Chapter 4

Experimental Investigation

4.1 Purpose of Experimental Investigation

The developed built-in-storage solar water heater was constructed as shown in Fig. 4.1. Several outdoor tests were conducted on the constructed built-in-storage solar water heater to investigate its thermal performance under actual operating conditions. A conventional solar water heater was also set up and tested simultaneously for comparison. The purpose of the experimental investigation can be specified as follows:

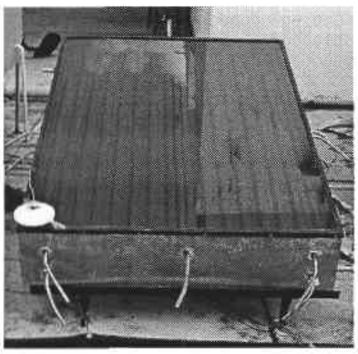

Fig. 4.1 Built-in-storage solar water heater.

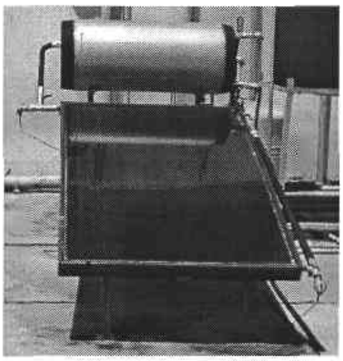

Fig. 4.2 The conventional solar water heater.

4.1.1 To investigate the effect on the system performance of the developed built-in-storage solar water heater due to the reverse and no reverse thermosyphon flow of warm water from storage to collector during the night-time period.

4.1.2 To compare the performance obtained experimentally from the developed built-in-storage solar water heater with those obtained from a conventional solar water heater, the collector of which is separated from the storage tank.

4.2 Configuration of Conventional Solar Water Heater

The conventional solar water heater that was tested simultaneously in this investigation is a product of the Electricity Generating Authority of Thailand (EGAT), Model S-150 as shown in Fig. 4.2. It consists of 2.16 m^2 of a collector area and 130 liters of a storage tank capacity. The blackened absorber plate is fixed with parallel fluid tubes and back insulation. It is covered with a single glass sheet. An air gap of 30 mm is left between the glass sheet and the absorber. The storage tank is of a cylindrical shape and thermally insulated at all outer surface. It is placed horizontally and leveled slightly higher than the collector. The collector is piped to the storage tank by an insulated connecting pipe. Both BIS and conventional systems are located on the deck of a building and also placed side by side at the same collector tilt angle.

4.3 Experimental Setup

4.3.1 Measurement and Instrumentation

The temperatures of the water in both solar water heaters are measured by k-type thermocouples. The locations of these thermocouples for each solar water heater are shown in Fig. 4.3 and Fig. 4.4. The ambient air temperature is also measured by a thermocouple. A pyranometer is used to measure the total solar irradiance on the collector surface. Wind speed around the test area is measured by a wind anemometer. A data logger is used to collect and record the data every 10 minutes. It is noted here that the temperatures are the instantaneous values at every 10 minutes, but the value of total solar radiation recorded at any 10 minutes is averaged from period of time.

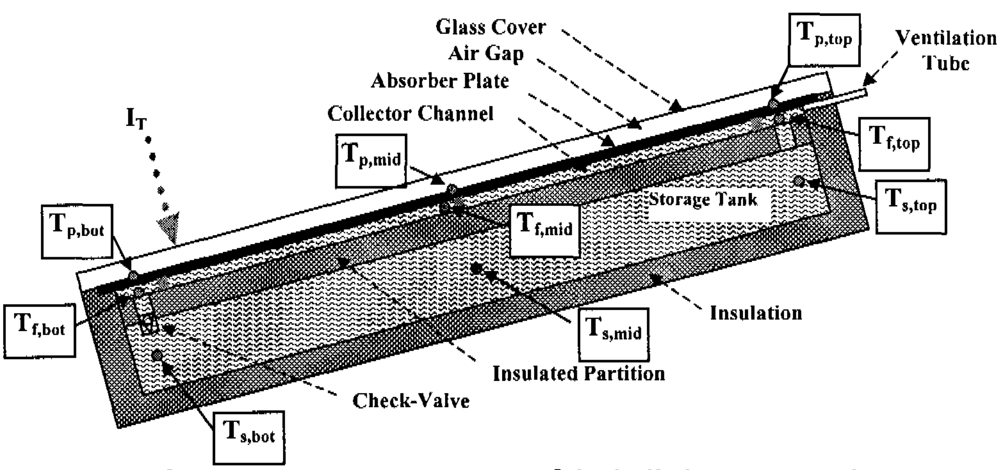

Fig. 4.3 Location of temperature measurements of the built-in-storage solar water heater.

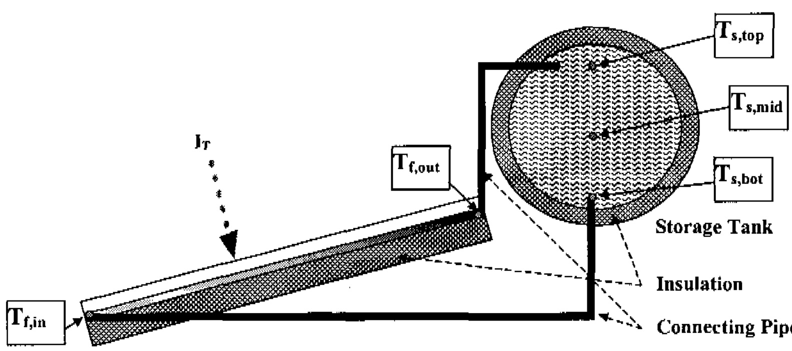

Fig. 4.4 Location of temperature measurements of the conventional solar water heater.

4.3 2 Test Procedure

The outdoor tests of the newly-designed BIS solar water heater have been done for three cases:

(1) those with reverse circulation at night i.e. the check-valve is forced open

(2) those without reverse circulation at night i.e. the check-valve is forced close and

(3) those with check-valve operated freely. In all test runs mentioned above,

the conventional solar water heater is also tested simultaneously for the purpose of comparison. Every test run begins around 06:00 hr before sunrise. Before each test run commences, the water temperatures inside each system are maintained close to the ambient temperature. No water is withdrawn from the system during the considered test period. The hot water storing in both tanks are completely withdrawn in the next morning before the next test run.

4.4 Experimental Test Runs and Results

The experimental results of different cases mentioned above were recorded for several days. Some graphs of those results were showed in Figs. 4.5, 4.6 and 4.7. The experimental data obtained from all these test runs can be found in Appendix A.

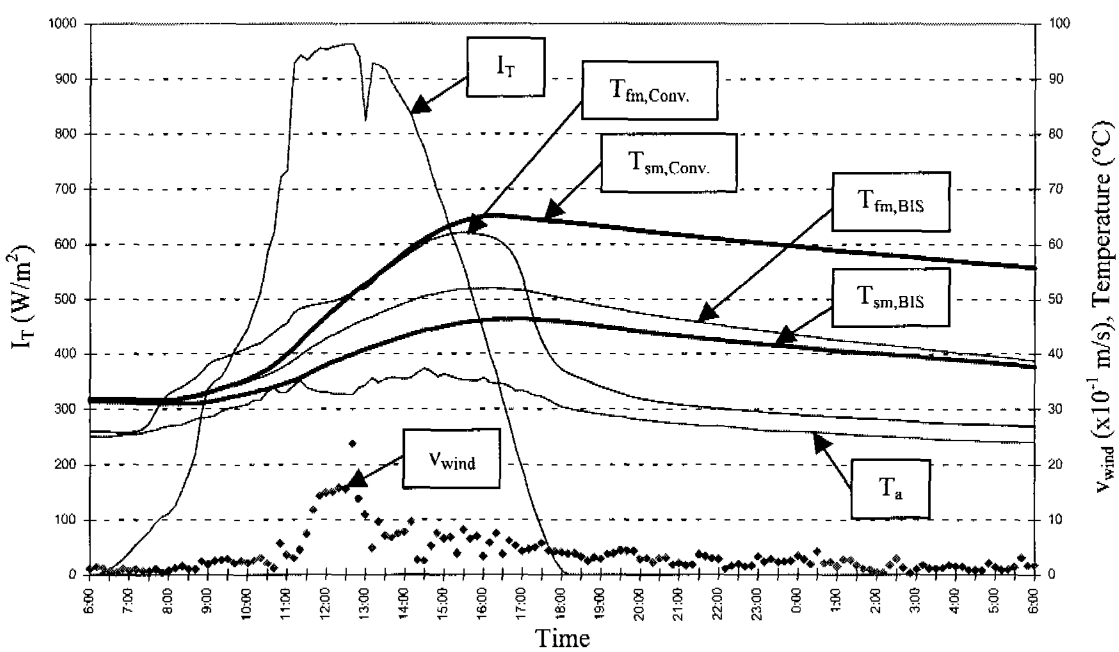

Fig. 4.5 Experimental data recorded on 9/10/2002 for the test on BIS system with reverse circulation at night.

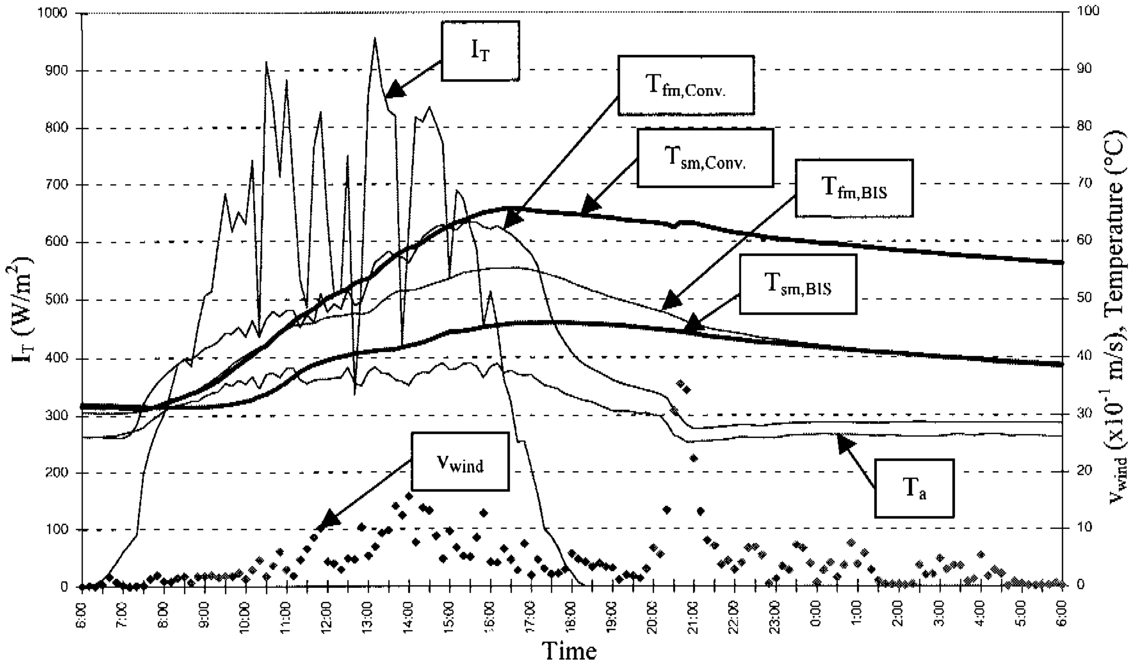

Fig. 4.6 Experimental data recorded on 3/10/2002 for the test on BIS system with check-valve operated freely.

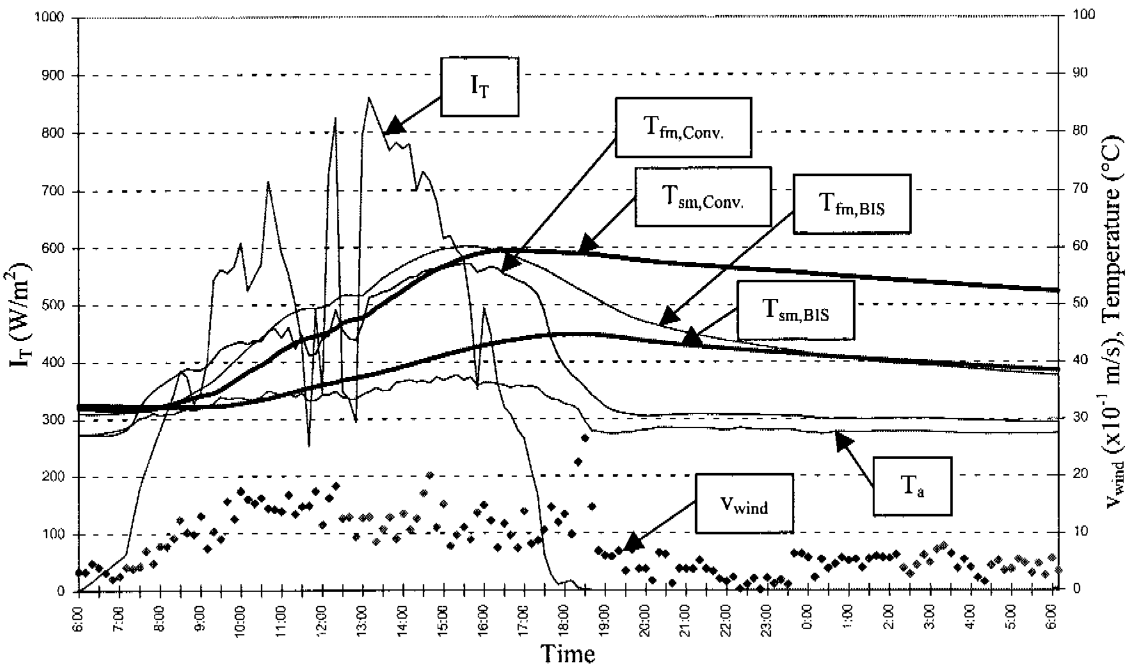

Fig. 4.7 Experimental data recorded on 14/7/2002 for the test on BIS system with no reverse circulation at night.

Figures 4.5, 4.6 and 4.7 show the experimental data obtained from the tests on three sunny days with total solar radiation on the collector surface for each day of about 20 MJ/m^2. A clearer sky can be seen on Fig. 4.5 while fluctuations of solar irradiance due to the presence of clouds appear on Figs.4.6 and 4.7. The ambient temperatures for both days increased to about 36-38 °C in the afternoon and dropped to about 24-25 °C in the night-time. The temperatures $T_{fm,BIS}$ and $T_{sm,BIS}$ are average values of water temperature in the collector channel and storage tank, respectively, of the BIS system, whereas $T_{fm,conv}$ and $T_{sm,conv}$ are those for the conventional system. The difference in the three tests is that the water temperatures of BIS system on Fig. 4.5 are obtained when the system operated with reverse circulation while those on Fig. 4.6 are recorded from the test when the check-valve in the BIS system was allowed to operate freely and those on Fig. 4.7 are obtained when the system operated with no reverse circulation. In both figures, the storage temperatures of the BIS system are lower than those of the conventional system due to the fact that the BIS system has larger volume of water storage. In fact, when amount of energy is concerned, both systems are considered compatible. It can be seen from Fig. 4.5 that, throughout the night, $T_{fm,BIS}$ is always higher than $T_{sm,BIS}$. This has demonstrated the result of the reverse circulation of the hot water from the storage tank to the collector channel. In comparison, this phenomena is not shown in Figs. 4.6 and 4.7 as $T_{fm,BIS}$, for a few hours after the sunset, becomes lower than $T_{sm,BIS}$. This implies that the reverse flow is reduced or even does not occur. Therefore it can be concluded that the check-valve can be successfully used for preventing reverse circulation.

From the experimental test results, the thermal performance parameters of both systems for each test run can be determined using the indicators mentioned in Chapter 3. The daytime collecting efficiency, η_c, which is a ratio of amount of heat stored in the tank from sunrise till sunset (from 06:00 to 18:00 hr in this study) to the total solar radiation falling on the collector surface for the same period of time, is calculated by eq. (3.17). The storage efficiency during the cool-down period at night, η_s, is determined based on the remaining heat content of the tank before sunrise of the next morning to the maximum possible heat losses from the tank. It is calculated by eq. (3.18). The system efficiency during 24 hours, $\eta_{24hours}$, can be determined by eq. (3.19). Amount of energy stored in the tank before sunrise of the next morning, $Q_{morning}$, can be calculated by eq. (3.20).

The results of these thermal performance parameters of both conventional and built-in-storage solar water heaters for various test runs under three different cases are presented in Table 4.1.

Table 4.1 Thermal performance parameters for BIS system obtained from various test runs in comparison with those of conventional system.

Date	I_T (MJ/m^2)	η_c		η_s		η_{24hour}		$Q_{morning}$ (MJ)	
Case 1: BIS system with reverse circulation at night (the check-valve was forced open throughout the test)									
		BIS	**Conv.**	**BIS**	**Conv.**	**BIS**	**Conv.**	**BIS**	**Conv.**
17/7/2002	12.3	44.7	38.7	58.9	76.3	15.2	26.4	10.1	10.0
5/10/2002	15.8	37.9	40.2	57.5	75.9	16.2	30.2	11.7	13.2
9/10/2002	20.7	42.3	40.9	50.2	73.9	17.4	29.1	15.6	17.2
13/10/2002	22.7	36.7	38.9	60.9	75.3	14.1	28.9	18.0	18.8
Average		**40.4**	**39.7**	**56.9**	**75.4**	**15.7**	**28.7**	**13.9**	**14.8**
Case 2: BIS system with check-valve operated freely (throughout the test)									
		BIS	**Conv.**	**BIS**	**Conv.**	**BIS**	**Conv.**	**BIS**	**Conv.**
17/8/2002	11.2	43.3	38.4	60.4	77.2	17.9	27.0	9.3	9.1
3/10/2002	20.7	39.9	42	61.7	75.2	18.7	30.0	14.2	16.3
11/10/2002	25.2	37.1	38.5	63.3	74.6	16.7	26.6	19.0	19.6
13/11/2002	18.7	36.1	43.8	60.7	76.0	17.5	32.1	13.1	15.7
15/11/2002	20.7	38.2	44.6	61.5	74.6	16.4	31.5	14.2	16.9
Average		**38.9**	**41.5**	**61.5**	**75.5**	**17.4**	**29.4**	**14.0**	**15.5**
Case 3: BIS system with no reverse circulation at night (the check-valve was forced open during the day but was forced close at night)									
		BIS	**Conv.**	**BIS**	**Conv.**	**BIS**	**Conv.**	**BIS**	**Conv.**
12/7/2002	19.7	40.2	39.6	61.7	79.2	22.9	29.9	11.9	14.2
14/7/2002	18.5	38.8	37.9	63.6	79.4	18.5	27.9	12.8	13.6
Average		**39.5**	**38.8**	**62.7**	**79.3**	**20.7**	**28.9**	**12.3**	**13.9**

It is shown that the average daytime collecting efficiency (η_c) of the BIS system under Case 2 (38.9%) and Case 3 (39.5%) are less than that under Case 1 (40.4%). This is because the check-valve in the latter case is forced fully open during the day while that in the two former cases it is allowed to work freely, i.e. the opening of the lid of the valve is dependent on the driving force of the flow. Therefore, the frictional force due to the partly-open valve would retard the flow and this results in smaller amount of water flowing out from the tank to the collector channel. As a consequence, the heat collected by system is less. For storage efficiency (η_s), it is clear that the average value for Case 2 (61.5%) is higher than that for Case 1 (56.9%). This means that the check-valve can automatically reduce the reverse circulation of hot water from the tank to the collector for reradiation to atmosphere during the night. It can be confirmed by a higher value in Case 3 (62.7%) in which the check-valve is forced completely close and hence, in such a case, no reverse flow is occurred. When overall system efficiency (η_{24hour}) is concerned, it can be seen that the value for case 2 (17.4%) is higher than that in Case 1 (15.7%). This indicates the significance of using the check valve into BIS system. Note that although the value for Case 3 (20.7%) is highest, it is not practical as it requires a mechanism to completely close the valve at night and open it during the day. In addition, the values of $Q_{morning}$ shown in the table suggest that the BIS system can supply a comparable amount of heat content of the water stored in the tank for uses in the next morning to that provided by the conventional system.

4.5 Conclusion of Experimental Investigation

The developed built-in-storage (BIS) solar water heater has been tested for different cases. The results show that the check-valve in the system can reduce a reverse circulation of hot water at night and an increase of about 5% in the average storage efficiency has been found. Although the check valve causes a slight drop in the daytime collecting efficiency, the overall system efficiency over 24 hours of the BIS system with check-valve is found to be better than that without check-valve. In addition, the developed BIS system can produce a comparable amount of hot water to that provided by the conventional solar water heater. It is hoped that the simple design and construction of the developed BIS solar water heater which requires low initial cost would be beneficial to users in rural or remote areas.