Chapter 2

Literature Reviews

Several investigation on built-in-storage type solar water heating systems have been found in the literature reviews and they can be categorized into 6 groups: (i) systems with simple configuration, (ii) systems using transparent insulation over the absorber, (iii) systems with baffle plate, (iv) systems with reflector, (v) system with thermal diode, and (vi) comparative study of different types of systems. The following sections briefly describe the configuration and design of these systems as well as their advantages and disadvantages.

2.1 Systems with Simple Configuration

Sodha, Nayak, Kaushik, Sabbarwal, and Malik (1979) designed a rectangular built-in-storage solar water heater as shown in Fig. 2.1. The developed model was used to predict the system performance in comparison with the experimental results as well as those obtained by the model developed by Garg (1975). The results indicated that the developed model was better than that of Garg as its efficiency was found to be 37 % while that of Garg's model was only 27%.

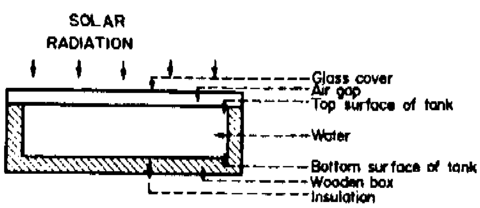


Fig. 2.1 Sodha et al.'s model.

A. Ecevit, Al-Shariah and Apaydin (1989) investigated a triangular built-in-storage solar water heater as shown in Fig. 2.2. The temperature distributions of water in the heaters of different volumes of 127, 168, and 220 liters were studied. The effect of the tilt angle of collector was also studied. Good agreement was found between the mathematical model and the experiment result. The results showed that the increase of temperature at the top zone of the tank for the collector having an inclination of 30° is 35° C, whereas this daily increase in temperature dropped to 33°C and 27°C for the inclination angles of 45° and 60° respectively. For volumetric effect, at the same of inclination angle of 30°, it indicated that the daily rise in temperature at the top of the small collector was 35°C, whereas the rises were 33°C and 31°C for medium and large collectors respectively. Moreover, the daily rise in temperature at the bottom of the collector was 19°C for the small, 15°C for the medium and 8°C for the large collectors. The heaters were found to have 24-hour cycle efficiencies of 0.31, 0.36, and 0.37 for small, medium and large collectors respectively. The reverse flow seemed to have diminished the efficiency in periods of no radiation. Increasing of efficiency of 2% could be achieved if the collectors were insulated during night-time using a 2-cm thick styrofoam plate.

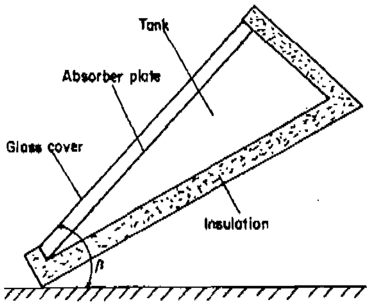


Fig. 2.2 Ecevit et al. (1989)'s model.

2.2 Systems with Transparent Insulation over Absorber

A. Goetzberger and M. Rommel (1987) designed and tested three integrated storage collectors with transparent insulation in central Europe as shown in Fig. 2.3(a). In this study an auxiliary heater was installed as a backup device for each system in different ways. In system (i), a heater was connected in series with the integrated storage collector as shown in Fig. 2.3(b). In system (ii), the last tank of the collector was equipped with an electric heater as shown in Fig.2.3(c). In system (iii), a separate storage tank with an electric heater was added as shown in Fig. 2.3(d). The results showed that the solar fractions of systems (i), (ii) and (iii) were 55.6%, 42% and 46% respectively, and their efficiencies were 35%, 26% and 29% respectively. In comparison with other collector systems, the efficiencies of approximately 22%, 20% and 46% were found in flat plate collector thermosyphon systems, flat plate collector active systems and vacuum tube collector systems, respectively. It was concluded that the built-in-storage system was superior to normal flat plate collector active and thermosyphon systems, but not better than the vacuum collectors systems.

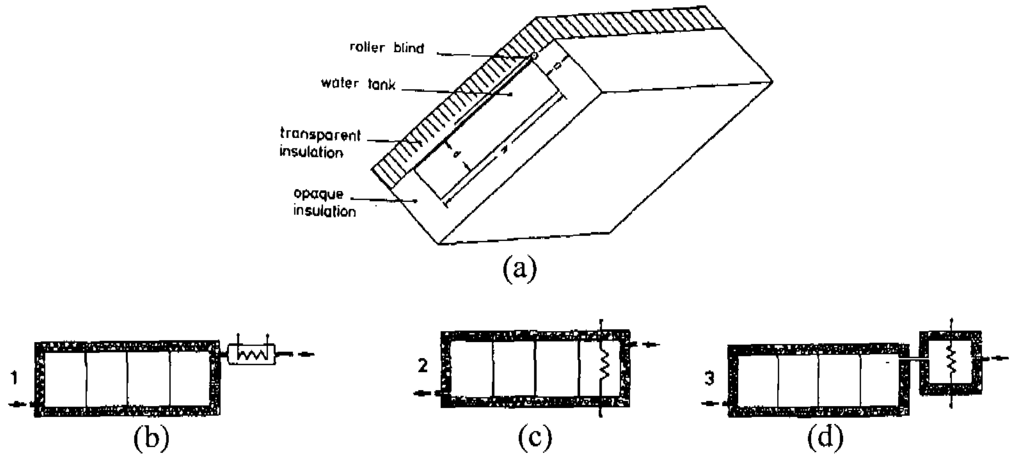
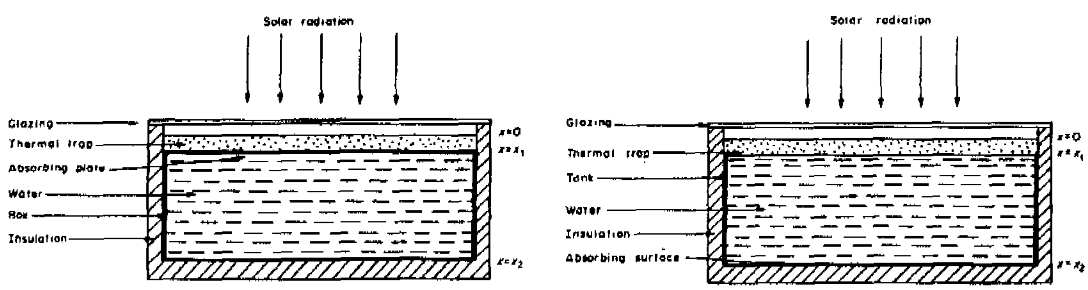


Fig. 2.3 Goetzberger and Rommel's collector model.

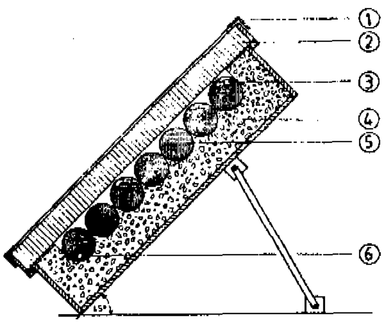
J. Prakash and E.Carnevale (1987) designed and studied two built-in-storage type solar water heaters with a thermal trap below the glazing. Both storages were rectangular, but one was a closed box while the other was an open box as shown in Fig. 2.4. These two models with different thicknesses (0.01, 0.02, 0.03, and 0.04 m) of thermal trap (made of methyl methacrylate material) were tested with and without a night insulation cover. The effect of flow rate was also studied. From the results, the efficiency of the model with thermal trap was higher than that without a thermal trap. The system with thermal trap could maintain higher water temperature after sunset than that without a thermal trap. Moreover, it indicated that, for no-flow condition, the thickness of only 0.04 m was not optimum, while for a flow rate of 30 kg/h, 0.02 m was the optimum thickness. It was also found that a night insulation cover could raise the efficiency for both cases. The highest efficiency of 67.5% was achieved on the system with a thermal trap and a night insulation cover. In fact, if the night insulation cover is used, the thermal trap should be negligible, because in the daytime, more energy is transmitted to the water in the heater without a thermal trap, while the heat loss during off-sunshine hours is nearly equal due to the use of the night insulation cover in both types of heaters.



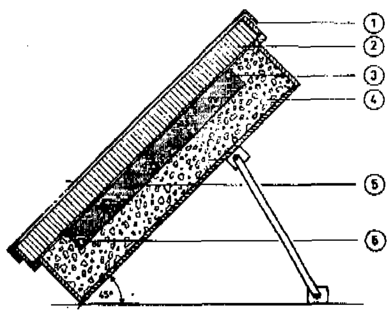
(a) close box type (b) open box type

Fig. 2.4 J. Prakash and E. Carnevale's model.

Schmidt, Coetqberger, and Schmid (1988) investigated and tested two integrated collector storage systems with transparent insulation. One used tubular subunits water tank having 117.8 liters/m^2 absorber surface, and the other used a whole rectangular shape tank containing 96 liters/m^2 as shown in Fig. 2.5. Two cases were investigated. One was that the hot water was withdrawn 40 liters every day and the other was the stagnation (no water flow) case. The influence of various parameters, those are water withdraw volume, angle of inclination, profile of water withdraw, required hot water temperature, yearly solar fraction and yearly efficiency of the heater were studied. From the results, the temperature for the stagnation case could be achieved to 105°C, whereas for the withdraw case, the temperature was in the range between 10-80°C. However, the efficiency of the withdraw case was 10% higher than that of the stagnation one. Too high water draw-off would result in a lower water temperature that could cause the risk of freezing in winter. The optimum withdraw water volume was found at 40 liters/m^2/day. For a required hot water temperature in Winter of 50°C, the solar fraction of the withdraw case was 58% (68% in Summer) with a system efficiency 28% (36% in Summer).



(a) tubular subunits system



(b) whole flat tank system

Fig. 2.5 Schmidt's model.

Prakash, kaushik, kumar, and Garg (1994) designed a triangular built-in-storage-type solar water heater with transparent insulation on the top and all of the sides except the bottom as shown in Fig. 2.6. The transparent insulation material used is Methyl Methacrylate. Many cases were investigated in the study as in the following:

1. The configurations considered were (i) without transparent insulation and with and without night insulation, (ii) transparent insulation only on the top, and (iii) transparent insulation on the top as well as at the sides. The maximum water temperature with transparent insulation on the top and at the sides was 4-6°C higher than the corresponding water temperature in the other cases.

2. Under no-flow operation, the efficiency of the system with transparent insulation on the top and at the sides, was 12% higher than those without transparent insulation.
3. The investigation under constant flow rates of 10,20,30, and 40 kg/h showed that as the flow rate increased, the maximum water temperature decreased, and higher average daily efficiency was also obtained at higher flow rate. The maximum efficiency of 76% was found at a flow rate of 40 kg/h.
4. For intermittent flow conditions, several constant flow rates of 20, 40, and 60 kg/h were withdrawn during the periods of 10-11 hrs, 14-15 hrs and 19-21 hrs. Similar results were obtained as in the case of constant draw-offs, except the average daily efficiency was lower.
5. The optimum thickness of the transparent insulation was between 2 and 3 cm, whereas the daily system efficiency was about 46%.

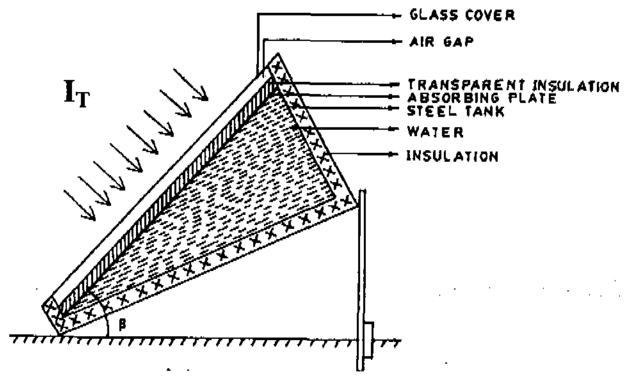


Fig. 2.6 Pragkash et al.'s model.

Arulanantham, Reddy and . Kaushika (1998) studied solar gain characteristics of absorber with transparent insulation materials that placed parallelly between the absorber plane and the glass cover of a solar collector storage system as shown in Fig. 2.7. The insulation was a slap of Methyl Methacrylate (MMA) material. The result showed that the MMA slap system efficiency was 12% lower than that obtain using honeycomb cover, but it showed higher efficiency as compared to those using single and double glass covers. It was suspected that the honeycomb insulation may have higher transmittance than the Methyl Methacrylate material.

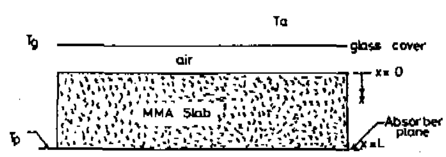


Fig. 2.7 Arulanantham et al.'s model.

2.3 Systems with Baffle Plate

Prakash, Garg and Datta (1985) investigated the performance of a built –in storage-type solar water heater with a holed baffle plate operating as a collector as shown in Fig. 2.8. Several cases were investigated as follows: (i) no flow, (ii) constant water flow rates, (iii) intermittent flow to meet requirements of hot water, and (iv) intermittent draw, with water withdrawn for a short time interval at specific hours. It was found that the water temperature reached about 60°C in summer and 50°C in winter for no flow conditions. Using a night insulation cover at night did not improve the performance in almost all cases, especially at high flow rates; except at no flow conditions, the temperature of night insulation cover system was higher than that of without night insulation cover system. Therefore, the heat losses during the night may be substantially reduced by a baffle plate that prevents convection from the storage to the collector channel, so the night insulation cover play little effect to improve the performance of the system.

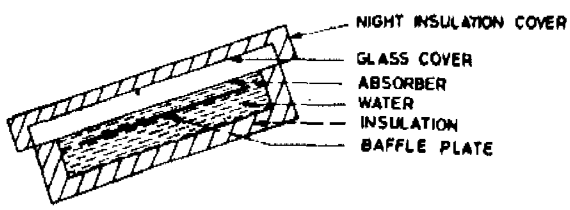


Fig. 2.8 Prakash et al.'s baffle plate model.

Vaxman and . Sokolov (1985) investigated and studied an integral compact solar water heater in which the storage was separated from the absorber by a baffle plate as shown in Fig. 2.9. In the no-draw case, the maximum bulk efficiency of the system was 53% and decreased to 15% at the end of the 24-hour cycle. In the withdrawing case the bulk efficiency was increased by 8% and 27% for the 30 and 110 liters, draw-offs respectively. However, in periods of no radiation, a reverse flow region developed, resulting in increased heat loss.

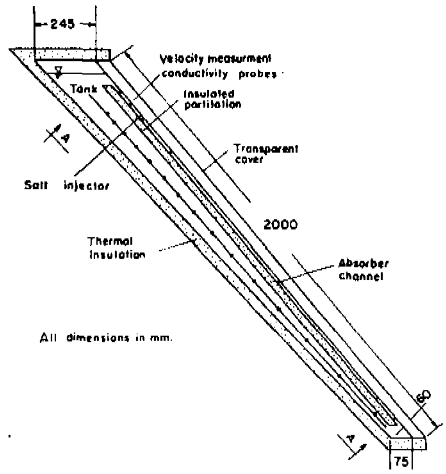


Fig. 2.9 Vaxman and Sokolov's model.

Siddiqui and Kimambo (1994) developed a compact integral solar water heater for Africa as shown in Fig. 2.10. The solar water heater was installed with an inner insulation partition. The absorber area was 1 m^2 and the tank capacity was 75 liters. The effects of varying the channel depths of 5, 10, and 15 mm between an absorber plate and the insulation partition were studied under dynamic load conditions in which 5 liters of hot water were drawn off every 2 hours during the daytime. Tests were also conducted with and without the insulation partition. The results showed that the heater could generate the maximum amount of hot water with 60°C at the channel depth of 15 mm. The system with the insulation partition produced a higher average temperature than that without the insulation partition. Under dynamic load operation, the performance of the heater was not as good as the static performance as expected since the temperature under dynamic load condition could reach only 52°C. It was also indicated in this study that if this heater ware commercially produced, the cost which was U.S.$ 100 for this prototype would come down to about U.S.$ 60 per heater.

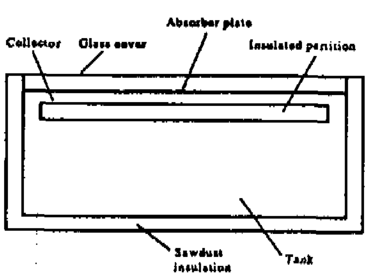
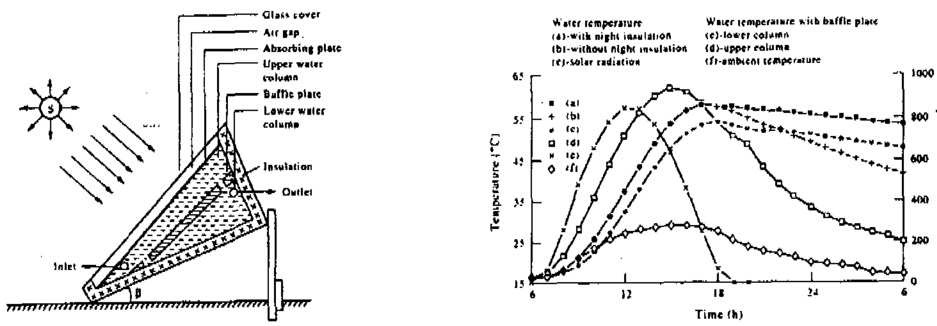


Fig. 2.10 Siddiqui and Kimambo's model.

Kaushik, Kumar and Garg (1995) investigated a triangular built-in-storage solar water heater with an insulating baffle plate which was used to separate the collector channel in upper and the storage tank in lower columns of water as shown in Fig. 2.11(a). The effects of the baffle plate on the system performance were studied for various cases such as varying the vent area, the water mass ratio in the two columns, and the drawing duration under constant flow rate. The effects of thermal conductivity and thickness of the baffle plate on the water temperature were also investigated. The model was also studied in the cases of without the baffle plate but having a night insulation cover. The results obtained are shown Fig. 2.11(b). Moreover, it was also found that the vent area had only marginal effect in the water temperature, and increasing the vent area made the temperature of the upper water column slightly fall. The temperature of the lower water column would slightly increase by the heat transferred from the upper to the lower water column. The mass ratio of two columns had a slight effect to change in the water temperature as decreasing mass of water in lower column could result in a slight increase in the water temperature in this column. The thermal conductivity and the thickness of the baffle plate were found to make no appreciable change in the water temperature.



(a) (b)

Fig. 2.11 (a) Kaushik et al.'s model, (b) Effect of temperature with and without the baffle plate.

<u>Kaptan and Kilic</u> (1996) investigated a novel built-in-storage-type solar water heater consisting of 5 pipes, each having 87 liters capacity, under no draw-off. A baffle plate was placed inside each pipe for good heat transfer to the water as shown in Fig. 2.12. Each pipe was 1.8 m in length and 12 cm in diameter. The experiments were tested inside the laboratory by using 27 lamps instead of the sunlight and tested for four constant insolations (245, 475, 600, and 890 W/m^2). It was found that the theoretical predictions and the experiment results were in good agreement. The mean collection efficiencies under each insolations were 48.3, 52.9, 53.7, 55% respectively. And insulated baffle plates was suggested to improve the energy losses during nights or periods of insufficient radiation.

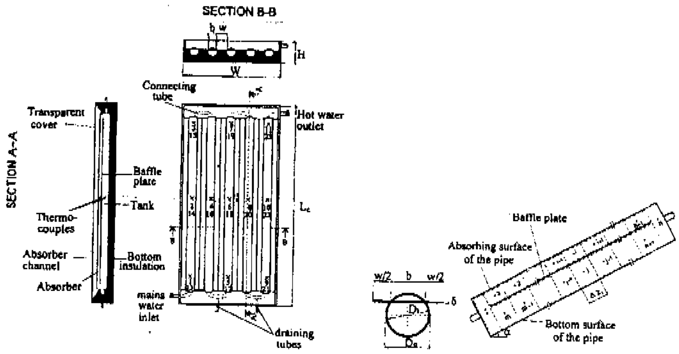
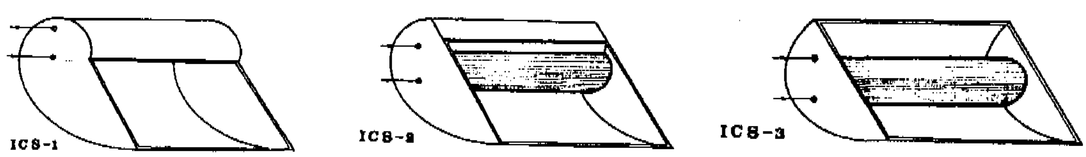


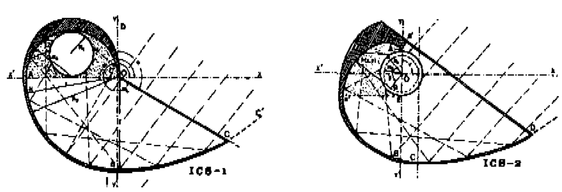
Fig. 2-12 Kaptan and Kilic's model.

2.4 Systems with Reflector

Tripanagnostopoulos and Yianoulis (1992) investigated the thermal losses from the absorber to the ambient of three stationary concentrating solar devices of the integrated collector and storage (ICS) system. The device consisted of a cylindrical tank placed horizontally in a properly shape as shown in Fig. 2.13(a). The models were separated into two groups, those are group A and group B. Group A used polished stainless steel sheet mirror and simple black paint absorber. Group B used selective absorber and aluminized mylar mirror. The results were also compared with a conventional flat plate solar water heater with the same selective absorber condition. It was found that the B type could produce higher temperature and conserve the hot water better because its geometry of various parts allowed less thermal losses from the absorber. It was also shown that the ICS-1 model of both types could trap the hot air in the collector better than the other one as shown in Fig. 2.13(b) since it could reduce heat losses during night better than the other. Comparing with the flat plate collector system, these models produced lower optical efficiency since the absorbed radiation came only from the mirror.



(a)



(b)

Fig. 2.13 Three prototype models of Tripanagnostopoulos and Yianoulis.

Kalogirou (1997) investigated an integrated collector storage system by comparing with a flat plate collector of the same aperture area and storage volume in term of thermal performance and economic life cycle. The model was a concentrating collector with inner cylindrical absorbed tank as shown in Fig. 2.14. It had 1.77 m^2 of aperture area, 0.2 m of absorber tank diameter, and 1.47 of a concentration ratio. From the results, the predictions of the end-of-day storage temperature agreed with the experiment within the maximum deviation of 5.1 %. The initial cost of the system was 13% lower than that of the flat plate collector system. The F-values (solar fraction) were 0.85 and 0.83 for the ICS system and the flat plate collector system, respectively. The life cycle saving of C£ 330 against C£ 201, and pay-back period of nine years against 11 years, were found. However, this model had high heat loss during night-time as the average storage tank temperature was decreased from 63.6°C at the end-of-day to 28.2°C in the next morning.

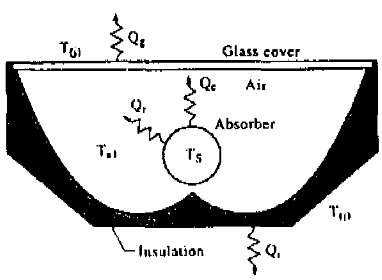
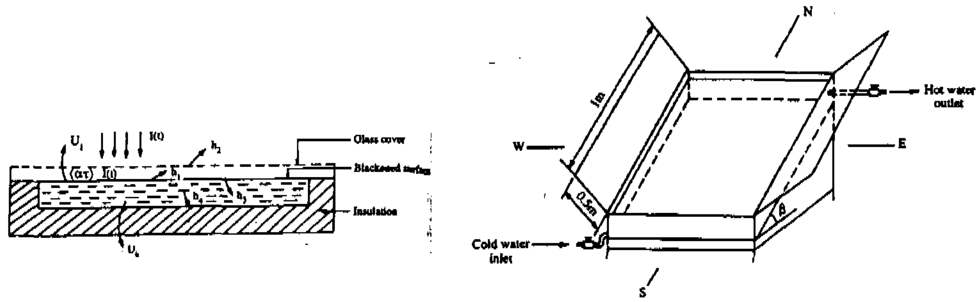


Fig. 2.14 K. Soteris's model.

Tiwari, Hong, and Goyal (1998) investigated a low cost solar water heater suitable for rural as well as urban areas of Vietnam by using three cases of a built-in-storage type solar water heater as shown in Fig. 2.15(a). The first case was a horizontal collector, the second case was a slope collector without reflector, and the third case was a slope collector with reflectors. The result showed that the slope collector with east-west reflectors as shown in Fig. 2.15(b) could get more radiation and had higher water temperature than the others. The thermal performance of the heater would be better if the effective transmittance-absorptance product of the absorber were on the higher value, i.e. the glass cover should be cleaned for better transmission, and the blackened surface should be reprinted for better absorption.

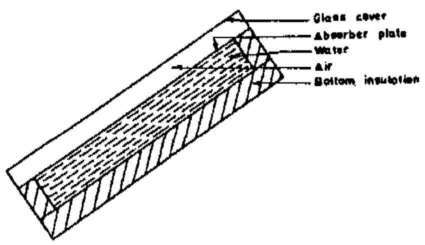


(a) (b)

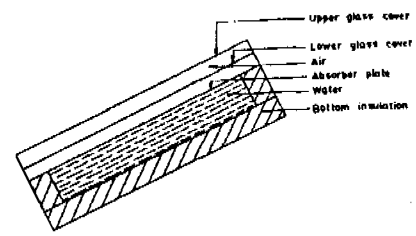
Fig. 2.15 Tiwari et al.'s models (a) Horizontal collector, (b) slope collector with reflector plates.

2.5 Comparative Study on Different Types of Systems

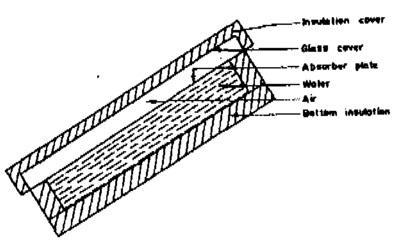
Garg and Rani (1982) designed and studied a rectangular built-in-storage solar water heater as shown in Fig. 2.16. Four cases were tested in the study, those are (i) when a single glass cover was used, (ii) when double glass covers were used, (iii) when a single glass system with night insulation cover was used, and (iv) when a single glass system with a baffle plate was used. It was found that (1) the model with only single glass cover could raise the water temperature faster than the one with double glass covers, but it also showed sharply fall of the water temperature, (2) the depth of water column of 10 cm was optimum for both operations during the day and night, (3) the night insulation and baffle plate improved the performance of this model, and the night insulation was more efficient during the night-time than the baffle plate, (4) both night insulation and baffle plate could supply sufficient hot water up to 55°C in the early morning hours.



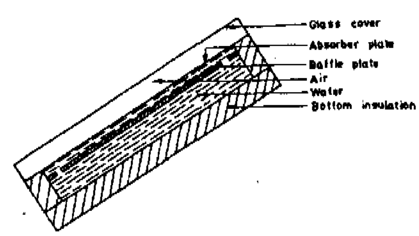
(a) System with single glazing.



(b) System with double glazing.



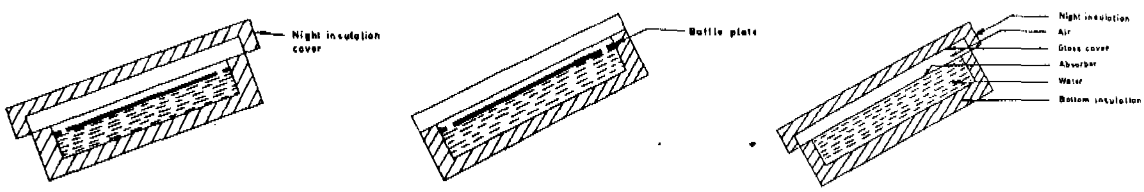
(c) System with night insulation cover.



(d) System with baffle plate.

Fig. 2.16 Garg and Rani's model.

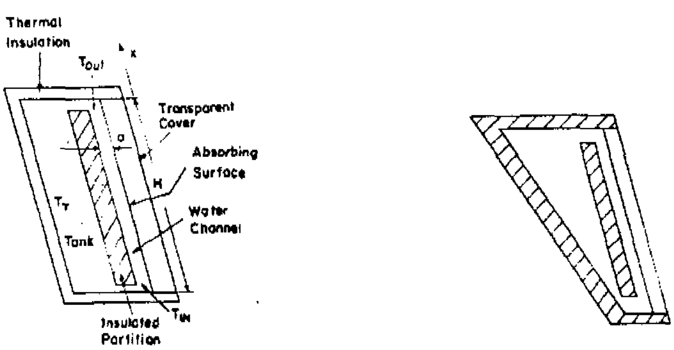
Prakask, Garg, and Datta (1983) investigated and studied the effect of baffle plate on the performance of a rectangular built-in storage type solar water heater as shown in Fig. 2.17. Three cases were tested in the study, those are (i) when a baffle plate and a night insulation cover were used, (ii) when only a baffle plate was used without a night insulation cover, (iii) when only a night insulation was used without a baffle plate. For the first case, at no draw condition, the water temperature of 50°C at 21:00 hour was found to remain greater than 40°C during the early morning hours. But if the water was drawn off at 30 l/hr, the average water temperature was at 38°C after the 8-hour period from 11.00-14.00 hr and reduced to about 24°C for the morning hours. In the second case the water temperature was 47°C at the end of day and remained about 35°C in the next morning under no draw of water. The results of the third case were similar to those of the second case.



(a) Case (i). (b) Case (ii). (c) Case (iii).

Fig. 2.17 Prakash (1983) et al.'s model

Sokolov and Vaxman (1983) designed and analyzed two integral compact solar water heaters with different geometry i.e. the rectangular and triangular shapes. Both models used insulated partitions as shown in Fig. 2.18. The numerical model developed was also compared with the experimental data. It was found that the triangular shape was superior. The study also showed that the efficiency of this model obtained from the experiment was 53% whereas it was 57% when predicted from the developed mathematical model.



(a) Rectangular shape. (b) Triangular shape.

Fig. 2.18 Sokolov and Vaxman's model.

Arshad Ali (1984) investigated a prismatic solar thermal collector as shown in Fig. 2.19. The investigation was carried out in two cases: one is when only an acrylic plate was used as a collector cover and the other is when an additional glass was placed on the acrylic plate. In the first case the optical efficiency of the collector was higher whereas, in the second case, the collector heat loss efficient was smaller. In case of high temperature, Ali's model had higher heat losses than the conventional collector. However a prismatic solar thermal collector could produce energy at half cost of electricity.

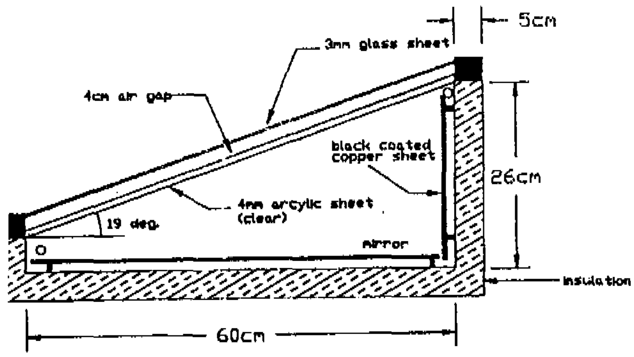


Fig. 2.19 Ali's model.

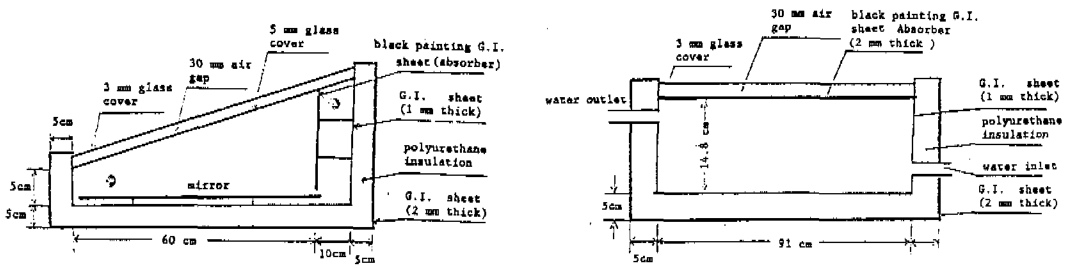
Prakash, Garg and Datta (1985) investigated the performance of a novel built-in storage type solar water heater containing a layer of phase change material (PCM) as shown in Fig. 2.20(a). The model was compared with the conventional built-in storage-type solar water heater as shown in Fig. 2-20(b). From the results, the PCM type could produce hot water at a temperature about 2-3°C higher than that obtained from the conventional type. Also its efficiency was found to be higher than that of the conventional type using night insulation cover. The model with 4-cm depth of PCM gave higher efficiency than the one with 2-cm depth.

(a) System with PCM layer (b) Conventional type

Fig. 2.20 Prakash et al.'s model.

Yun Fei (1987) compared two built-in storage-type solar water heaters; those are conventional rectangular box type and prismatic type as shown in Fig. 2.21. The experimental results showed that, when considering as collectors, the prismatic type solar water heater has better instantaneous collector performances than the conventional type.

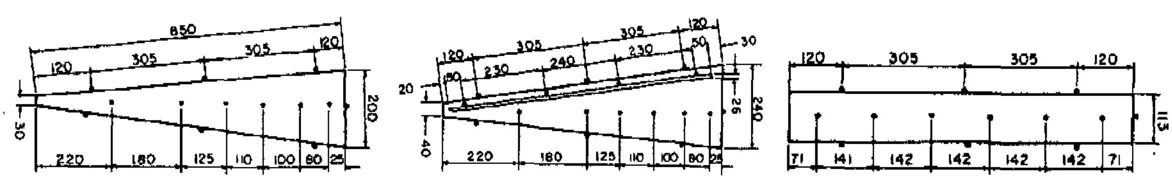
Its optical efficiency and overall heat loss coefficient of the prismatic type were 80% and 13.1 W/m^{2}K respectively, while those of conventional box type heater were 73% and 12.1 W/m^{2}K respectively. The system performance of the prismatic type was better than that of the conventional box type by about 6%. In the case of economic analysis, both types of built-in-storage solar water heaters were found to be cheaper than solar water heater with separated storage and could also produce useful energy at about half of the price of electricity.



(a) Prismatic type (b) Conventional rectangular box type

Fig. 2.21 Yun Fie's model.

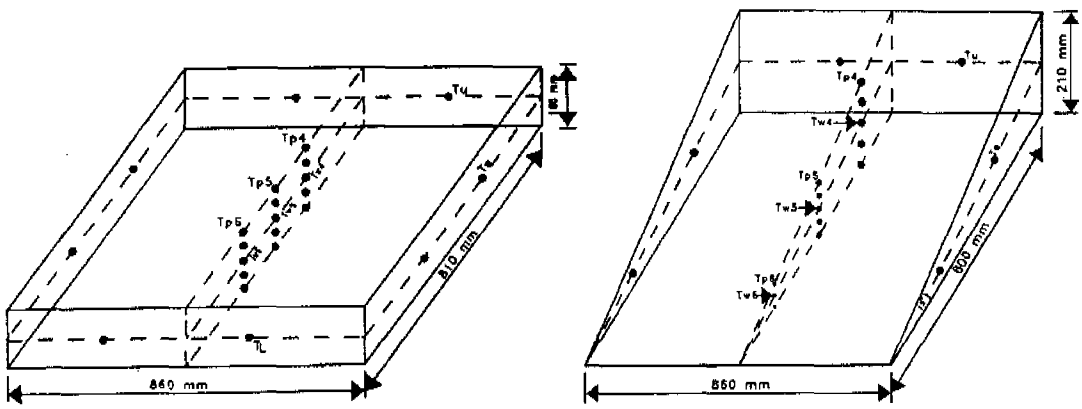
Ecevit, Wais and Al-Shariah (1990) compared the performance of three built-in-storage-type solar water heaters i.e. a rectangular system, a triangular system, and a triangular system with a baffle plate that separated between collector channel and the storage tank, as shown in Fig. 2.22. These three models were tested under identical conditions and had equal volume. The baffle plate that used in the triangular system was constructed by sandwiching 20-mm thick styrofoam between two 3 mm-thick sheets of Plexiglas. For cases without baffle plate, it was found that (i) the triangular model had higher rate of heating than that the rectangular model, leading to a higher forward circulation rate and an enhance convection in the triangular system, and (ii) during the cooling period, a smaller reverse circulation obtained in the triangular system due to a faster cooling compared with the rectangular system. For the viewpoint of the effect of the baffle plate, it was found that this baffle plate did not help increasing the efficiency but made the efficiency drop during the heating period.



(a) (b) (c)

Fig. 2.22 Ecevit et al. (1990)'s model (a) the triangular without baffle plate, (b) the triangular with baffle plate, and (c) the rectangular.

Somchart, Chaiyong and Suvit (1994) compared two built-in-storage-type solar water heaters. One was a rectangular shape and the other was a triangular shape as shown in Fig. 2.23. Each had one glass cover, 0.7 m^2 of absorbing area, and approximately 75 liters of water storage capacity. The result showed that the average efficiencies ware 59% and 63%, the average maximum water temperatures were approximately 52.6°C and 50.3°C, for rectangular and triangular built-in-storage solar water heater respectively, where the next morning temperatures are the same (35.8°C) for both types. The heat loss at night was less for the triangular solar water heater. It was also obtained that the triangular shape had better water circulation during the day but worse at night. The rectangular type had greater temperature difference in the channel depth, and also had higher maximum temperature hence heat losses were found.



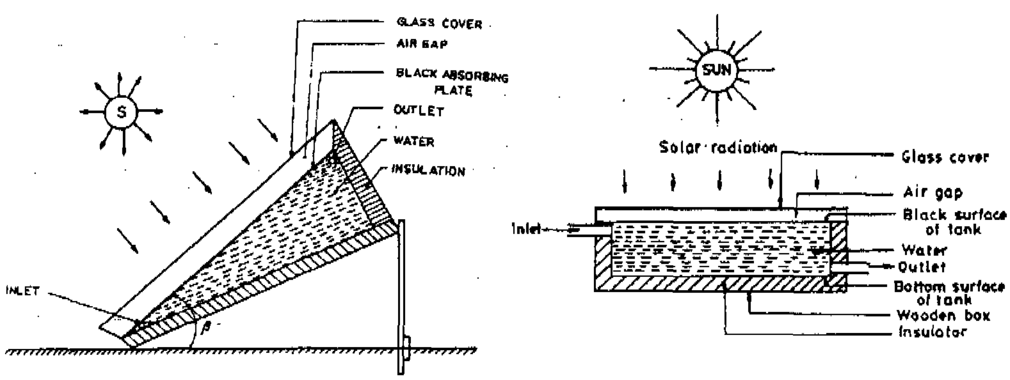
(a) Rectangular type (b) Triangular type

Fig. 2.23 Somchart et al.'s models.

Kaushik, Kumar, Garg and Prakash (1994) analyzed a triangular built-in-storage solar water heater compared with the rectangular one under winter conditions. The two models are shown in Fig. 2.24. The performance of system was analyzed under several operating condition; i.e. no flow, constant flow rate (at 9, 18, 27 and 36 kg/h) and intermittent flow rate (at 18, 36 and 54 kg/h for durations 10-11, 14-15 and 19-21 hours, respectively) conditions. The effect of the night insulation cover and the tilt angle of the absorber were also analyzed. The results found are as in the following;

1. Under no flow condition, at the same end-of-day water temperature, the water temperature in the next morning of the system with night insulation cover was nearly 24°C higher than the ambient temperature, whereas that of the system without night insulation cover was 14°C. The efficiency of the system with night insulation was 17% higher that that without night insulation cover.

2. Under constant flow rate condition, the system had a higher efficiency than that under no flow. The system with low flow rate had a higher water temperature than the system with high flow rate, especially after the 14:00 hours. But the higher flow rate system had higher efficiency.
3. Under intermittent flow conditions of the system without night insulation cover. At the flow rate of 18 kg/h, the temperature of water for the periods 14-15 h and 19-21 h was 30°C and between 25°C and 35°C, respectively. For the flow rate of 54 kg/h, the temperature of water for the periods 14-15 h and 19-21 h was 26°C and between 23°C and 33°C, respectively. And it was indicated that if the flow rate was 18 kg/h for the above-mentioned periods, 98 liters of water was available next morning at a temperature of 12°C higher than the ambient temperature. When the flow rate was increased to 54 kg/h, the next morning water temperature was only 6°C higher than the ambient temperature.
4. The investigation on the effects of angle of inclination of the collector at 11.5°, 30°, 45° and 60° on the water temperature of the system without night insulation showed that at 45°, the water temperature was higher for the whole period as compared to the other cases. At the lowest performance of the triangular system which was at a tilt angle of 15°, it was found that the water temperature was higher than that of the rectangular system of similar dimensions.



(a) (b)

Fig. 2.24 (a) Kaushik et al.'s model (b) the compared model.

2.6 System with Thermal Diode

Mohamad (1997) investigated an integrated triangular solar collector-storage tank system with thermal diode. The model was of triangular shape and a back insulated (by a styrofoam board). Plexiglas sheet was used to separate the collector channel into the upper part and the storage tank into the lower part. Spaces were left at the top and the bottom as the vent areas as shown in Fig. 2.25. This insulating separator plate was fixed with a thermal diode at the bottom to prevent a reversible flow in the night-time. It was found that the thermal diode could reduce the rate of heat transfer during the night-time. The thermal efficiency was about 50%, which was considered to be comparable with those of conventional collectors.

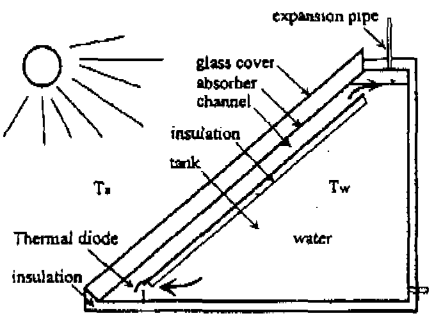


Fig. 2.25 Mohamad's model.

2.7 Concluding Remarks from the Reviews

The reviews of the built-in-storage type solar water heater can be concluded as in the following:

1. The conventional system with simple configuration has higher optical efficiency than other systems but it produces higher heat losses during off-sunshine hours.
2. The triangular geometry has a little better water temperature distribution than the rectangular geometry.
3. The night insulation cover is good to prevent heat losses during night-time, but it is not convenient under actual operation.
4. The baffle plate is effective to reduce heat losses passing through the aperture area, but it still suffers from heat convection losses due to reverse circulation during off-sunshine.

5. Fixing with transparent insulation above the absorber surface could prevent heat losses passing through the aperture area, but its optical efficiency is also reduced.
6. The simple system with reflector has higher optical efficiency because it can receives greater solar intensity to the absorber area in the day-time, but it still suffers from heat losses passing through the aperture area in the night-time.
7. The thermal diode is significant to prevent reverse circulation during off-sunshine hours, which should be considered for further research.

According to the conclusion, the new model of the built-in-storage type solar water heater should be developed to produce high thermal performance on heating periods and conserve hot water at high temperature during the night-time for uses in the next morning. Moreover, the successive development of the new built-in-storage type solar water heater that is inexpensive will induce to popularly use for water heating by such solar water heater.