مجلة العلوم البحثة والتطبيقية
Journal of Pure & Applied Sciences
www.Suj.sebhau.edu.ly ISSN 2521-9200
Received 13/11/2017 Revised 01/02/2018 Published online 30/06/2018

Performance of flat Plate Solar Collector for Water Heating at Sebha Weather Conditions

*Mohamed I. Alowa[a], Hamed A. Said[b], and Zakareia A. Alarabi[c]
[a] Faculty of Energy and Mining Engineering, Sebha University, Libya
[b]Faculty of Sciences and Technology, Sebha University, Libya
[c]Higher Institute of Sciences& Technology, Bent Baya, Libya
*Corresponding author: moh.alowa@sebhau.edu.ly

Abstract In this paper the performance of a flat plat solar collector for water heating is analyzed under the weather condition of Sebha in the south of Libya. The effect of collector components properties including cover type, absorber plate type, and the tilt angle are predicted. Two days of 21 January and 21 July at a clock of 13 were selected the analyzing. The working fluid is water and its circulation is by thermosyphone. By applying the control equations through a matlab computer program the results show that for the three types of collector's covers, glass, polycarbonate, and polytetrafluoroethylene , the last one gave the best efficiency. For collector with the absorber plates of copper black have the higher efficiency than that of the copper and iron absorber plates. The collector tilt angle selected was 27º for the required flow rate.

Keywords: Flat Plate, Solar, Collector, Water Heating.

أداء المجمع الشمسي المستوي لتسخين الماء عند ظروف مناخ مدينة سبها

*محمد إبراهيم علوه[1] و حامد عبد الحق السعيد[2] و زكريا أبو القاسم العربي[3]
[1]كلية هندسة الطاقة و التعدين- جامعة سبها، ليبيا
[2]كلية العلوم- التقنية جامعة سبها، ليبيا
[3]المعهد العالي للعلوم و التقنية بنت بيه، ليبيا
*للمراسلة: moh.alowa@sebhau.edu.ly

الملخص في هذه الورقة تم تحليل أداء المجمع الشمسي المستوي لتسخين الماء تحت ظروف مدينة سبها بالجنوب الليبي. كل من أنواع الأغطية و الأسطح الماصة كذلك زاوية ميلان المجمع تمت دراستها. و قد اختير يوم 21 من شهري يناير و يوليو عند الساعة الواحدة بعد الظهر وقتا للدراسة. ومائع التشغيل هو الماء بدوران طبيعي. أنشاء برنامج حاسوب بلغة mat lab لحل المعادلات الحاكمة لعملية أداء المجمع الشمسي المستوي لتسخين الماء. وضحت النتائج أن من بين الأغطية الثلاثة الزجاج، و البولي كربونات و البولي تترا فلوري اثلين كان الأخير هو الذي أعطى أعلى كفاءة للمجمع. ومن حيث السطح الماص للمجمع كان النحاس المطلي بالأسود أفضل كفاءة من سطح النحاس غير المطلي ومن سطح الحديد. وقد كانت زاوية الميلان 27 oهي الزاوية المناسبة للحصول على معدل سريان طبيعي أفضل و بالتالي أفضل أداء.

الكلمات الافتتاحية: المجمع الشمسي المستوي، تسخين الماء.

Introduction

The energy from solar for thermal applications is widely used now a day and these applications are ranging from a simple domestic solar water heating to sophisticated solar plant for power generation [1]. The thermal solar systems are essentially have a solar collector where the solar radiation converted to heat, the flat plate solar collector is one of the simplest collector type and mainly consists of transparent cover, absorber plate, transport pipes insulation material, and these components are assembled into the collector box [2]. Therewith the thermal solar systems performance depend on the solar collector design, therefore a lot of studies for decades focused on the developing of the collector [3]. The studies were carried out theoretically by using modelling technique [4], and experimental work [5]. The collector cover is a component that allow the radiation to pass from which has an effect factor on the collector performance the cover thermal and refractive index studied [6] where the study clarify that the combination of optimum number (two) and lower refractive index result improved useful heat. The solar radiation is absorbed by the absorber plate and its properties directly share of radiation conversion to heat, the different selective surface coatings were investigated to conclude their effect on the performance characteristics of the collector [7]. The collector receives radiation and the radiation incident angle has to be the best which require an optimum collector tilt angle, for collect maximum radiation amount [8], [9].

Flat Plate Collector Control Equations:

1. Revere to figure (1) the loss heat coefficient from the top of collector plate to the ambient for a single glass cover is.

$$U_{top} = \left(\frac{1}{\frac{C}{T_{pm}}\left[\frac{(T_{pm}-T_a)}{(1-f)}\right]^e} + \frac{1}{h_w} \right)^{-1} + \frac{\sigma(T_{pm}+T_a)(T_{pm}^2+T_a^2)}{\frac{1}{\varepsilon_p+0.00591h_w}+\frac{2+f-1+0.133\varepsilon_p}{\varepsilon_g}-1} \qquad (1)$$

where N= number of glass covers
f= (1 + 0.089h_w − 0.1166$h_w\varepsilon_p$)(1 + 0.07866N)
C= 520(1 − 0.000051β^2) for 0◦ < β < 70◦; for 70◦ < β < 90◦ , use β = 70◦
e= 0.430(1 − 100/T_{pm})
T_a=(28.455863-2.3566852t+0.3687955t^2-0.01127815*t^3)

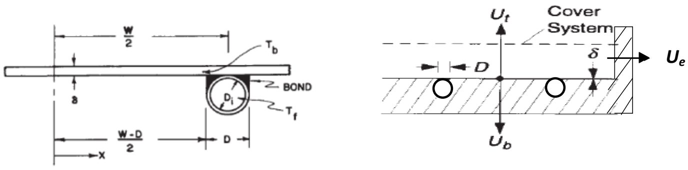


Fig. 1: Flat Plate Solar Collector Dimensions

2. The heat coefficient loss from the collector bottom is due to conduction through the insulation is :-

$$U_b = \frac{k}{L} \qquad (2)$$

3. The heat coefficient loss from the edge of the collector heat due to the conduction from the edge of the collector through the insulation material is.

$$U_e = \frac{(UA)_{edge}}{A_c} \qquad (3)$$

4. The Collector Overall Heat Loss Coefficient is sum of all the losses:

$$U_L=U_t+U_b+U_e \qquad (4)$$

5. The useful energy gain
The useful energy gain is the absorbed energy minus the rate heat loss of the collector to its surrounding.

$$Q_u = A_c\,[S - U_L\,(T_{pm} - T_a)] \qquad (5)$$

6. The flat plate solar collector instantaneous efficiency can be evaluated by an energy that determines the portion of the incoming radiation delivered as useful energy to the working fluids for flat plate collector.

$$\text{ç} = \frac{Q_u}{I_T A_c} \qquad (6)$$

7. The ratio of total radiation in an hour to total radiation in a day.

The ratio of hours are designated by the time for the midpoint of the hour, and days are assumed to be symmetrical about solar noon.

$$r_T = \frac{\pi}{24}(a + b\cos \text{ù})\,\frac{\cos \text{ù} - \cos \text{ù}_s}{\sin \text{ù}_s - \frac{\pi \text{ù}_s}{180}\cos \text{ù}_s} \qquad (7)$$

$\omega = (t - 12) \times 15$

$\omega_s = \cos^{-1}(-\tan\varphi.\tan\delta)$

The coefficients a and b are given by

a = 0.409 + 0.5016 sin(ω_s− 60)

b = 0.6609 − 0.4767 sin(ω_s− 60)

$$I_{hor} = H_{hor} \times r_t \qquad (8)$$

Where :-

$$H_{hor} = H_b + H_d \qquad (9)$$

$$r_d = \frac{\text{ð}}{24}\,\frac{\cos \text{ù} - \cos \text{ù}_s}{\sin \text{ù}_s - \frac{\text{ðù}_s}{180}\cos \text{ù}_s} \qquad (10)$$

$$I_d = H_d \times r_d \qquad (11)$$

$$I_b = I_{hor} - I_d \qquad (12)$$

8. Transmittance
the average transmittance of the component of the reflected radiation parallel to the surface and component of the reflected radiation perpendicular to the surface.

$$\text{ô}_r = \frac{1}{2}\left(\frac{1-r_\parallel}{1+r_\parallel} + \frac{1-r_\perp}{1+r_\perp}\right) \qquad (13)$$

9. Hourly irradiation
The total irradiation for each hour of the average day of each month is then calculated as:-

$$I_T = (I_b + I_d A_i)R_b + I_d(1 + A_i)\left(\frac{1+\cos \text{â}}{2}\right)\left(1 + f\sin^3\left(\frac{\text{â}}{2}\right)\right) + (I_b + I_d)\text{ñ}_g\left(\frac{1-\cos \text{â}}{2}\right) \qquad (14)$$

where :-

$$R_b = \frac{\cos(\text{ö}-\text{â})\cos \text{ä}\cos \text{ù} + \sin(\text{ö}-\text{â})\sin \text{ä}}{\cos \text{ö}\cos \text{ä}\cos \text{ù} + \sin \text{ö}\sin \text{ä}}$$

10. absorbed solar radiation
absorbed solar radiation can be as defined an average transmittance-absorptance product multiply by the total solar radiation**.**

$$S = (I_b + I_d A_i)R_b(\text{ôá})_b + I_d(1 + A_i)(\text{ôá})_d\left(\frac{1+\cos \text{â}}{2}\right)\left(1 + f\sin^3\left(\frac{\text{â}}{2}\right)\right) + (I_b + I_d)(\text{ôá})_g\left(\frac{1-\cos \text{â}}{2}\right) \qquad (15)$$

Flat-Plate Solar Collector Calculations

The flat plate solar collector equations that described above are solved by the MATLAB program to calculate the characteristics of the collector, and the running conditions are as follows:-

- Calculations are for Sebha city in Libya Latitude 27.02° N.
- Calculations of the ambient temperature and solar hourly radiation for 21 January and 21 July at 13 clock.

- The solar collector tilted angle are selected of 22°, 27°, 32°.
- The absorber plates are copper black paint, iron, copper.
- The collector cover are taken of commercial glass, polycarbonate and polytetrafluroethylene.
- The calculations are done for the different above conditions and, the first characteristics results are taken to get the best collector performance.

Results and Discussion

By using the constructed MATLAB program, the results according to the input data (collector specifications, are received to test the characteristics of flat plate solar collector and the factors that effect on it. If the collector is operated at Sebha city 27.02^{o} .N latitude January 21 and July 21 at 13 clock.

The specifications of the flat plate solar collector are listed in Table (1).

Table 1: Flat Plate Solar Collector Specifications

len× Wid× D_i×D_o×W	1.75×0.84×0.08 m 0.019×0.02×0.15	ε	n	
Cover Material	Polytetrafluoro-ethelene	0.77	1.37	
	Glass	0.8	1.5	
	Polycarbonate	0.8	1.6	
			α	K(w/(m.
Absorber Plate Material	Copper Black Paint	0.97	0.97	385
	Copper	0.8	0.6	385
	Iron	0.6	0.9	80
Insulation	Fiber Glass			0.045
Bond	Welding Material			300
Collector tilt angels	22° 27° 32°			

The variations of the total solar radiation and the ambient temperature for Sebha at 21 Jan and 21 July are shown in fig. (2) and fig. (3) respectively.

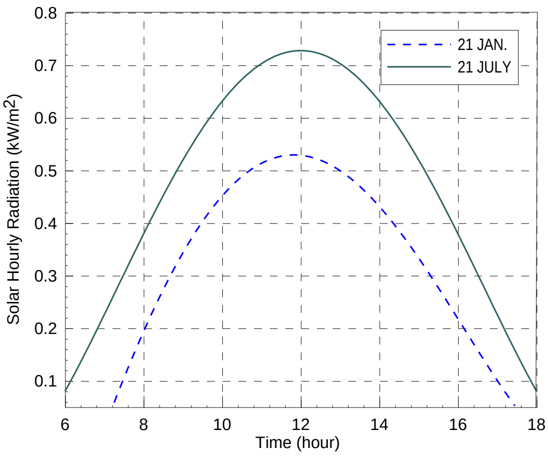


Fig. 2: Solar hourly radiation vs time for Sebha city for 21 Jan and 21 July

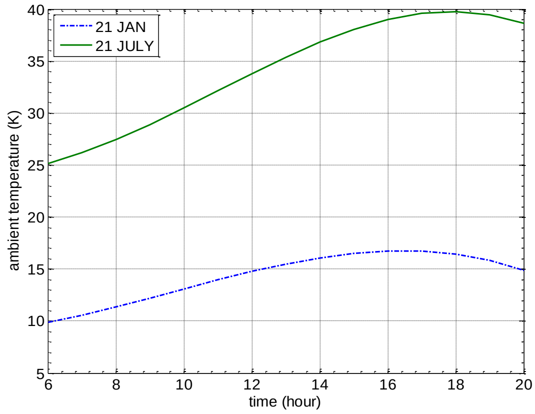
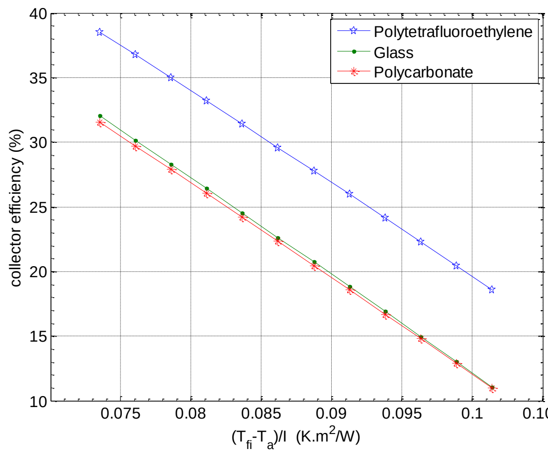


Fig. 3: Ambient temperature vs Time for 21 Jan and 21 July

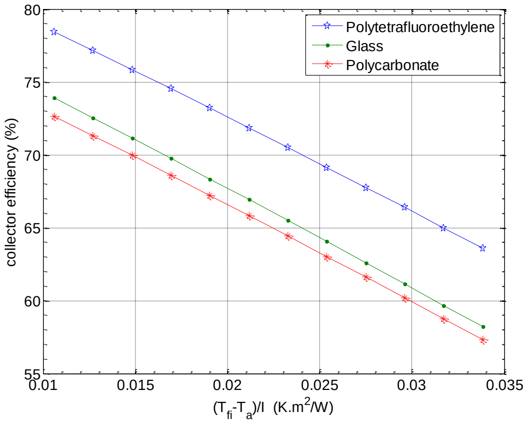
The performance of the solar collector depends on the weather data of the collector location at the earth, the collector components materials and design, and operating conditions. There are some parameters that give a measure of the flat plate solar collectors performance. The way of fixing absorber plate onto the collector pipes effects on the heat transferring from this plate to the fluid inside the pipes and this heat transferring depends on the plate material conductivity and the distance between the pipes.

Effect of cover type on the collector efficiency:

Observing fig. (4) reveals that the collector with polytetrafluroethylene cover has the higher efficiency than that with Glass and the polycarbonate covers. that is because polytetrafluroethylene has the lower refraction index. Also it can be deduced that as the temperature difference between the fluid (water) inlet to the collector and the ambient temperature reduced the collector efficiency increased. In other hand as the solar radiation increased the efficiency of the collector increased.



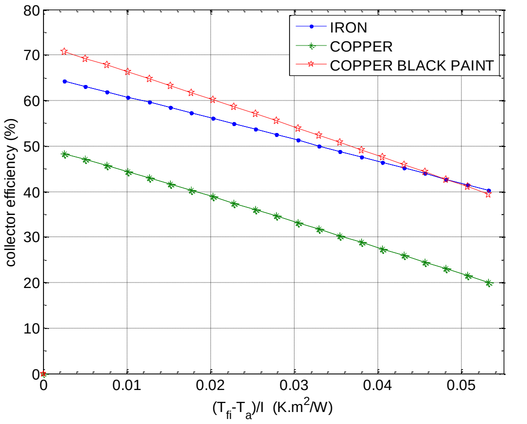
(a)



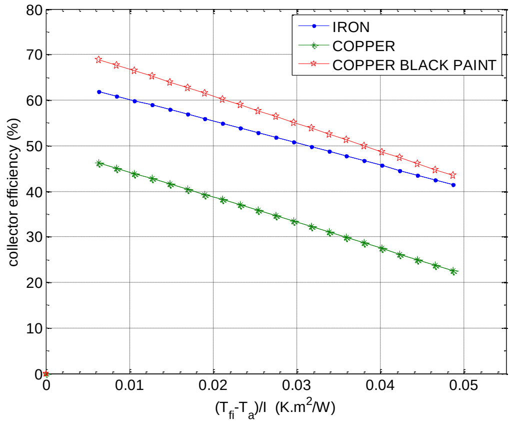
(b)

Fig. 4: Collector efficiency vs $T_{fi} - T_a/I$ at 13:00 pm for different cover, β = 27 °, copper black paint plate and different T_{fi}, at (a) 21 Jan. and (b) 21 July

Effect of absorber plate type:
The absorber plate is the part where the solar radiation is absorbed and converted to a heat and transfers it to the collector fluid. From fig. (5) it's noticeable that beside the difference between the inlet fluid and ambient temperature the type of the plate has an important effect on the collector efficiency. Which exposed in fig. (5) where the copper black paint absorber plate gives the highest efficiency comparing to the iron and copper. That is because the copper black paint absorber has the higher absorbtance, conductance and lower emittance, further more the absorber plate conductance is a partnership in the efficiency of the collector.



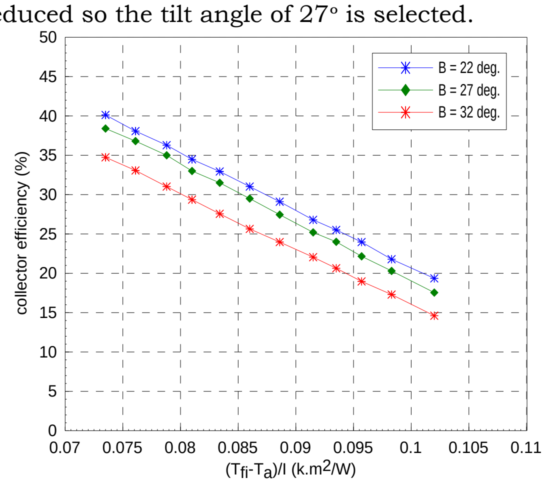
(a)



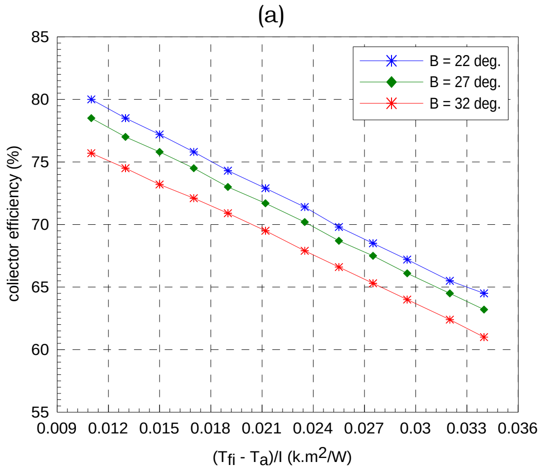
(b)

Fig. 5: Collector efficiency vs $T_{fi} - T_a/I$ at 13:00 pm for different absorbed plat, β = 27 °, for Glass cover and different T_{fi}, at (a) 21 Jan. and (b) 21 July

Effect of the collector tilt angle: The collector is facing the equator and tilt angle is measured from horizontal (ground level) to the sun. The collector tilt angle effects of the efficiency of the collector that can be concluded from fig (6), where the best efficiency is at the tilt angle of 22° and the efficiency is increased by reducing the tilt angle due to the time of this data is at clock 13 that means the radiation is approach to be normal to the collector. But since the water flow through the collector is a natural circulation (thermosyphon) which means, as the tilt angle decreasing the flow rate is going to reduced so the tilt angle of 27° is selected.



(a)



(b)

Fig. 6: Collector efficiency vs $T_{fi} - T_a/I$ at 13:00 pm for different collector tilt angles, polytetrafluoroethylene cover, copper black paint plate, at (a) 21 Jan. and (b) 21 July

Effect of the day of year: From the above results the collector with the polytetrafluoroethylene cover , the copper black paint and the tilt angle of 27° has the better efficiency. for such collector the effect of the day of year is obviously clarified through figures 3,4,5 and 6. Where the better values are at 21July than that at 21 January. Furthermore Figure (7) shows the efficiency difference between these two days and that is because both of solar radiation and ambient temperature are higher in 21 July.

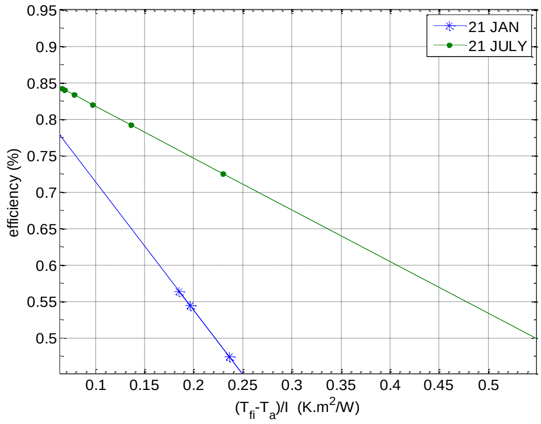


Fig. 7 Collector efficiency vs $T_{fi} - T_a/I$ at β = 27° , polytetrafluoroethylene cover, copper black paint plate

Conclusions:

The flat plate solar collector have been investigated, with regard to factors that effect on the collector performance. This investigation is applied under operation of the collector for water heating purpose at a Sebha weather data and climate, on the days of 21Januury and 21 July at 13 a clock point of time. By construct a MATLAB program for flat plate solar collector depending on the design equations the results show that the factors effect on the collector efficiency are the solar collector components materials and, the design conditions. From this study, we can conclude:-

- The glazing material (collector cover) effects on the collector efficiency, by which the highest efficiency is got for the one that has a higher transmittance and lower reflectance. In this study a polytetrafluoroethylene cover gave a better efficiency over glass and polycarbonate covers.
- The highest efficiency due to effect of the collector absorber plate was concluded, for that the plate of copper black paint is the best one among of the iron and copper plates, because the copper black paint has the higher radiation absorbtance thermal conductance.
- The collector tilt angle, also effects the collector efficiency. Angle 27° is selected as the better collector efficiency concurring to the natural circulation of the water through the collector (thermosyphon effect).
- For the same flat plate solar collector operation the number of the day during the year shares with a valuable amount on the collector efficiency. Where the collector has best efficiency when its operated at 21 July than that at 21 January.

Nomenclatures

A_c	Collector area (m²)
a, b	Coefficients in empirical relations
B	Bond width (m)
C_b	Bond conductance (W/m.K)
C_p	Specific heat (J/kg.K)
D	Diameter (m)
F	Fin efficiency factor
F'	Collector efficiency factor
F''	Collector flow factor
F_R	Collector heat removal factor
H	Irradiation for a day (W/m²)
H_b	Daily beam radiation on a horizontal surface (W/m²)
H_d	Daily diffuse radiation on a horizontal surface (W/m²)
H_{fi}	Heat transfer coefficient inside tube (W/m².K)
H_w	Wind heat transfer coefficient (W/m².K)
I	Irradiation for an hour (W/m²)
I_d	An hour's diffuse radiation on a horizontal surface (W/m²)
I_b	An hour's beam radiation on a horizontal surface (W/m²)
K	Thermal conductivity (W/m.K)
L	Thickness of insulation (m)
m	Mean
$\dot{m}$	Mass flow rate (kg/s)
n	Index of refraction & Day of year
N	Number of covers
Nu	Nusselt number
t	Time (s)
T	Temperature (K) & (C°)
Q_u	The useful energy gain (W)
R_b	Ratio of beam radiation on a tilted surface
r_d	Ratio of diffused radiation in an hour to diffused in a day
r_t	Ratio of total radiation in an hour to diffused in a day.
$r_{//}$	Component of the reflected radiation perpendicular to the surface.
$r_{\perp}$	Component of the reflected radiation parallel to the surface.
Σ	Absorbed solar radiation per unit area (W/m²)
Y_{Λ}	Collector overall heat transfer loss coefficient (W/m².K)
Ω	Distance between tubes (m)
α	Absorptance
β	Collector inclination angle (deg.)
γ	Surface azimuth angle (deg.)
$\gamma_{\beta o}$	Bond thickness (m)
δ	Declination (deg.)
δ_{σ}	Sheet thickness (deg.)
ε	Emittance
η	Efficiency (%)
θ	Angle between surface normal And incident radiation
ρ_{γ}	Ground reflectance
ʃ	Stefen-Boltzmann constant (=5.67×10^{-8} W/m^2.K^4)

τ_ρ Transmittance
ϕ Latitude angle (deg.)
ω Hour angle
ω_σ Sunset (or sunrise) hour angle

Subscripts

a Ambient
b Bottom
e Edge
f Fluid
fm Mean fluid
g Glass
i Inlet, Inside
o Outside

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