Thermal design and field experiment of transparent honeycomb insulated integrated-collector-storage solar water heater

N.D. Kaushika *, K.S. Reddy

Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 110016, India

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Abstract

A simulation model for solar heating of a storage water tank, cuboid in shape, transparent honeycomb insulated at the top surface and covered with opaque insulation at all other sides is described. The validity of the model is examined by the observations made with a prototype field experiment which show good agreement. Explicit simulation results on the optimisation of honeycomb effectiveness for heat loss reduction and solar gain characteristics are presented. A honeycomb depth of 5–7.5 cm and aspect ratio of 15–20 exhibit optimum performance. Compounding of the honeycomb array with an air layer of 12 mm and the use of a selective absorber provide the benefit of added solar gain and thermal storage.

Keywords: Transparent insulation material; Integrated-collector-storage system; Solar water heater; Honeycomb cover system

Nomenclature

\( A_c \) area of the solar absorber surface of the tank (m²)
\( C_{pt} \) specific heat of tank material (J/kg K)
\( C_{pw} \) specific heat of water (J/kg K)
\( h \) depth of tank (m)
\( h_{rt} \) combined conductive and radiative heat loss coefficient across the honeycomb (W/m² K)
\( h_{cw} \) convective heat loss coefficient due to wind (W/m² K)
\( I_{s}(t) \) solar beam radiation at time \( t \) (W/m²)
\( I_{d}(t) \) solar diffuse radiation at time \( t \) (W/m²)
\( k \)  
- extinction coefficient of cover plate (m\(^{-1}\))

\( k_i \)  
- conductivity of opaque insulation (W/m K)

\( l \)  
- characteristic length of tank (m)

\( L \)  
- depth of the honeycomb (m)

\( m \)  
- no. of cover plates

\( M \)  
- \(- M_{w0} C_{pw} + M_{C_0}\)

\( M_{w0} \)  
- mass of the tank (kg)

\( M_{w0} \)  
- mass of the water in the tank (kg)

\( Q_1 \)  
- total heat loss from top surfiace (W/m\(^2\))

\( Q_2 \)  
- heat loss from absorber plane to top cover (W/m\(^2\))

\( Q_3 \)  
- heat loss from top cover to ambient (W/m\(^2\))

\( Q_{4i}(t) \)  
- total heat loss from the system (W/m\(^2\))

\( Q_{4i}(t) \)  
- solar radiant energy reaching the absorber plane (W/m\(^2\))

\( Q_{4i}(t) \)  
- retrieved heat flux per unit area of heater (W/m\(^2\))

\( R_b \)  
- tilt factor for beam radiation

\( R_{ba} \)  
- ratio of bottom heat loss to top heat loss of the tank

\( R_3 \)  
- tilt factor for diffuse radiation

\( R_r \)  
- tilt factor for reflected radiation

\( R_{si} \)  
- ratio of side heat loss to top heat loss of the tank

\( S(t) \)  
- solar intensity at time \( t \) (W/m\(^2\))

\( t_c \)  
- thickness of cover plate (m)

\( t_b \)  
- bottom opaque insulation thickness (m)

\( t_s \)  
- side opaque insulation thickness (m)

\( t_i \)  
- time duration between two successive observations (s)

\( T_a \)  
- average ambient air temperature (°C)

\( T_{a_{max}} \)  
- maximum average ambient air temperature (°C)

\( T_{a_{min}} \)  
- next day final average ambient air temperature (°C)

\( T_{c} \)  
- top cover temperature of honeycomb array (°C)

\( T_{a} \)  
- average sky temperature (°C)

\( T_{w} \)  
- average water temperature in the tank (°C)

\( T_{w_{0}} \)  
- next day final water temperature in the tank (°C)

\( T_{w_{max}} \)  
- maximum water temperature in the tank (°C)

\( T_{w_{0}}(t) \)  
- ambient air temperature at time \( t \) (°C)

\( T_{w_{0}}(t) \)  
- water temperature at time \( t \) (°C)

\( T_{w}(t-i) \)  
- water temperatures at time \((t-i)\) (°C)

\( U_{b} \)  
- overall heat loss coefficient (W/m\(^2\) K)

\( U_{b} \)  
- bottom heat loss coefficient (W/m\(^2\) K)

\( U_{r} \)  
- side heat loss coefficient (W/m\(^2\) K)

\( U_{i} \)  
- top heat loss coefficient (W/m\(^2\) K)

\( V \)  
- wind speed (m/s)

**Greek letters**

\( \alpha(\theta) \)  
- absorptivity of the top (blackened) surface

\( \alpha_{b} \)  
- absorptance–transmittance product for beam radiation

\( \alpha_{s} \)  
- absorptance–transmittance product for sky diffuse radiation

\( \alpha_{g} \)  
- absorptance–transmittance product for ground diffuse radiation

\( \alpha_{eff} \)  
- effective absorptance–transmittance product

\( \beta \)  
- tilt angle of water heating system (deg)

\( \epsilon_c \)  
- emittance of top cover plate

\( \mu \)  
- refractive index of cover plate

\( \rho \)  
- albedo of the ground

\( \sigma \)  
- Stefan–Boltzmann constant (W/m\(^2\) K\(^4\))
\( \theta \)  
angle of incidence (deg)

\( \theta_r \)  
angle of refraction (deg)

\( \theta_z \)  
zenith angle (deg)

\( \tau_b(\theta) \)  
beam radiation transmittance

\( \tau_{0g} \)  
diffuse radiation transmittance for ground

\( \tau_{0s} \)  
diffuse radiation transmittance for sky

1. Introduction

The use of a honeycomb device to reduce heat losses through the cover system of a flat plate collector is well known. In recent years transparent honeycomb insulations have been considered for application in solar integrated-collector-storage systems which use water as the collector-storage medium; these have been reported to have several advantages over conventional hot water systems wherein collection, transport and storage of energy are accomplished by separate units such as solar collectors, heat transport pipes and water storage tanks. Several configurations of transparently insulated solar Integrated-Collector-Storage (ICS) hot water systems have been proposed and tested; the configurations based on the storage water tank seem very suitable for domestic and industrial hot water production applications. Kaushika and Banerjee, in ref. [1], suggested and analysed a configuration which consists of a storage water tank which is cuboid in shape, transparently heated at the top surface and covered with opaque insulation on all other sides. Subsequently, Goetzberger and Rommel, in ref. [2], examined the prospects of such a system for application in central Europe. A cubic storage water tank using transparent insulation on its surface as well as side walls [3, 4], and a simulated well-stratified tank made of tubular subunits [5] have also been considered for transparent honeycomb insulated water heaters. All these analyses/evaluations are based on discrete measurements of solar transmittance and heat losses across the honeycomb cover system. In simulation models, very little attention has been paid to the formulation of solar beam and diffuse radiation transmittance and thermal loss reduction characteristics of the honeycomb device. This paper presents design and performance data of honeycomb insulated water heaters; it uses a computer simulation approach based on recent accurate determinations of the criteria of convection suppression, solar transmittance and thermal loss reduction characteristics of honeycomb devices [6, 7].

2. Simulation model and approximations

A schematic of the system is shown in Fig. 1. Solar energy after transmission through the transparent honeycomb cover falls on the blackened absorber plane which is inclined to the horizontal to receive maximum energy. Part of the absorbed energy is used to heat the water, the remaining energy being lost to the surroundings. The thermal energy balance for water can be written as:

\[
M \frac{dT_w(t)}{dt} = Q_d(t) - Q_L(t),
\]

(1)
where $M = M_a C_{pw} + M_t C_{pc}$. The radiant energy reaching the absorber plane is given by:

$$Q_e(t) = (\alpha\eta)_b I_b(t) R_b + (\alpha\eta)_{ab} I_a(t) R_d + (\alpha\eta)_{ab} [I_b(t) + I_a(t)] R_t,$$

(2)

where

$$R_b = \frac{\cos \theta}{\cos \theta_2}, \quad R_d = \frac{1 + \cos \beta}{2} \quad \text{and} \quad R_t = R_b \left( \frac{1 - \cos \beta}{2} \right).$$

The cover system, in general, consists of the top cover, the honeycomb array and the bottom cover. Its transmittance–absorptance product $(\alpha\eta)_b$ for solar beam radiation may be expressed by an approximate equation, which does not take into account the multiple reflections between cellular array and cover plates, as follows:

$$(\alpha\eta)_b = T_1(\theta).T_2(\theta).T_3(\theta).\alpha(\theta),$$

(3)

where $T_3(\theta)$, the transmittance based on reflection of the encapsulating cover plates, is given by [8]:

$$T_1(\theta) = \frac{1}{2} \left[ \frac{1 - \rho_1}{1 + (2m - 1)\rho_1} + \frac{1 - \rho_2}{1 + (2m - 1)\rho_2} \right].$$

(4)

where

$$\rho_1 = \frac{\sin^2(\theta_t - \theta)}{\sin^2(\theta_t + \theta)}, \quad \text{and} \quad \rho_2 = \frac{\tan^2(\theta_t - \theta)}{\tan^2(\theta_t + \theta)}$$
with
\[
\frac{\sin \theta}{\sin \theta_r} = \mu,
\]

When
\[
\theta = 0, \quad \rho_1 = \rho_2 = \frac{(1 - \mu)^2}{(1 + \mu)^2}.
\]

\( T_2(\theta) \), the transmittance based on absorption of the encapsulating cover plates, is given by Bouger's law:
\[
T_2(\theta) = \exp \left( -\frac{\mu \theta}{\cos \theta_r} \right).
\]

where the extinction coefficient, \( k \) varies from approximately 4 m\(^{-1}\) for good quality “water white” glass (which appears white when viewed on the edge) to approximately 32 m\(^{-1}\) for poor glass (with iron impurity, having greenish edges).

The formulations for beam radiation transmittance, \( T_b(\theta) \) of honeycomb array have been reported by Hollands \textit{et al.} in ref. [9] and Kaushika and Padmapriya in ref. [10], and have been adopted here.

The diffuse radiation transmittance–absorptance product can be obtained by integrating the beam radiation results over an appropriate range of the angle of incidence. Following Arulanantham and Kaushika in ref. [7], solar diffuse radiation transmittances for ground and sky are given as:
\[
\tau_{bg} = \frac{\int_{-\frac{\pi}{2}-\beta}^{\frac{\pi}{2}} \int_{\sin^{-1}\left(\frac{\sin \theta}{\sin \theta_r}\right)}^{\frac{\pi}{2}} \tau_b(\theta) \cos \theta \sin \theta \, d\phi d\theta}{\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_{\sin^{-1}\left(\frac{\sin \theta}{\sin \theta_r}\right)}^{\frac{\pi}{2}} \cos \theta \sin \theta \, d\phi d\theta}, \quad (6)
\]
\[
\tau_{gs} = \frac{\int_{-\frac{\pi}{2}-\beta}^{\frac{\pi}{2}} \int_{\sin^{-1}\left(\frac{\sin \theta}{\sin \theta_r}\right)}^{\frac{\pi}{2}} \tau_b(\theta) \cos \theta \sin \theta \, d\phi d\theta + \int_{\frac{\pi}{2}-\beta}^{\frac{\pi}{2}} \int_{\sin^{-1}\left(\frac{\sin \theta}{\sin \theta_r}\right)}^{\frac{\pi}{2}} \tau_b(\theta) \cos \theta \sin \theta \, d\phi d\theta}{\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_{\sin^{-1}\left(\frac{\sin \theta}{\sin \theta_r}\right)}^{\frac{\pi}{2}} \cos \theta \sin \theta \, d\phi d\theta + \int_{\frac{\pi}{2}-\beta}^{\frac{\pi}{2}} \int_{\sin^{-1}\left(\frac{\sin \theta}{\sin \theta_r}\right)}^{\frac{\pi}{2}} \cos \theta \sin \theta \, d\phi d\theta}. \quad (7)
\]

The total heat loss \([Q_L(t)]\) from the water reservoir is given by:
\[
Q_L(t) = U_L [T_w(t) - T_a(t)] \quad (8)
\]
where $U_L$, the overall heat loss coefficient, is given by:

$$U_L = U_t + U_b + U_s$$ (9)

If honeycomb array dimensions are matched to the temperature difference across the air layer to ensure it to be non-convective, the top surface heat loss ($Q_{t1}$) from absorber to top cover can be evaluated by considering two loss mechanisms only: conduction and the radiation,

$$Q_{t1} = h_{t1}(T_w - T_c)$$ (10)

where $h_{t1}$ is the combined conductive and radiative heat loss coefficient for the encapsulated honeycomb array; Arulananthham and Kaushika in ref. [11] have dealt in detail with the coupled conductive radiative heat transfer for the calculations of $h_{t1}$; their computer program has been used as subroutine in the present simulation program.

The heat loss from top cover to ambient ($Q_{t2}$) consists of convective and radiative components [8]:

$$Q_{t2} = h_w(T_c - T_a) + \sigma c_v \left[ (T_c + 273.3)^4 - (T_{sky} + 273.3)^4 \right]$$ (11)

where $h_w = 5.7 + 3.8 V$

In steady state $Q_{t1} = Q_{t2} = Q_t$ (say), so the value of top cover temperature $T_c$ may be obtained by iterating the Eqs. (10) and (11) such that $Q_{t1} = Q_{t2}$ using the Secant iteration method [12] to an accuracy of ±0.001. The top loss coefficient, $U_t$, is then obtained as:

$$U_t = \frac{Q_t}{T_w - T_a}$$ (12)

The conductive heat loss through the bottom and side insulation (opaque) may be obtained from first principles. The edge effects may not be negligible; the approximate geometrical shape factors have, therefore, been incorporated to allow for edge effects. Following Langmuir et al. in ref. [13] and Boelter et al. in ref. [14], the conductive heat loss coefficients for the bottom and sides may be expressed as:

$$U_b = \frac{1}{A_c} \left[ \frac{A_c k_b}{l_b} + 2.16 l_k + 0.6 l_b k_b \right],$$ (13)

$$U_s = \frac{1}{A_c} \left[ \frac{A_c k_s}{l_s} + 2.16 l_k + 0.6 l_s k_s \right],$$ (14)

where $l = \sqrt{A_c}$, for a heater of square cross-section.

The ratios of heat losses through the bottom and sides to those through the top cover system, respectively, are:

$$R_{b1} = \frac{U_b}{U_t}$$ (15)

and
\[ R_{st} = \frac{U_s}{U_t}. \]  

(16)

The Eq. (1) may be written as:

\[ M \frac{dT_w(t)}{dt} = Q_s(t) - U_L[T_w(t) - T_a(t)], \]

\[ \frac{dT_w(t)}{dt} + AT_w(t) = F(t), \]  

(17)

where

\[ A = \frac{U_L}{M} \quad \text{and} \quad F(t) = \frac{Q_s(t) + U_L T_a(t)}{M}. \]

Eq. (17) is a linear differential equation with integrating factor \( e^{At} \). Applying initial conditions, \( T_w(t) = T_{wo} \) at \( t = 0 \), the solution is obtained as:

\[ T_w(t) = e^{-At} \int_0^t e^{At} F(t) \, dt + T_{wo} e^{-At}. \]  

(18)

This equation may be used to compute water temperature \( T_w(i) \) at a small interval of time \( (t) \) and during this interval \( F(t) \) may be regarded as constant \( (F) \).

So we have,

\[ T_w(t) = \frac{1}{A} F[1 - e^{-At}] + T_{wo} e^{-At}. \]  

(19)

Eq. (19) can be used to calculate the mean water temperature as a function of time. The collection efficiency of the transparent honeycomb insulated integrated-collector-storage water heater may be expressed as:

\[ \eta_c = \frac{\int_0^t Q_a(t) \, dt}{A \int_0^t S(t) \, dt}. \]  

(20)

3. Experimental validation

With a view to validating the above simulation model, a prototype field experiment has been carried out. The honeycomb cover is the most important component of the system. It has been fabricated from extruded cellular array supplied by ArtEl Energy Ltd, Israel. The product is in
the form of cellular strips of (1.6 × 70 × 5 cm) and (1.6 × 70 × 10 cm) sizes. The square cells are of width 3 and 4 mm. The strips were glued to form a slab. The gluing process was carried out manually using pure liquid chloroform (CHCl₃, which is a solvent for lexan) as adhesive. The slab was finally encapsulated in a tray made of a transparent polycarbonate sheet of 0.5 mm thickness. The cover system is easy to handle and has sufficient built in strength to maintain rigidity. The system has a tank of 251 (66 × 45 × 8.5 cm) with a rectangular cross-section; it is made from an 18 gauge galvanised iron sheet. It is kept in an inclined position and facing due south. The inclination of the system can be adjusted manually according to the requirement of placing the absorber plane perpendicular to solar rays at noon. The top surface of the tank is black painted to absorb the solar radiation, and transparently insulated with honeycomb to reduce the heat losses. The temperature of water inside the tank was measured by Copper–Constantan thermocouples. We have arranged Copper–Constantan thermocouple wires in the form of a multichannel probe, wherein the junctions are placed at a separation of 10 cm to measure the vertical temperature distribution in the water heater. The thermocouple probe is connected to a SC-7501 multi logger (IWATSU Electric Ltd, Japan). The water temperatures have been recorded at an interval of 1 h. The water heater is shown in Fig. 2.

The time history of temperature development in the tank at various heights is illustrated in Fig. 3(a). The observations correspond to the month of December (Dec 11–13, 1996), a winter month, and the water is not drained out from the tank for 2 days. The temperature gradient builds up during the day and diffuses during the night. The system exhibits significant retention of heat during off-sunshine hours.

The experimental variation of mean water temperature in the tank is compared with simulation results based on $U_L$ and the transmittance–absorptance product $(xτ)_{eff}$ values determined from formulations given in the previous section. Solar intensity [$h_0(t)$ and $I_0(t)$] and

![Fig. 2. Photograph of the system.](image-url)
Fig. 3. (a) Temperature distribution in the tank at different heights, (b) experimental validation of system performance.
ambient temperature $T_a(t)$ values measured for the same days at New Delhi, are used in the simulation. The results are portrayed in Fig. 3(b). The thermophysical parameters used in the simulation model are as follows: $M_w = 25$ kg, $M_t = 6$ kg, $C_{pw} = 4190$ J/kg.$^\circ$C, $C_{pt} = 486$ J/kg.$^\circ$C, $k_t = 0.037$ W/m.$^\circ$C, $t_b = 0.08$ m, $t_w = 0.05$ m, $l = 0.66$ m, $h = 0.08$ m, $t_i = 1$ hr, $k = 5$ m$^{-1}$

The overall heat loss coefficient ($U_L$) of the system has also been determined experimentally using the night cooling observations as follows. Night time $U_L$ may be expressed as:

$$ U_L = \frac{M}{t_i} \ln \left( \frac{T_w(t) - T_a(t)}{T_w(t-t_i) - T_a(t)} \right) $$

(21)

For a 5 cm encapsulated honeycomb cover system the values of overall heat loss coefficient ($U_L$) are:

Theoretical $= 2.916$ W/m$^2$.$^\circ$C.

Experimental $= 3.068$ W/m$^2$.$^\circ$C (night time average value).

4. System optimisation and trade offs

An experimentally validated simulation model may be used for the derivation of optimum design parameters and trade off characteristics. For a given solar absorber area, the temperature in the tank will be lower for tanks of larger capacity (hence larger depth) and the efficiency of heat collection/storage will be larger at lower temperature. The variation of efficiency and final water temperature with capacity of the tank (or depth of the tank, $h$) are illustrated in Fig. 4(a) and (b), which is based on calculations made from the simulation model for a tank of absorber area, $A_s = 1$ m$^2$. It may be used for trade-off between the system efficiency and required hot water temperature. The ratios $R_{ht}$ and $R_{dt}$ of heat losses through the bottom and sides to those through the top cover (honeycomb) system respectively may be used for optimising such geometric parameters as insulation thickness and depth of the tank. The variations of $R_{ht}$ and $R_{dt}$ with these parameters are illustrated in Fig. 5(a) and (b); it indicates that for a hot water requirement of 50–60$^\circ$C, the insulation thickness of 10–12 cm and water tank depth of 8–10 cm is a good optimisation.

The effectiveness of a honeycomb cover system on the development of mean water temperature in the tank, ($A_s = 1$ m$^2$) is illustrated in Fig. 6(a and b). Two configurations of the cover system are considered: (1) honeycomb cover system which consists of the encapsulated cellular array, and (2) compound honeycomb cover system which consists of an encapsulated air layer (12 mm thickness placed in the bottom region) and the cellular array; in this geometry the air layer remains in near critical Rayleigh regime and provides additional insulation without affecting the solar transmittance of the cover system. The system performance tends to level at a honeycomb cover depth of 7.5 cm. Compounding of honeycomb with an air layer tends to improve the performance; the honeycomb cover depth of 5 cm is near optimum in this configuration.
Fig. 4. Functional dependence of tank depth on efficiency and final water temperature: (a) black absorber, (b) selective absorber.
Fig. 5. (a) Variation of $R_{st}$ with thickness of opaque insulation. (b) Variation of $R_{st}$ with thickness of opaque insulation.
Fig. 6. Effectiveness of honeycomb cover system on average water temperature: (a) uncompounded honeycomb, (b) honeycomb compounded with an air layer.
The integrated-collector-storage units have often been used as solar water preheaters. Our experiments were performed during December (winter month at New Delhi, 28.6°N). The inclination of the tank was adjusted such that the absorber plane was perpendicular to sun rays at noon. It was found that the hot water temperature of 50–60°C could be attained with solar energy alone. The year round performance of the system was, therefore, studied. The simulation results are illustrated in Fig. 7; which portrays the possibility of using the water heater of adjustable inclination as 100% solar fraction system. However, the adjustment of the inclination is often considered as a liability by the users. In the cuboid shape, the tanks of large capacity may also be used; they may be segmented or made from tubular subunits to simulate well-stratified tanks of good structural stability.

In fixed tilt configurations several design variations are possible. For example, one could use a triangular shaped tank wherein the honeycomb and absorber plane are inclined perpendicular to sun rays at winter noon. The tank of cubic shape may also be used. These configurations would allow much larger tanks to be made. However, the solar absorption area to water volume ratio would be rather small in these configurations, which may perhaps be more suitable as solar water preheaters.

Besides honeycomb (cellular), several other types of transparent insulation materials (TIM) are available. These may be classified as follows: (1) absorber-parallel structures such as single or multiple glazings parallel to the absorber, (2) absorber-perpendicular structures such as honeycombs and capillaries, (3) cavity structures such as duct plates and foams and (4) homogeneous materials such as aerogels or plastic balls.

![Fig. 7. Year-round performance of ICS solar water heater with honeycomb cover.](image-url)
Fig. 8. Comparison of various configurations of cover systems on ICS solar water heater.

A comparative study of different TIM cover systems for the present application has been made in Fig. 8 using the simulation results of the performance of ICS solar water. The following TIM cover systems have been considered:

1. single glazing
2. compound honeycomb
3. duct plates (6 mm GE plastics structured product); and
4. aerogels (6–8 mm diameter).

The corresponding overall heat loss coefficient ($U_t$), effective absorptance and transmittance product ($\alpha\tau_{\text{eff}}$) and solar gain characteristics are summarised in Table 1. The results indicate that the solar ICS water heater with a compound honeycomb as the cover system shows better performance as compared with other cover systems. The effect of the selective absorber ($\alpha = 0.9$ and $\epsilon = 0.17$) on the system performance is also illustrated in Fig. 8; which indicates further improvement in the system performance.

5. Conclusions

In this paper solar heating of a storage water tank, cuboid in shape, transparent honeycomb insulated at the top surface, and covered with opaque insulation at all other sides, is investigated theoretically as well as experimentally for solar hot water production application. Explicit results on the optimisation of honeycomb effectiveness for heat loss reduction, solar
Table 1
Comparison of TIM cover systems on ICS solar water heater; Initial temperature (T_{wo}) = 10.3°C and Insulation = 5.49 kWh/day m²

<table>
<thead>
<tr>
<th>Configuration</th>
<th>( u_i ), W/m² ( \cdot ) °C</th>
<th>( \alpha_{eff} ) at ( \theta = 0 )</th>
<th>Performance characteristics</th>
<th>Storage water temp. °C</th>
<th>Collection/storage eff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>I day</td>
<td>II day</td>
<td>I day</td>
</tr>
<tr>
<td>Single glazing (5 mm tempered glass)</td>
<td>7.20</td>
<td>0.76</td>
<td>39.3</td>
<td>22.3</td>
<td>42.8</td>
</tr>
<tr>
<td>Compound honeycomb</td>
<td>2.78</td>
<td>0.86</td>
<td>43.1</td>
<td>34.0</td>
<td>58.6</td>
</tr>
<tr>
<td>Duct plates (6 mm)</td>
<td>3.60</td>
<td>0.57</td>
<td>34.5</td>
<td>26.1</td>
<td>43.7</td>
</tr>
<tr>
<td>Aerogels (6–8 mm dia.)</td>
<td>1.71</td>
<td>0.43</td>
<td>29.5</td>
<td>26.2</td>
<td>41.4</td>
</tr>
</tbody>
</table>

gain and thermal storage characteristics of the system are presented. The system performance data indicate the possibility of using it as a water heater with 100% solar energy if the tank inclination is adjusted (on a monthly basis) such that the solar absorber is perpendicular to sun rays at noon.

The transparent honeycomb cover system has been compared with such TIM cover systems as single glazing, duct plates (6 mm GE Plastics structured product) and aerogels (6–8 mm diameter balls); it is found that the compound honeycomb cover system excels over others. The use of the selective absorber provides the benefit of added solar gain and thermal storage.

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