# Comparison Study of Solar Flat Plate Collector with Single and Double Glazing Systems

H.Vettrivel*‡ and P.Mathiazhagan *

*Department of Mechanical Engineering, Pondicherry Engineering College,Pillaichavady, Puducherry - 605 014 India,
(vettri9994@gmail.com, pmathi@pec.edu)

‡ Corresponding Author, Department of Mechanical Engineering, Pondicherry Engineering College, India,
vettri9994@gmail.com

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**Abstract-**Solar energy can be converted into useful energy in the form of thermal energy. One of the most efficient methods is to harvesting heat energy by using solar flat plate collector. The function of solar collector is to heat water from the atmospheric temperature. The heated water can be used for domestic and industrial applications etc. The efficiency of the solar collector is depend with many parameters such as number of glass cover, wind velocity, space between absorber plate to the glass cover and overall top loss heat transfer coefficient out of which top loss heat transfer coefficient top loss($U_t$) plays an important role for design of solar collector. Taking this point under consideration the present work is to reduce the overall top loss heat transfer coefficient and improve the collector efficiency. A double glaze system was introduced and optimized the space between the absorber plate to glass cover (1) and glass cover (2)were considered to analysis the overall top loss heat transfer coefficient ($U_t$). The single and double glazing solar flat plate collectors were fabricated with same dimensions and installed at a latitude angle of 12 degree facing towards N-S direction. The experiment has been carried out between 10.00 AM to 4.00 PM with thermosyphonprinciple. The result shows that the efficiency of double glazing is higher compared to single glazing system with same solar intensity. The higher efficiency has obtained because of the overall top loss heat transfer coefficient was reduced in double glazing system. However, the efficiency of collector is not constant; it varies with wind velocity, convective, radiative heat transfer coefficient and solar intensity.

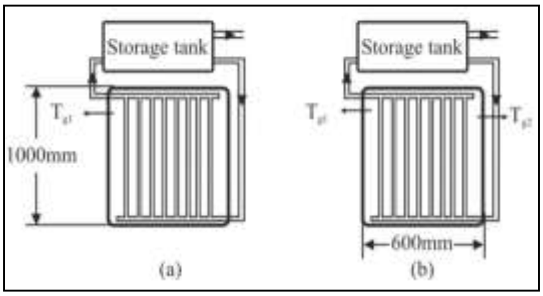
**Keywords**Solar collector; double glazing system;single glazing system;collector efficiency.

## 1. Introduction

Flat-plate collector is the simplest and most commonly used for converting the solar energy into useful heat energy. The collector is generally designed at moderate temperature for water and space heating applications. Presently the use of solar water heater is playing an important role in the domestic sector due to their no electricity cost compared to conventional electrical heaters [1]. However the efficiency of the solar collector is reduced because of the higher top loss heat transfer coefficient and hence lower thermal performance[2].The total heat loss occur from the top side of flat plate collector was found 75% [3].The output useful energy from the collector depends on the thermal and optical losses occuring within the collector [4]. Thermal losses of flat plate collector as a funtion of number of glass cover,wind velocity and ambient temperature [5].The conduction-convection losses from absorber plate to glass cover is (4-8cm) to minimize losses [6].The wind loss coefficient increases, the efficiency of the collector decreases [7]. The efficiency of double glazing showing higher efficiency compared to single glazing [8].The hot water is produced in a collector depending upon the location, solar intensity, wind velocity, overall top loss heat transfer coefficient and number of glass covers. Solar intensity and wind velocity which cannot be controlled by humans. The efficiency of flat plate solar collector is strongly influenced by the heat transfer between the absorber plate to water and overall top loss heat transfer coefficient ($U_t$). The prediction of overall top loss coefficient ($U_t$) is very much important because it combines convection and radiation heat transfer processes. The wind velocity also plays a key role and enhanced the wind convective heat transfer coefficient from the top surface of the solar collector. Finally increased ($U_t$) values and reduce the overall thermal performance of the collector.In most cases solar radiation is sufficient but the ambient air temperature is too low,to use more than one glass cover is more appropritate **[9].**To reduce the upper surface heat loss,honeycomb or double transparent cover can be used **[10]**. Based on the literature the present work focuses toward the optimum space between the absorber plate to glass cover (5cm),wind velocity and double glazing effect also considered.

## 2. Experimental Procedure

Higher density water from the bottom of the tank again enters the flat plate collector gets heated and moves up and stored in the water storage tank. Hot water from the storage tank can be used for domestic and industrial applications. The experiments have been carried out from 10.00 AM to 4.00 PM. The measured values are presented in the tables 2 and 3. The line sketch and experimental setup are shown in the fig. 1. The collector specifications are shown in Table 1.It consists of absorber plate, two class cover with 8 numbers rise tubes. The collector has installed at a tilted angle of 12 degree facing south north directions after fabrication. The six thermocouples were fixed in a collector and connected to digital temperature display unit to measure the temperature. The Pyranometer (PRY 300-3V) and anemometer (ambient airspeed by accuracy ± 0.03 m/s) are used to measure the solar intensity and wind velocity. Water from the storage tank enters the flat plate collector through header and riser tubes. Water gets heated in the riser tubes of the flat plate collector due to the solar radiation and its density will decrease the lighter density water move up and stored in the upper portion of storage tank.




(a) Single (b) Double glazing collector

**Fig. 1**. Line sketch and Experimental set-up

**Table 1**. Specification of flat plate collector

| | | |
|---|---|---|
| Collector length | 1 | m |
| Collector width | 0.6 | m |
| Collector area of the collector | 0.6 | $m^2$ |
| Aperture area of the collector | 0.5 | $m^2$ |
| Collector Depth for Single/Double Glazing | 0.1/0.15 | m |
| Absorber Plate material | Aluminum | - |
| Thickness of absorber plate | 0.02 | m |
| Riser tube diameter | 0.01 | m |
| Header tube diameter | 0.012 | m |
| Tube center to center distance | 0.05 | m |
| Plate -to -cover space | 0.05 | m |
| Cover -to -cover space | 0.05 | m |
| Number of tubes | 8 | - |
| Glass cover emmisivity ($\varepsilon_g$) /Transmittance ($\tau$) | 0.88 | - |
| Absorber plate emmisivity ($\varepsilon_p$) /Absorbtance ($\alpha$) | 0.95 | - |
| Diameter of header pipes | 0.012 | m |
| Insulating material | Foam | - |

**Table 2.** Experimentally observed values of single glaze

| Time (hr) | 10.00 | 11.00 | 12.00 | 1.00 | 2.00 | 3.00 | 4.00 |
|---|---|---|---|---|---|---|---|
| I | 632 | 750 | 932 | 946 | 886 | 787 | 482 |
| V | 1.2 | 2.4 | 1.9 | 1.7 | 1.9 | 2.0 | 1.7 |
| $T_p$ °C | 59 | 75 | 68 | 82 | 79 | 78 | 65 |
| $T_{g1}$ °C | 53 | 67 | 64 | 76 | 73 | 75 | 61 |
| $T_0$ °C | 32 | 36 | 52 | 49 | 42 | 38 | 32 |
| v | - | 0.2 | 1.4 | 1.2 | 0.6 | 0.4 | - |

**Table 3.** Experimentally observed values of double glaze

| Time (hr) | 10.00 | 11.00 | 12.00 | 1.00 | 2.00 | 3.00 | 4.00 |
|---|---|---|---|---|---|---|---|
| I | 632 | 750 | 932 | 946 | 886 | 787 | 482 |
| V | 1.2 | 2.4 | 1.9 | 1.7 | 1.9 | 2.0 | 1.7 |
| $T_p$ °C | 78 | 87 | 88 | 90 | 89 | 86 | 77 |
| $T_{g1}$ °C | 77 | 78 | 84 | 87 | 87 | 84 | 72 |
| $T_{g2}$ °C | 64 | 68 | 67 | 70 | 63 | 67 | 61 |
| $T_0$ °C | 32 | 41 | 65 | 63 | 58 | 44 | 32 |
| v | - | 0.4 | 3.4 | 3.0 | 1.8 | 1.4 | - |

## 3.Energy Balance

Energy balance equation for flat plate collector

$$I_s (\tau_c \alpha_p) A_C = Q_u + Q_l \quad (1)$$

Useful heat gain from the collector

$$Q_u = A_c[S-U_t (T_{pm}-T_a)] \quad (2)$$

Solar flux absorbed by the collector can be expressed

$$S = I_s (\tau_c \alpha_p) A_C \quad (3)$$

Heat loss from the absorber plate to atmospheric can be expressed [11].

$$Q_l = U_t A_c (T_{pm} -T_a) \quad (4)$$

Useful heat absorbed by the water can be expressed

$$Q_w= m_w c_w (T_o-T_i) =\rho v c_w (T_0-T_{in}) \quad (5)$$

The Collector efficiency $\eta_c$:

$\eta_c$= Heat transferred to the water ($Q_w$) / Solar flux absorbed by collector(S).

$$\eta_c = Q_w/ S A_p \quad (6)$$

The Instantaneous efficiency $\eta$:

$\eta$= Useful heat gain collected($Q_u$) / solar energy incident on the collector ($I_s$) x Collector Area ($A_c$) [12].

$$\eta= Q_u/I_sA_c \quad (7)$$

Where,

- $I_s$ - Solar intensity W/m$^2$
- $\tau_c$ -Transmittance of the cover
- $\alpha_p$ -Absorptivity of the absorber plate
- $Q_u$ - Useful heat gain W
- $Q_l$ - Rate of heat loss from collector W
- $Q_w$ - Heat energy absorbed by water W
- $A_c$ - Collector Area of the collector m$^2$
- $A_p$ - Aperture area of the collector m$^2$
- S - Solar flux absorbed by collector W
- $U_t$ - Overall top loss heat transfer coefficient W/m$^2$ K
- $T_{pm}$ -Absorber plate mean temperature $^0$C
- $T_1$ -Absorber plate temperature $^0$C
- $T_2$ -First glass temperature $^0$C
- $T_a$ - Ambient temperature $^0$C
- V -Wind velocity m/sec
- v - Volume of water collected m$^3$
- $m_w$ - Mass flow rate kg/sec
- $c_w$ - Specific heat of water J/kg K
- $\rho$ - Density of water kg/m$^3$
- $T_o$ -Outlet temperature of water $^0$C
- $T_{in}$ -Inlet temperature of water $^0$C
- $\eta_c$ -Collector efficiency %
- $\eta$ -Instantaneous efficiency %

## 4.Analysis and Calculation of Overall Top Loss Heat Transfer Coefficient

The Overall Top loss heat transfer coefficient of single glaze system was calculated using thermal network concept. The conduction heat loss from absorber plate to bottom and side loss of the collectors were not considered. The overall top loss heat coefficient for single glaze system can be expressed ($U_t$).

$$U_t =1/ (R_1 +R_2) \quad (8)$$

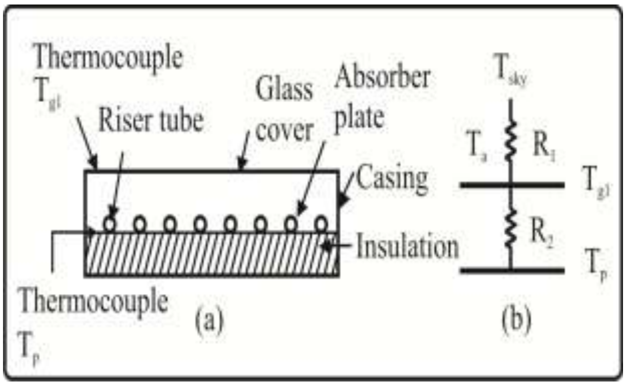



**Fig. 2.**Thermal resistance of single glaze flat plate collector

The Thermal Resistance between the glass cover to ambient temperature represented by $R_1$ and the resistance between the absorber plates to glass covers represented by $R_2$ as shown in figure 2. The Resistance $R_1$ is the combination of wind and radiation effects. The Thermal Resistance $R_2$ is the combination of free convection and radiation heat transfer.

The wind convective heat transfer coefficient and $T_{sky}$ calculated by using equations [6 and 7]. The calculated values are shown in table 4, 5 and 6. The forced convection heat transfer coefficient ($h_w$) can be calculated using a correlation in terms of wind velocity (v), as shown in Equation 10 [13].

$$R_1= 1/ (h_w+h_{rg1a}) \quad (9)$$

$$h_w= 2.8 + 3.0V \quad (10)$$

$$h_{rg1a}=\sigma.\varepsilon_g\{T_{g1}^4-T_{sky}^4\}/\{T_{g1}+T_a\} \quad (11)$$

$$T_{sky} = T_a – 6 \quad (12)$$

$$R_2= 1/ (h_{cpg1}+h_{rpg1} \quad (13)$$

$$h_{cpg1} =K_1 \text{ x } N_{u1}/ L_1 \quad (14)$$

$$h_{rpg1}=\{\sigma/(1/\varepsilon_p+1/\varepsilon_g-1)\}(T_p^2+T_{g1}^2) (T_p +T_{g1}) \quad (15)$$

**Table 4.** Calculated resistance values of single glazing system

| Time (hr) | $h_{cpg1}$ | $h_{rpg1}$ | $R_2$ | $h_w$ | $h_{rg1a}$ | $R_1$ |
|---|---|---|---|---|---|---|
| 10:00 | 1.9 | 6.8 | 0.114 | 6.4 | 7.8 | 0.070 |
| 11:00 | 2.04 | 7.8 | 0.101 | 10 | 7.6 | 0.056 |
| 12:00 | 1.79 | 7.5 | 0.107 | 8.5 | 7.6 | 0.061 |
| 1:00 | 2.1 | 8.5 | 0.094 | 7.9 | 7.7 | 0.063 |
| 2:00 | 1.86 | 8.2 | 0.099 | 8.5 | 7.7 | 0.061 |
| 3:00 | 1.48 | 8.2 | 0.103 | 8.8 | 7.7 | 0.060 |
| 4:00 | 1.76 | 7.3 | 0.110 | 7.9 | 7.6 | 0.064 |

**Table 5.** Calculated values of $U_t$, $Q_u$, $Q_l$ and η (%) for single glazing system

| Time (hr) | S (W) | $U_t$ ($W/m^{2o}C$) | $Q_l$ (W) | $Q_u$(W) | η (%) |
|---|---|---|---|---|---|
| 10:00 | 317 | 5.3 | 77 | 240 | 63 |
| 11:00 | 376 | 6.3 | 148 | 228 | 50 |
| 12:00 | 467 | 5.8 | 119 | 348 | 62 |
| 1:00 | 474 | 6.4 | 180 | 294 | 51 |
| 2:00 | 444 | 6.2 | 163 | 281 | 52 |
| 3:00 | 394 | 6.1 | 163 | 231 | 48 |
| 4:00 | 241 | 5.7 | 107 | 134 | 46 |

**Table 6.** Calculated value of m, $Q_w$ and $\eta_c$ for single glazing system

| Time (hr) | Flow rate of water (Kg/sec) x $10^{-3}$ | Heat absorbed by water $Q_w$ (W) | Collector efficiency $\eta_c$ (%) |
|---|---|---|---|
| 10:00 | 0 | 0 | 0 |
| 11:00 | 0.05 | 0.1 | 0.5 |
| 12:00 | 0.38 | 27 | 12.0 |
| 1:00 | 0.33 | 28 | 11.8 |
| 2:00 | 0.16 | 7.0 | 3.0 |
| 3:00 | 0.11 | 3.0 | 1.4 |
| 4:00 | 0 | 0 | 0 |

The Overall heat transfer coefficient of double glazing system was calculated using thermal network concept. The overall top loss heat transfer coefficient for double glazing system can be expressed ($U_t$).

$$U_t=1/(R_1+R_2+R_3) \quad (16)$$

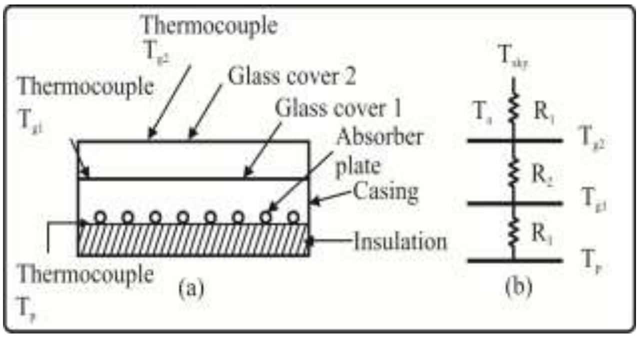



**Fig. 3.** Thermal resistance of double glazeflat plate collector

The Thermal Resistance between the glass cover (1) to ambient temperature represented by $R_1$, the resistance between the glass cover (1) to glass cover (2) represented by $R_2$ and the resistance between the absorber plates to glass cover (2) represented by $R_3$ as shown in figure 3. The resistance $R_1$ is the combination of wind and radiation effects. The Thermal Resistance $R_2$ is the combination of free convection and radiation heat transfer. The Thermal Resistance $R_3$ is also the combination of free convection and radiation heat transfer .The calculated values are shown in table (7, 8, 9).

$$R_1=1/ h_w+h_{rg2a} \quad (17)$$

$$h_w=2.8 + 3.0\ V \quad (18)$$

$$h_{rg2a}= \sigma.\ \varepsilon_g\{ T_{g2}^4 -T_{sky}^4\}/ \{T_{g2} +T_a\} \quad (19)$$

$$R_2=1/ h_{cg1g2}+h_{rg1g2} \quad (20)$$

$$h_{cg1g2} = K_2 * N_{u2}/ L_2 \quad (21)$$

$$h_{rg1g2} =\{\sigma/ (2/\varepsilon_g-1)\}\ (T_{g1}^2 +T_{g2}^2)\ (T_{g1} +T_{c2}) \quad (22)$$

$$R_3= 1/ (h_{cpg1}+h_{rpg1}) \quad (23)$$

$$h_{cpg1} =K_1 \times N_{u1}/ L_1 \quad (24)$$

$$h_{rpg1}= \{\sigma/ (1/\varepsilon_p+1/\varepsilon_{g1} -1)\}\ (T_p^2 +T_{g1}^2)\ (T_p^2 +T_{g1}^2) \quad (25)$$

The natural convection heat transfer coefficient between the absorber plate to first cover or between two covers is calculated from the Rayleigh numbers ($Ra_L$) and Nusselt number ($Nu_L$) [14].

$$Ra_L\cos\beta= 9.81 * \frac{1}{Tm} * \frac{(Tp/g1- Tg1/g2)*L1^3}{V^2} * p_r * \cos\beta \quad (26)$$

$$Nu_L=1+ 1.446\ (1-\frac{1708}{Ra_L\cos\beta})\ ;1708 < Ra_L\cos\beta < 5900 \quad (27)$$

**Table 7.**Calculated resistance values ofdouble glazing system

| Time(hrs) | $h_{cpg1}$ | $h_{rpg1}$ | $R_3$ | $h_{cg1g2}$ | $h_{rg1g2}$ | $R_2$ | hw | $h_{rg2a}$ | $R_1$ |
|---|---|---|---|---|---|---|---|---|---|
| 10:00 | 1.2 | 8.2 | 0.106 | 2.22 | 7.2 | 0.106 | 6.4 | 6.7 | 0.076 |
| 11:00 | 2.05 | 7.4 | 0.105 | 2.21 | 6.9 | 0.109 | 10 | 7.6 | 0.056 |
| 12:00 | 1.72 | 8.9 | 0.094 | 2.46 | 7.1 | 0.104 | 8.5 | 7.6 | 0.062 |
| 1:00 | 1.99 | 9.1 | 0.090 | 2.45 | 7.3 | 0.102 | 7.9 | 7.68 | 0.064 |
| 2:00 | 1.33 | 9.0 | 0.096 | 2.69 | 7.1 | 0.102 | 8.5 | 7.64 | 0.061 |
| 3:00 | 1.52 | 8.8 | 0.096 | 2.46 | 7.5 | 0.100 | 8.8 | 7.65 | 0.060 |
| 4:00 | 1.74 | 8.1 | 0.101 | 2.22 | 6.7 | 0.112 | 7.9 | 7.65 | 0.064 |

**Table 8.** Calculated values of $U_t$, $Q_u$, $Q_l$ and η (%) for double glazing system

| Time (hr) | S (W) | $U_t$ (W/m$^2$ $^o$C) | $Q_l$ (W) | $Q_u$ (W) | η (%) |
|---|---|---|---|---|---|
| 10:00 | 317 | 3.4 | 92 | 225 | 59 |
| 11:00 | 376 | 3.6 | 109 | 267 | 59 |
| 12:00 | 467 | 3.8 | 123 | 344 | 61 |
| 1:00 | 474 | 3.8 | 128 | 346 | 60 |
| 2:00 | 444 | 3.8 | 127 | 317 | 59 |
| 3:00 | 394 | 3.8 | 120 | 274 | 58 |
| 4:00 | 241 | 3.5 | 89 | 152 | 52 |

**Table 9.**Calculated value of m and $Q_w$ and $\eta_C$ for double glazing system

| Time (hr) | Flow rate of water (Kg/sec) x $10^{-3}$ | Heat absorbed by water $Q_w$ (W) | Collector efficiency $\eta_c$ (%) |
|---|---|---|---|
| 10:00 | 0 | 0 | 0 |
| 11:00 | 0.1 | 4 | 2 |
| 12:00 | 0.9 | 130 | 55 |
| 1:00 | 0.8 | 108 | 48 |
| 2:00 | 0.5 | 55 | 23 |
| 3:00 | 0.3 | 20 | 9 |
| 4:00 | 0 | 0 | 0 |

## 5.Results and Discussion

The graph plotted between solar intensity with time as shown in fig. 4.The results indicated that the solar intensity increases with respect to time and maximum intensity was observed around 1.00 PM after that it has decreases with time due to low solar intensity.

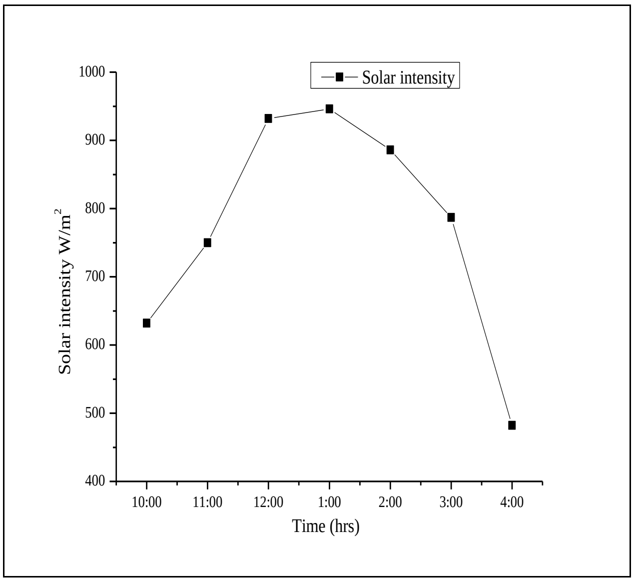



**Fig. 4.** Solar intensity vs Time

The figure (5) had shown the thermal resistance of single glaze system. The result shows that at 11.00 AM resistance values ($R_1$and $R_2$) are reduced due to high wind velocity (2.4 m/sec) because of increase intop heat loss coefficient as 6.3 W/m$^2$ $^0$C. However $R_2$ value is more because the resistance in between the absorber plate to glazing less and hence minimize the top loss heat transfer coefficient. After 11.00 AM resistance ($R_1$) stable became of there is no much variation of wind velocity.However the resistance $R_1$ is less compared to $R_2$ because of wind interact with the surface of glass cover and it is cooled. The temperature difference (ΔT) between the absorber plate to glass cover having higher values because of wind convective heat transfer coefficient ($h_w$) has increased.In single glaze flat plate collector, glass cover temperature obtained 53$^0$ C. However double glaze system ($T_{g1}$ and $T_{g2}$) temperature were achieved 64$^0$ C and 77$^0$ C.The present work is consistent with previous workers [15].

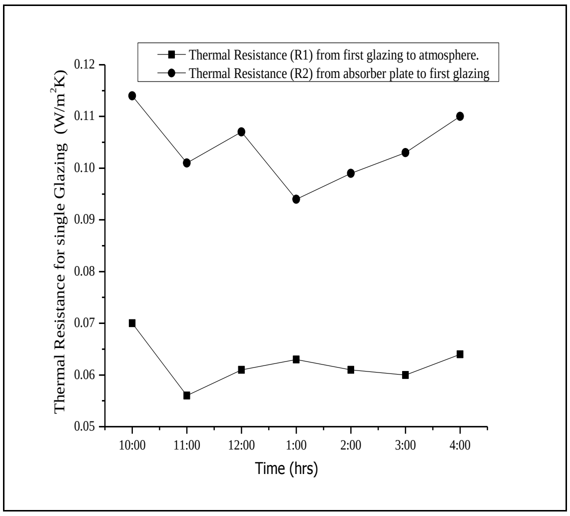



**Fig 5.**Thermal Resistance for Single Glazing vs Time

From fig. 6, shows the thermal resistance of double glaze system. The result shows that at 11:00 AM resistance values ($R_2$ and $R_3$) are increased and $R_1$ is reduced due to high wind velocity (2.4 m/sec) and overall top loss heat transfer coefficient is reduced (3.6 W/m$^2$ K) compare to single glazıng system due to double glazıng effect.However the resistances ($R_2$ and $R_3$) having higher values compared to $R_l$ due to optimization of gap (5cm)from absorber plate to (2) and (1) glaze cover. The top loss heat coefficient is less because of air is present in between the glass cover (1) and (2) thus top heat loss coefficient is reduced. The resistance of $R_2$ is high compared to $R_1$ and $R_3$ due to cover (2) which is acting as a barrier and also maintains temperature ($10^0$C) between absorber plates to cover (1). Thus, the convection heat transfer coefficient between absorber plate and glass cover (1) ($hcpg_1$) and radiative heat transfer coefficients are lower ($hrpg_1$).Therefore convective and radiative losses are reduced by increase in convective resistance ($R_2$) compared to other convective resistances ($R_3$ and $R_1$). At 3.00 PM the same effect was noticed as in 11.00 AM due to high wind velocity (2 m/sec) .

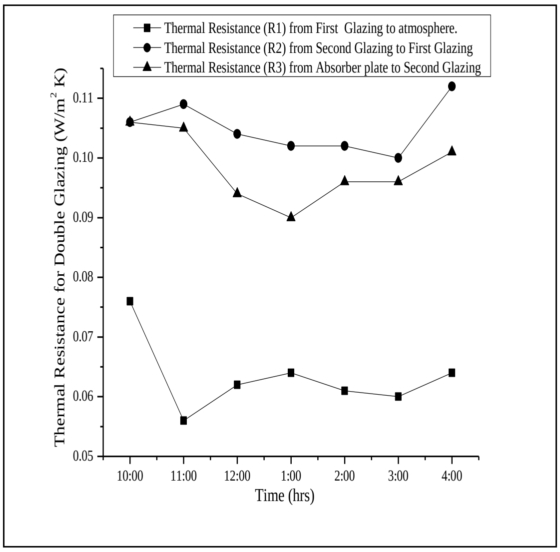



**Fig. 6.** Thermal resistance for double glazing vs Time

Overall top loss heat transfer coefficient of single and double glazing systems with respect to time are shown fig. 7. The overall top loss heat transfer coefficient much affected by many parameters such as wind, solar intensity, gap from absorber plate to glass cover (1 and 2) . The results show that the overall top loss coefficient is higher for single glazing compare to double glazing systems due to effect of wind velocity as shown in Table 4 and 8. In double glass system the temperature difference ($\Delta$T) is less between absorber plates to cover (2), the convective heat transfer coefficient is less and radiative heat transfer coefficient is high as shown in Table3.

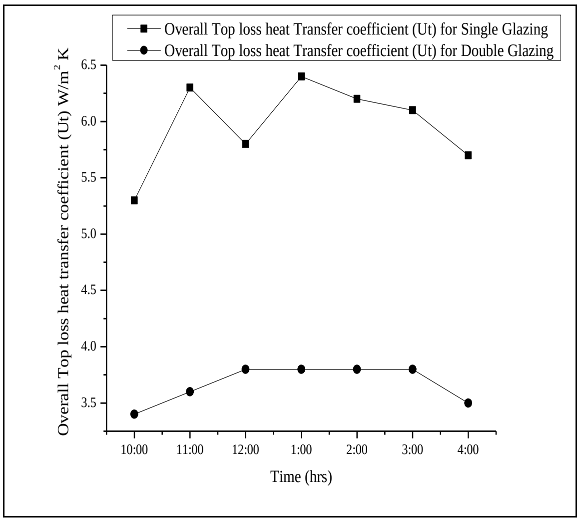



**Fig. 7.** Top loss heat loss coefficient vs Time

From the fig.8.The result shows that the useful heat gain ($Q_u$) is higher for double glazing compared to single glazing system due to top heat loss coefficients are lessfor double glazing system and heat is converted properly and heat the water beacuse of more useful gain absorbed in double glazing system.

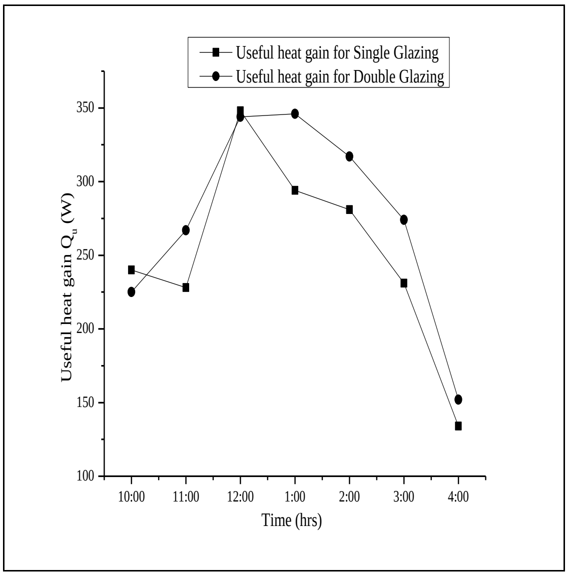



**Fig. 8.** Useful heat gain vs Time

From the fig. 9.The volume of water collected in double glazing system is more due to high useful heat is transfered to the water and heated water flow faster due to density difference and collected high volume of water compared to single glazing system.

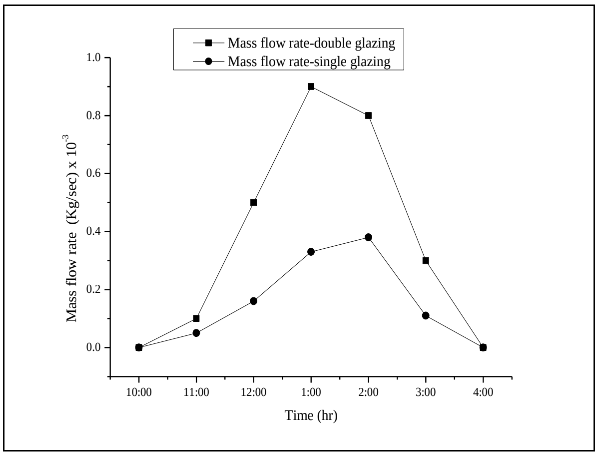



**Fig. 9.** Mass flow rate vs Time

From the fig. 10.In double glazing system much heat is absorbed compared to single glazing system.This because of the overall top loss heat transfer is less for double glazing system.

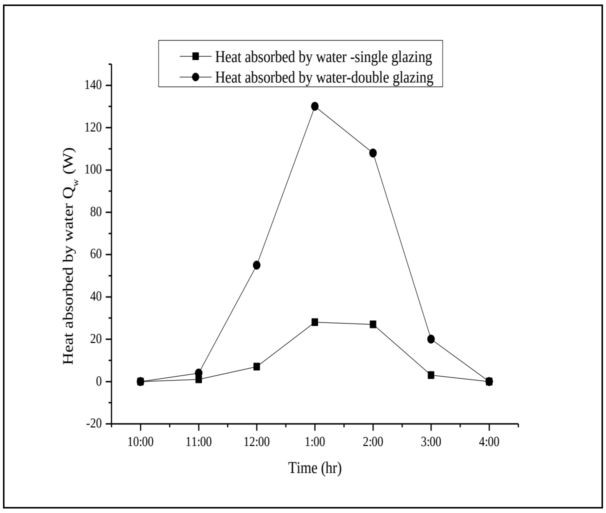



**Fig. 10.** Useful heat absorbed by water vs Time

From the fig. 11.The effect of spacing and double glazing, the outletheated watertemperature 65 $^0$C ($T_0$) was obtained. However only 52 $^0$C achieved insingle glazing system with same solar intensity,spacing,dimensions and experimental conditions.

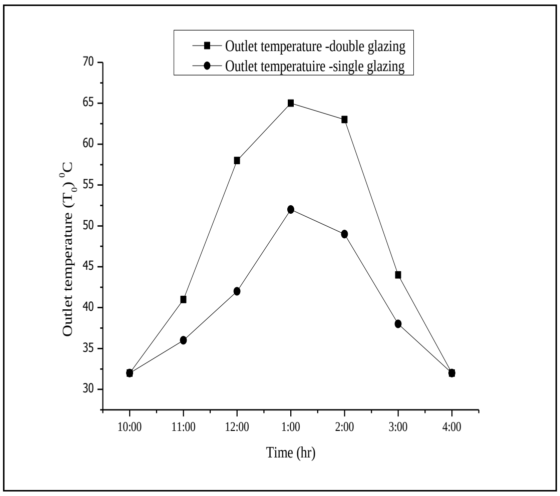



**Fig. 11.** Outlet temperature vs Time

From the fig. 12.The effect of double glazing and spacing the collector efficiency achieved around 55% due to the higher heat gain.However single glazing having only 12%.The reduction of efficiency for single glazing due to the higher top loss heat transfer coefffient and heat transfer rate is less.

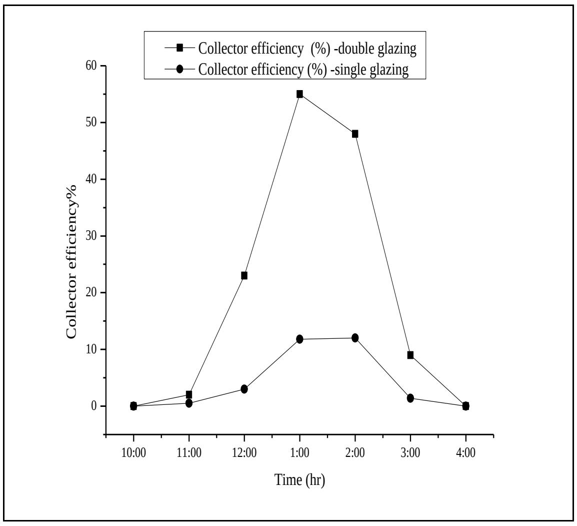



**Fig. 12.** Collector efficiency vs Time

From the fig. 13.The instantaneous efficiency of double glazing system having consistency compared to single glazing system for the same day 10.00 AM to 4.00 PM for the same operating conditions.

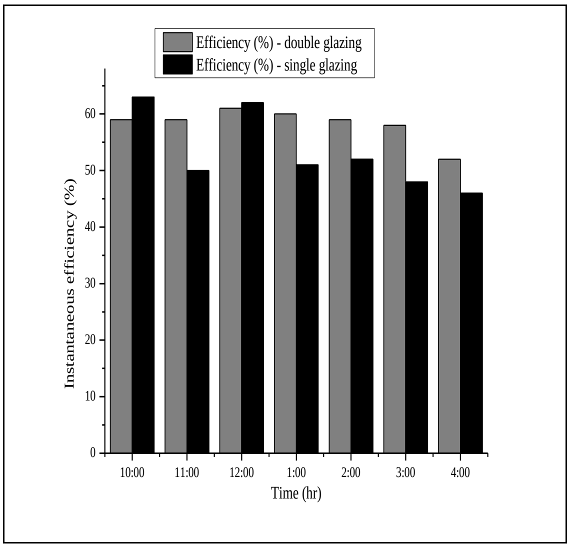



**Fig. 13.** Instantaneous efficiency vs Time

## 6. Conclusions

From the experimental investigations the following results were obtained.

1. The collector efficiency was obtained 55 % for double glazing system. However single glazing system having only 12% with same solar intensity and dimensions.

2. The top loss heat transfer coefficient is observed less for double glazing compare to single glazing system.

3. The volume of water collected higher in the case of double glazing compared with single glazing system.

4. The maximum outlet temperature was obtained 65 $^0$C for double glazing system, butfor single glazing system having 52 $^0$C only.

5. The double glazing system outlet temperature around 10$^0$C - 15 $^0$C more compared with single glazing system.

6. Further improvement in collector efficiency of solar flat plate collector, the nanofluid may be considered for future research.

## Nomenclatures

$Tg_1$ Mean temperature of First cover, $^0$C
$Tg_2$ Mean temperature of second glass cover, $^0$C
$h_w$ Wind convective heat transfer co-efficient, W/m$^2$ K

## Greek symbols

$Ra_L$ Rayleigh number
Pr Prandtl number
Nu Nusselt number
B Collector tilt angle, degrees
$\varepsilon_p$ Emissivity of plate
$\varepsilon_c$ Emissivity of cover
$\sigma$ (Stefan Boltzmann constant) 5.67 x 10$^{-8}$ W/m$^2$ K

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