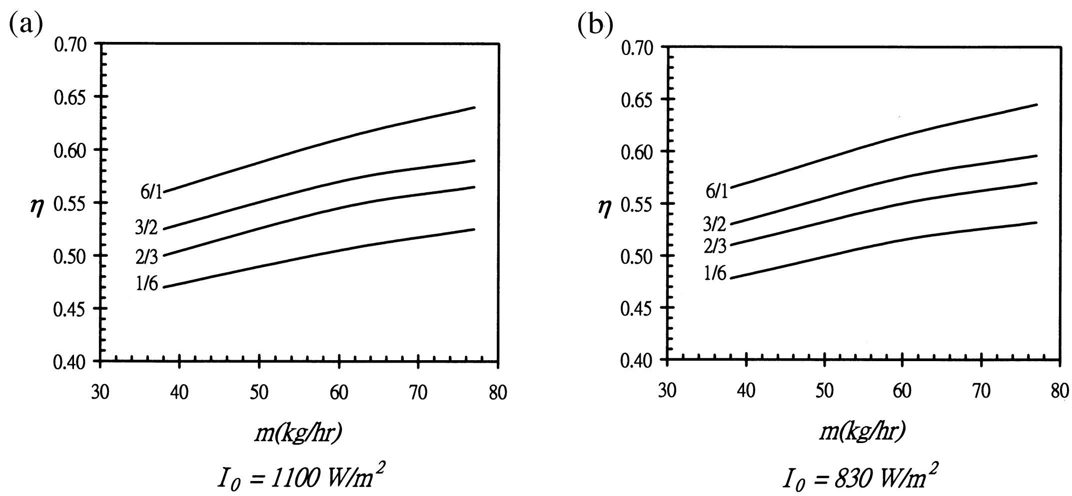

Fig. 4. Effect of collector aspect ratio on collector efficiency in flat-plate solar air heaters with fins.

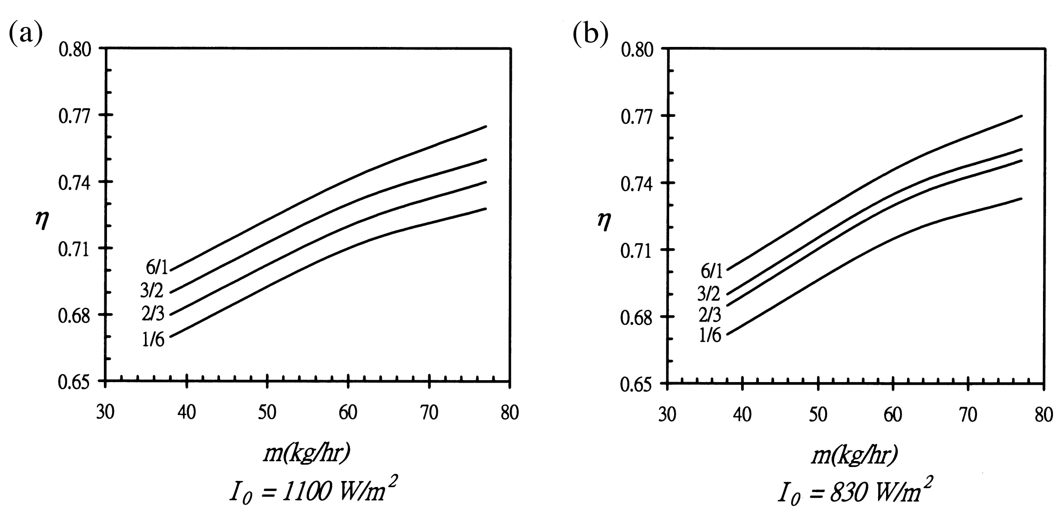

Fig. 5. Effect of collector aspect ratio on collector efficiency in flat-plate solar air heaters with fins attached by baffles.

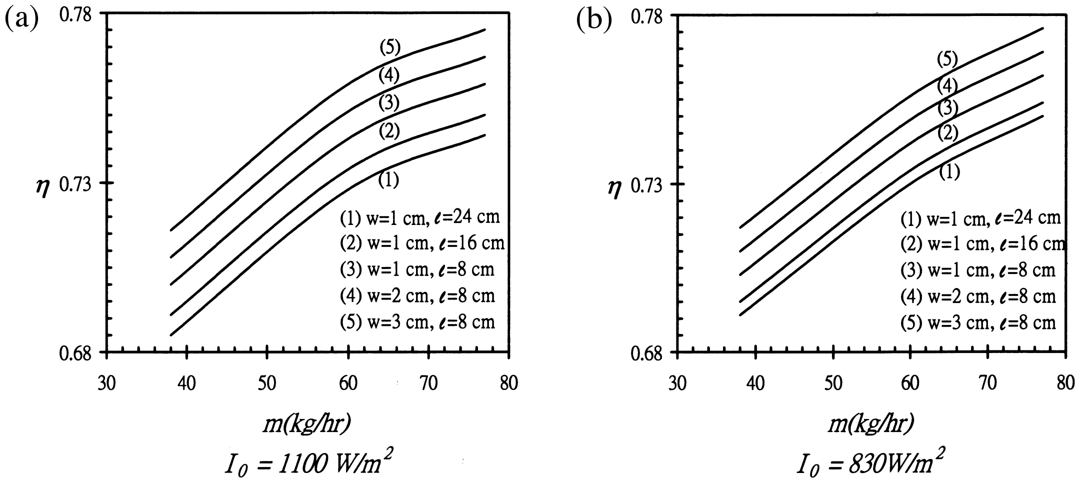

Fig. 6. Effect of baffle density on collector efficiency in baffled solar air heaters of collector aspect ratio 6/1.

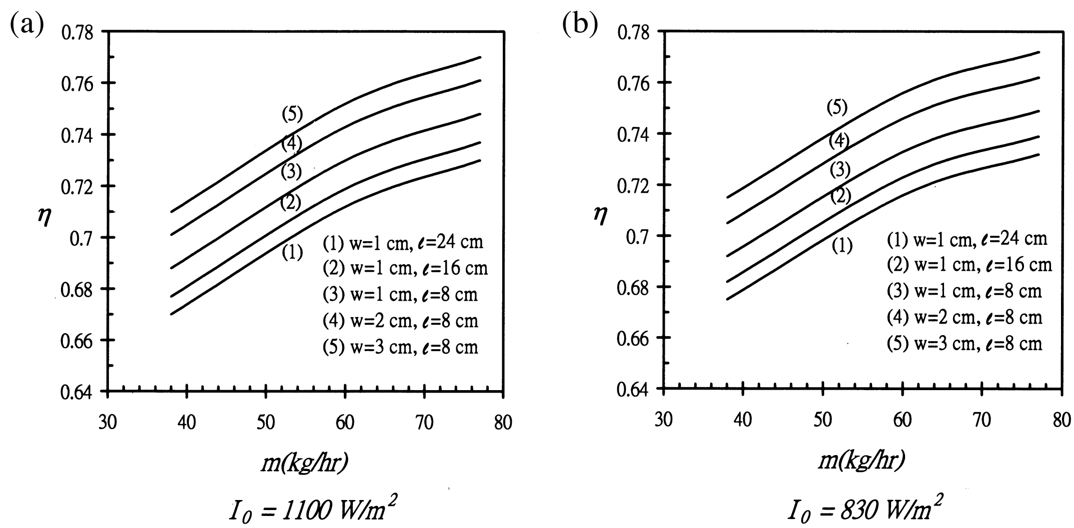

Fig. 7. Effect of baffle density on collector efficiency in baffled solar air heaters of collector aspect ratio 3/2.

the aspect ratio decreases the cross-sectional area of the air duct and thus increases the velocity of air flow and also the convective heat-transfer rate from the surface of the absorbing plate to the flowing air. It is also seen from Figs. 3–5 that the order of collector efficiencies for flat-plate collectors is [5,6] the following: collectors with fins and baffles > collectors with fins > collectors without fins and baffles. By contrast, the changes in efficiency for increasing collector aspect ratios are in the reverse order. Furthermore, the collector efficiency changes greatly with the aspect ratios for collectors without fins and baffles but changes very little for collectors with fins attached by baffles.

Figures 6 and 7 show the effects of baffles on the collector efficiencies of flat-plate collectors with fins. Considerable improvement is obtained for the collector efficiency of solar air heaters with baffles attached to the fins. Furthermore, increasing the density of the baffles, i.e. either increasing $W/D_{e,b}$ or decreasing ℓ/L, also increases the collector efficiency. The same results were obtained experimentally in previous work [5].

It is concluded that either increasing the collector aspect ratio or providing fins attached with baffles on the collector, will improve the collector efficiency, However, increasing the collector aspect ratio or constructing the collector with fins and baffles not only increases the fixed charge but also increases the fan power and thereby leads to increased operating cost. Consequently, proper increase of the collector aspect ratio and proper installation of fins and baffles should be economically feasible in the design of a solar air heater.

REFERENCES

1. Seluck, M. K., *Solar Air Heaters and Their Applications*, ed. A. A. M. Sayigh. Academic Press, New York, 1977, pp. 155–182.
2. Kreith, F. and Kreider. J. R., *Principles of Solar Engineering*, Vol. 4. McGraw-Hill, New York, 1978, pp. 203–309.
3. Yeh, H. M. and Ting, Y. C., *Appl. Energy*, 1985, **22**, 145.
4. Yeh, H. M. and Ting, Y. C., *Energy—The International Journal*, 1988, **13**, 543.
5. Yeh, H. M. and Chou, W. H., *Energy—The International Journal*, 1991, **16**, 983.
6. Yeh, H. M., *Energy—The International Journal*, 1992, **17**, 697.
7. Yeh, H. M. and Lin, T. T., *Energy—The International Journal*, 1995, **20**, 1041.
8. Whillier, A., Solar energy collection and its utilization for house heating. ScD Thesis, MIT, MA, 1953.
9. Hottel, H. C. and Whillier, A., *Transaction of the Conference on the Use of Solar Energy*. University of Arizona Press, AZ, 1958, Vol. 2, Part 1, p. 74.
10. Whillier. A., *Applications of Solar Energy for Heating and Cooling of Buildings*. ASHRAE, New York, 1977.
11. Bliss, R. W., *Solar Energy*, 1959, **3**(4), 55.
12. Duffle, J. A. and Beckman, W. A., *Solar Engineering of Thermal Processes*, 3rd ed. Wiley, New York, 1977, pp. 223, 238, 245 and 705.
13. Chou, W. R., A study on collector efficiency of baffled solar air heaters. M. S. Thesis, Department of Chemical Engineering, Cheng Kung University, Tainan, Taiwan, 1987,

NOMENCLATURE

A_b = Total surface area of baffles (m^2)
A_c = Surface area of the collector, LB (m^2)
A_f = Total surface area of fins (m^2)
B = Collector width (m)
C_p = Specific heat of air at constant pressure (kJ-kg^{-1}-K^{-1})
D_e = Equivalent diameter of the conduit without fins, $2H/(1 + H/L)$ (m)
$D_{e,f}$ = Equivalent diameter of the conduit with fins, $2H/(1 + H/w_1)$ (m)
F' = Efficiency factor of the solar air heater
F_R = Heat-removal factor for the solar air heater
H = Height of the air tunnel in the solar collector (m)
h, h_1, h_2 = Convective heat coefficient for fluid flowing over a flat plate (kJ-h^{-1}-m^{-2})
h_r = Radiant heat-transfer coefficient between two parallel plates (kJ-h^{-1}-m^{-2}-K)
I_0 = Incident solar radiation (kJ-m^{-2}-h^{-1})
k, k_s = Thermal conductivity of air, insulator (kH-h^{-1}-m^{-2}-K)
L = Collector length (m)
ℓ = Distance between two baffles on a fin (m)
ℓ_s = Thickness of the insulator (m)
m = Mass-flow rate of air (kg-h^{-1})
n = Number of fins on an absorbing plate, B/w_1
Q_u = Useful gain of energy carried away by air per unit time (kJ-h^{-1})
T_a = Ambient temperature (K)
$T_{f,i}$ = T_f at the inlet and outlet of the solar air heater (K)
t = Thickness of the fin (m)
U_b = Loss coefficient from the surface of edges and the bottom of the solar collector to the ambient (kJ-h^{-1}-m^{-2}-K)
U_L = Overall loss coefficient (kJ-h^{-1}-m^{-2}-K)
V = Wind velocity (m-h^{-1})
w = Width of the baffles (m)
w_1 = Distance between fins (m)
w_2 = Height of the fins (m)
α_p = Absorptivity of the absorbing plate
η = Collector efficiency
η_b = Baffle efficiency
η_f = Fin efficiency
ϕ = Dimensionless quantity defined by Eq. (4)
τ_g = Transmittance of the glass cover
ϵ_g, ϵ_p, ϵ_R = Emissivity of the glass cover, absorbing plate, bottom plate
ρ = Air density (kg-m^{-3})
μ = Air viscosity (kJ-m^{-1}-h^{-1})
σ = Stefan–Boltzmann constant = 2.04 $\times 10^{-7}$ KJ-h^{-1}-m^{-2}-K^{-4}