CHAPTER 7

EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental work consisted of developing two prototypes of the zeolite-water solar refrigerator and detailed performance study of both for long duration. The first prototype was aimed at establishing the working of the system. The second prototype was an engineered design taking into consideration all the operational and maintenance aspects.

As explained in Chapter 6 the refrigerator was designed and developed to produce 1 kg of ice during the adsorption cycle. This ice was to keep the refrigerator cool during the next whole day time. To actually ensure that the ice formed inside the evaporator keeps the refrigerator cool for sufficiently long time, experiments were conducted using an available refrigerator body and ice. It was observed that ice had to be kept at the top portion of the refrigerator to cool the entire refrigerator. Ice maintained the refrigerator temperature below 8 degree C for 18 hrs.[1].

Fig. 7.1 is a graph showing the temperature profile during these tests.

7.1 DEVELOPMENT OF THE PROTOTYPE

During the course of this work two prototypes of the solar refrigerator were developed. The first one was an experimental model on which many modifications and alterations were incorporated during the developmental

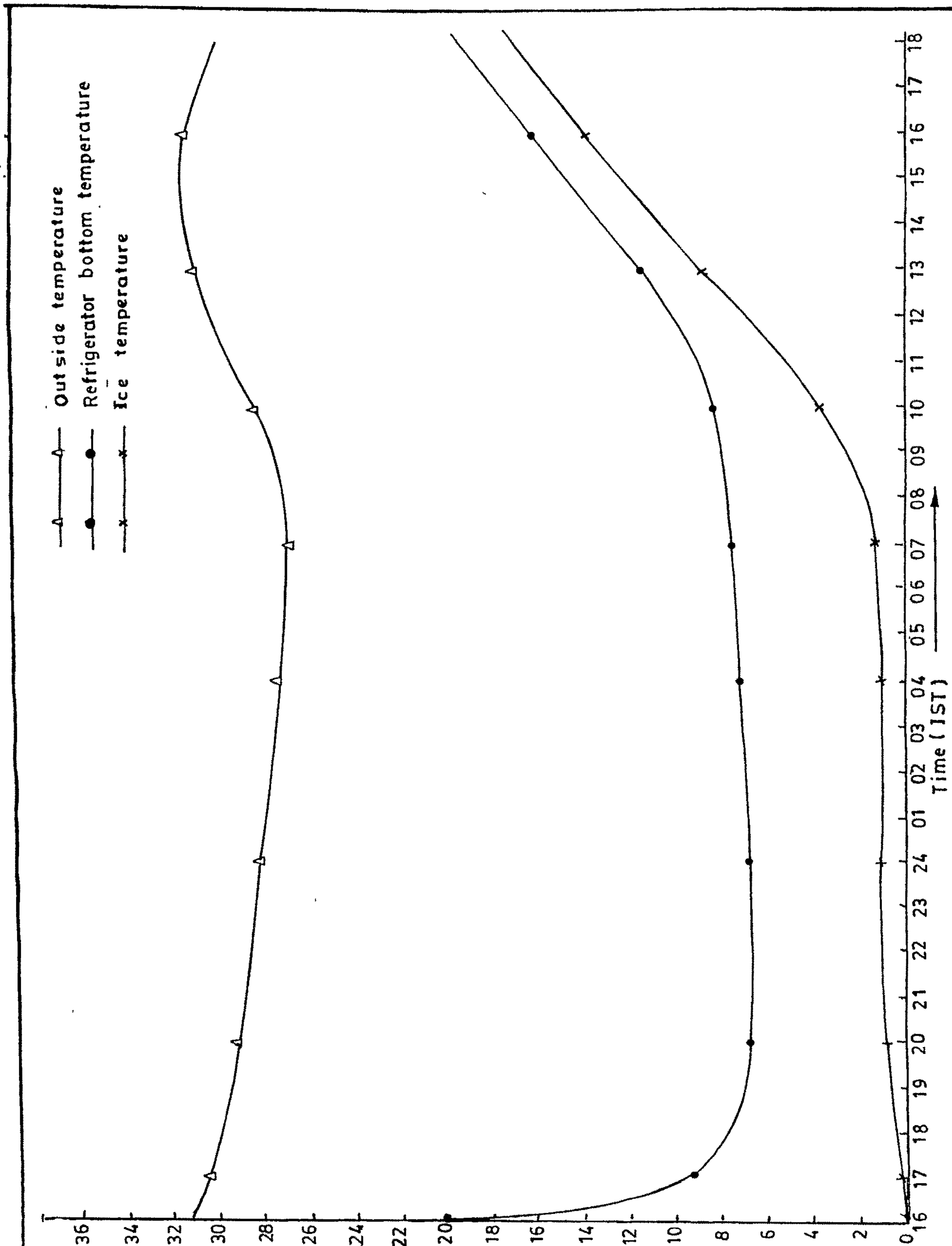

Fig: 7.1 Temperature profile during cooling a refrigerator using ice process. The second prototype was an engineered model of the earlier prototype wherein the short comings of the first prototype were rectified. As far as specifications and subsystems are concerned, both the models are almost the same. As the complete system had to work under vacuum conditions, the materials for construction and the welding work were of the highest possible quality.

Fig. 7.2 shows the photographs of the first prototype of the zeolite refrigerator that was developed. The solar collector painted black was tilted at 37 degree which is the required angle for winter optimization[2]. Glass wool was used as the insulating material in the collector. The collector glazing cover could be kept open as shown in figure during the desorption cycle to facilitate fast cooling.

The condenser pipe network was kept inside a MS tank. The collector and condenser were fitted on a metal frame. The evaporator of the system was made of a copper pipe of 100 mm diameter. But to observe the functioning of the system and to see the ice produced inside the evaporator a glass flask was used in place of the metallic evaporator for a short duration. Fig. 7.3 shows a closer view of the flask containing ice produced during operation. The glass flask could not be used as the evaporator for a long duration as it was found to break in a few cycles due to the pressure exherted during freezing of water.

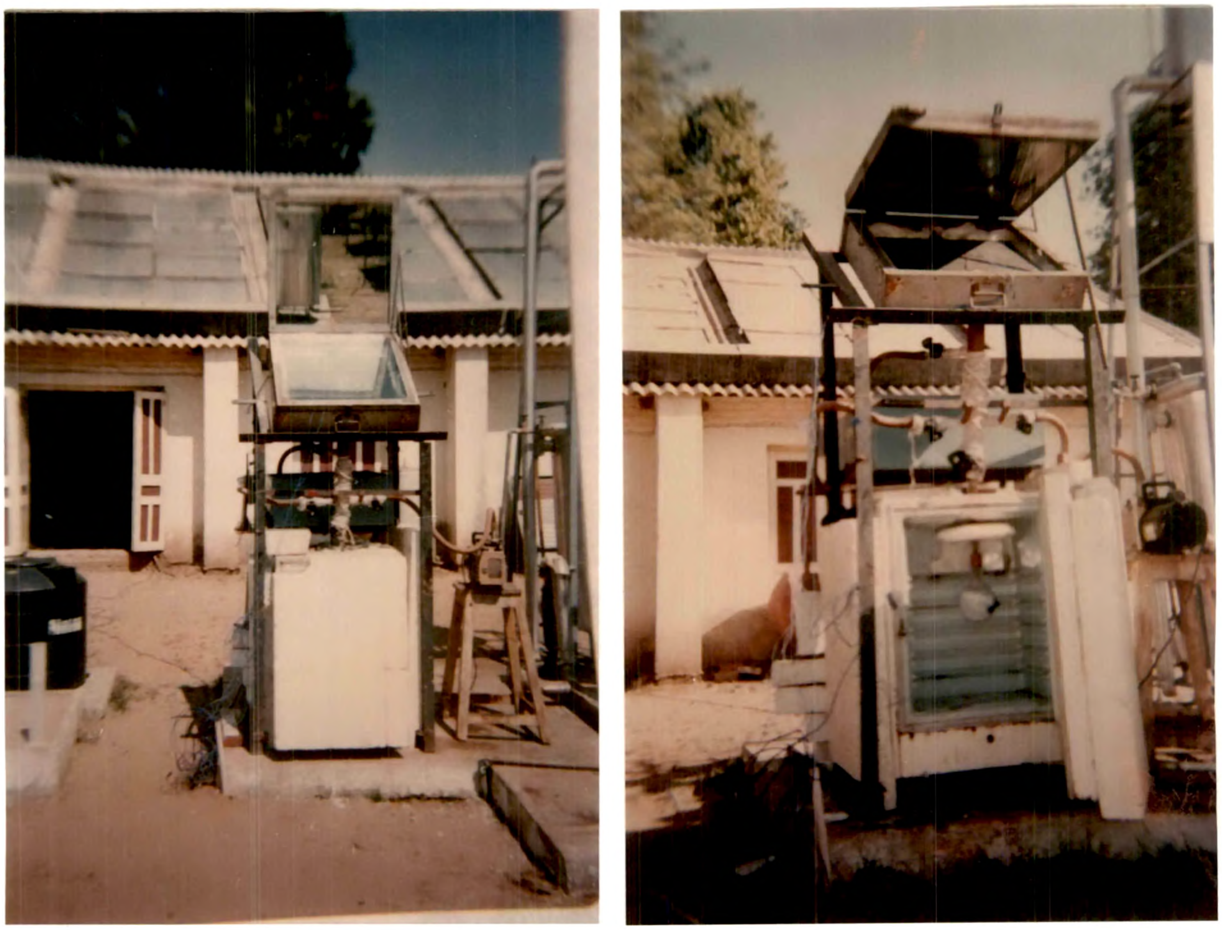

Fig. 7.2 : Solar refrigerator (left) during day cycle, (right) during night cycle

Fig. 7.3 : Close up of ice formed inside the glass evaporator

In order to obtain maximum collector temperature during the day time, various radiation booster arrangements were made and tested. The two mirror arrangement shown in Fig. 7.4 contributed little in the morning and evening. The eight sided booster arrangement shown in Fig. 7.5 was designed to provide a minimum of 5 hrs. of uninterrupted sun shine on the collector. As this arrangement was found to perform satisfactory throughout the day cycle and in all seasons, it was incorporated into the system as shown in Fig. 7.6.

To prevent direct sun light from falling on the insulated box and also to keep the box in a cool atmosphere to decrease heat leaks, a double walled brick structure was built around the insulated box. The space between the walls was filled with river bed sand which could be kept cool by spraying water. Such an arrangement provided a 5 to 10 degree C cooler surrounding for the insulated box. This prototype was tested over a year and performance data was collected in the different seasons. Though the performance of the system was quite satisfactory, certain drawbacks were observed which were mainly due to the construction materials used for the condenser tank, collector outer box, frame, insulated box etc. Hence it was decided to develop an engineered model of the zeolite refrigerator. The salient features of this engineered model are the following.

As the system was expected to be installed in a rural health centre where a semi skilled or unskilled hospital worker was to operate the system, the manual operations were

Fig. 7.4 : Two mirror booster arrangement for solar refrigerator

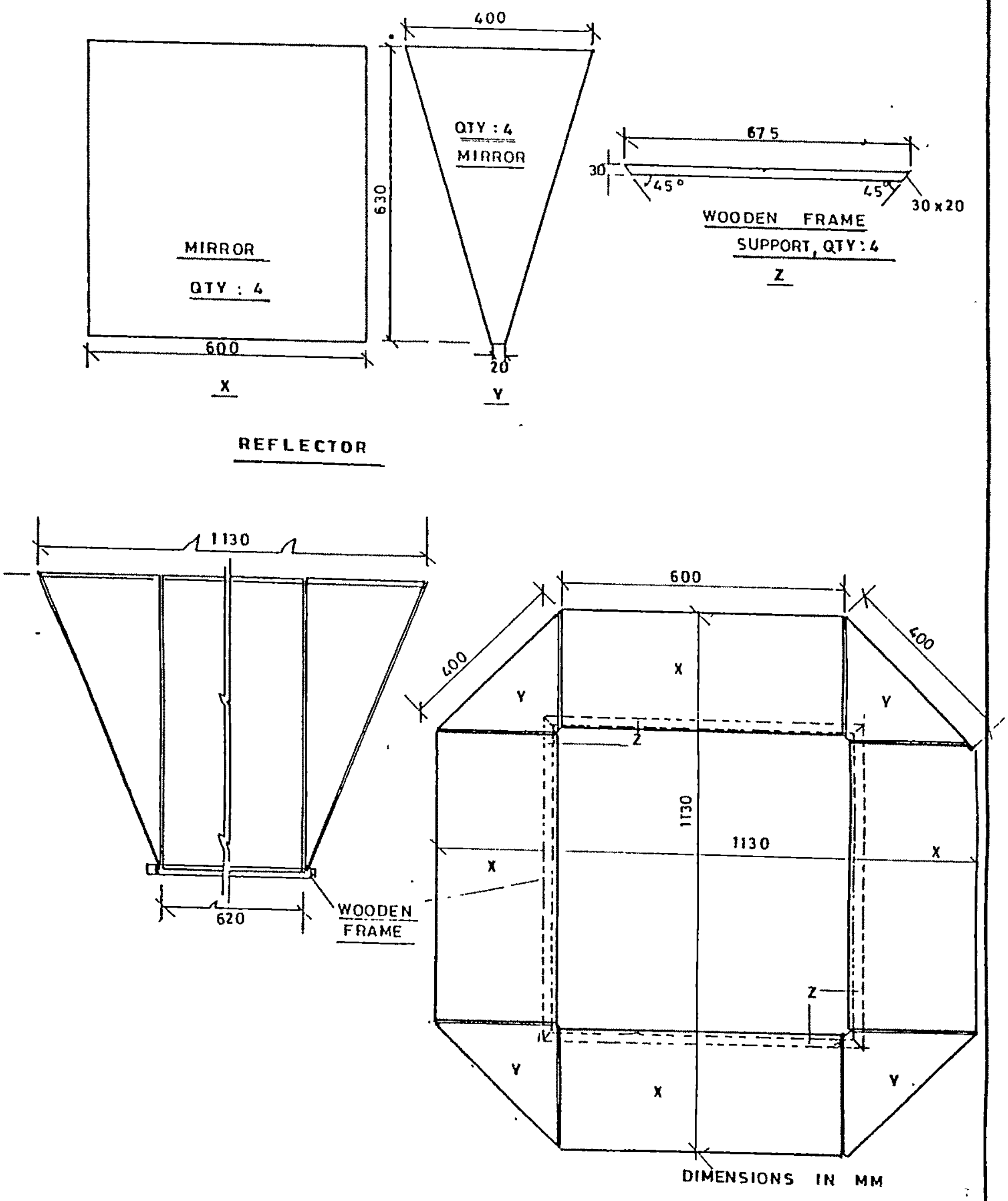

Fig. 7.5 Eight sided booster arrangement.

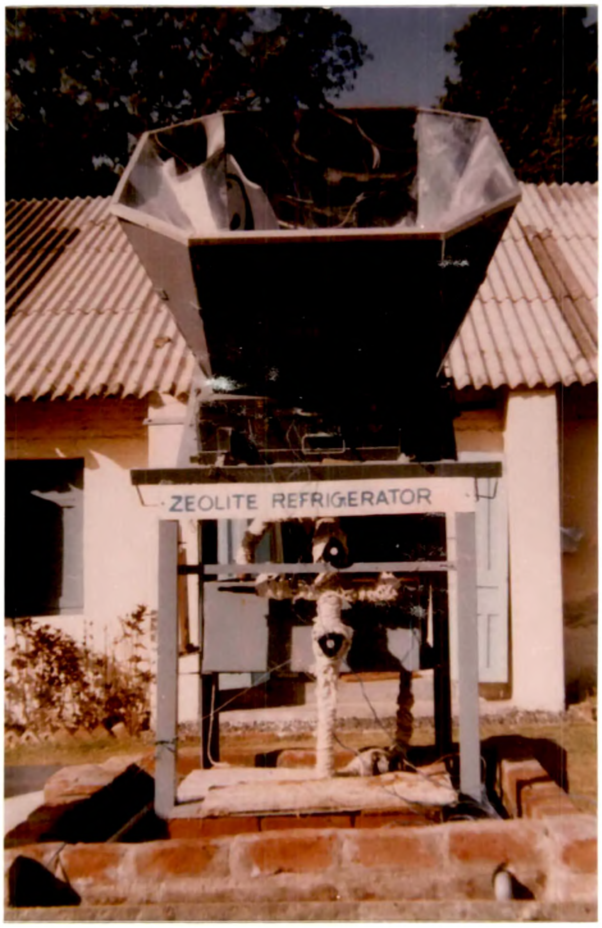

Fig. 7.6 : Prototype with eight sided booster arrangement

reduced and simplified. The height of the system was lowered so that a person of average height and build can easily operate the system. Also the number of valves in the system were reduced from six in the earlier model to four in the engineered model. Out of the four only three valves needed to be operated by the operator. All the valves were positioned at convenient height and locations.

The zeolite refrigerator needs to be kept outdoors for its operation. This means that the system will be exposed to sun light, dust and rain. To prevent the system from damage due to UV radiation and corrosion, suitable construction materials and treatment are essential. Hence the outer box of the collector and the complete frame of the model were made of aluminium. Side covers provided on the frame to shade the insulated box from direct sun light were also made of aluminium. The outer metal parts exposed to sun light were painted with UV stabilized powder coating. To provide good finish to the frame, all joints were made using aluminium rivets. The condenser tank was prepared using a synthetic loft tank of 150 l capacity to prevent corrosion. The 25 l cold box used to house the evaporator was prepared using a 40 l synthetic insulated cold box. Extra insulation was provided inside the box to improve thermal insulation. The box volume after adding the extra insulation and a plastic inner shell was 25 litres. Three compartments with shutters were built into the refrigerator to place the load at convenient positions. To approach the load, one needs to first open the common outer door and then open the specific inner door.

All pipes used in the engineered model was of 25 mm diameter. Three 25 mm diameter diaphragm valves were used in the system to regulate its operation. The fourth valve was used to seal the system after evacuation.

The interconnections between the components were made using flexible stainless steel bellows and fabricated standard vacuum joints. All joints had male-female connectors with neoprene 'O' rings.

The booster mirror arrangement was made using acrylic reflectors to reduce the weight and also breakage. The positioning of all the components like collector, condenser and evaporator were done carefully to facilitate easy mass flow in the system.

The engineered model was developed in such a way that the complete system could be assembled, leak tested and charged in a laboratory or factory. The objective was to eleminate any assembly or evacuation in the site as these operations are complex and would be difficult at the site. The only arrangement that was to be built at the site was to construct a platform and the brick walls to install the system. The complete system could then be transported to the site and lowered on to the platform.

The engineered model was installed for testing exactly as it would be installed at the field. A three sided double walled brick structure was built around the insulated box to keep the cold box cool. As the north side did not require a wall, the box was installed with the lid on the north to facilitate easy opening.

Figure 7.7 shows the side view of the system. The front and back view of the system are shown in figures 7.8 and 7.9. The insulated box with the lid open showing the three compartments alongwith doors and the evaporator is shown in Fig. 7.10. The engineered model was tested for over a year for data collection.

7.2 PERFORMANCE OF THE PROTOTYPES

One of the important requirements for the satisfactory performance of the system is leak proofing. Hence each component of the system was first leak tested and then the system was assembled and again leak tested. Appropriate corrective measures were taken whenever any leak in the system was noticed. When the system was leak proof, charging was undertaken. For this the evaporator was taken out and filled with distilled water and reassembled with the system. The water in the evaporator was boiled and frozen alternatively with a vacuum pump continuously pumping out any air so as to completely degas the water. Once this was done, the valve between the evaporator and collector was opened for adsorption to begin. The system was left in this

Fig. 7.7 : Engineered prototype of the solar refrigerator

Fig. 7.8 : Front view of the refrigerator

Fig. 7.9 : Back view of the refrigerator

Fig. 7.10 : Cold box and the evaporator

condition till the zeolite got saturated with water vapour. Once it was done, the system was ready for operation.

During performance study, temperature of collector, condenser, evaporator and ambient were measured round the clock using a data logger. Fig. 7.11 and Fig. 7.12 are the temperature profile during one typical desorption and adsorption cycles with two sided booster arrangement. As can be seen from the graph, the collector temperature reached about 120 degree C at 1500 hrs IST. The consequent adsorption cycle produced a minimum evaporator temperature of -1 degree C. The initial increase in the collector temperature in Fig. 7.12 was due to the heat of adsorption released by zeolite. The fast drop in temperature of the evaporator shows high adsorption in the initial stage. Once all the water in the evaporator freezes, the rate of adsorption slows down considerably. Figures 7.13 and 7.14 are temperature profiles of the system for two consecutive days after the eight sided booster was fixed. As can be noticed from the figures, the maximum collector temperature was above 140 degree C and the minimum evaporator temperature was -2 degree C. Also it can be noticed from the figures that the temperature inside the refrigerator is maintained within the acceptable limit of 3 to 8 degree C throughout the day and night cycles.

The performance data collected on the first prototype model for one full year from December 1991 on a monthwise basis is shown in Fig. 7.15. The performance of the system has been

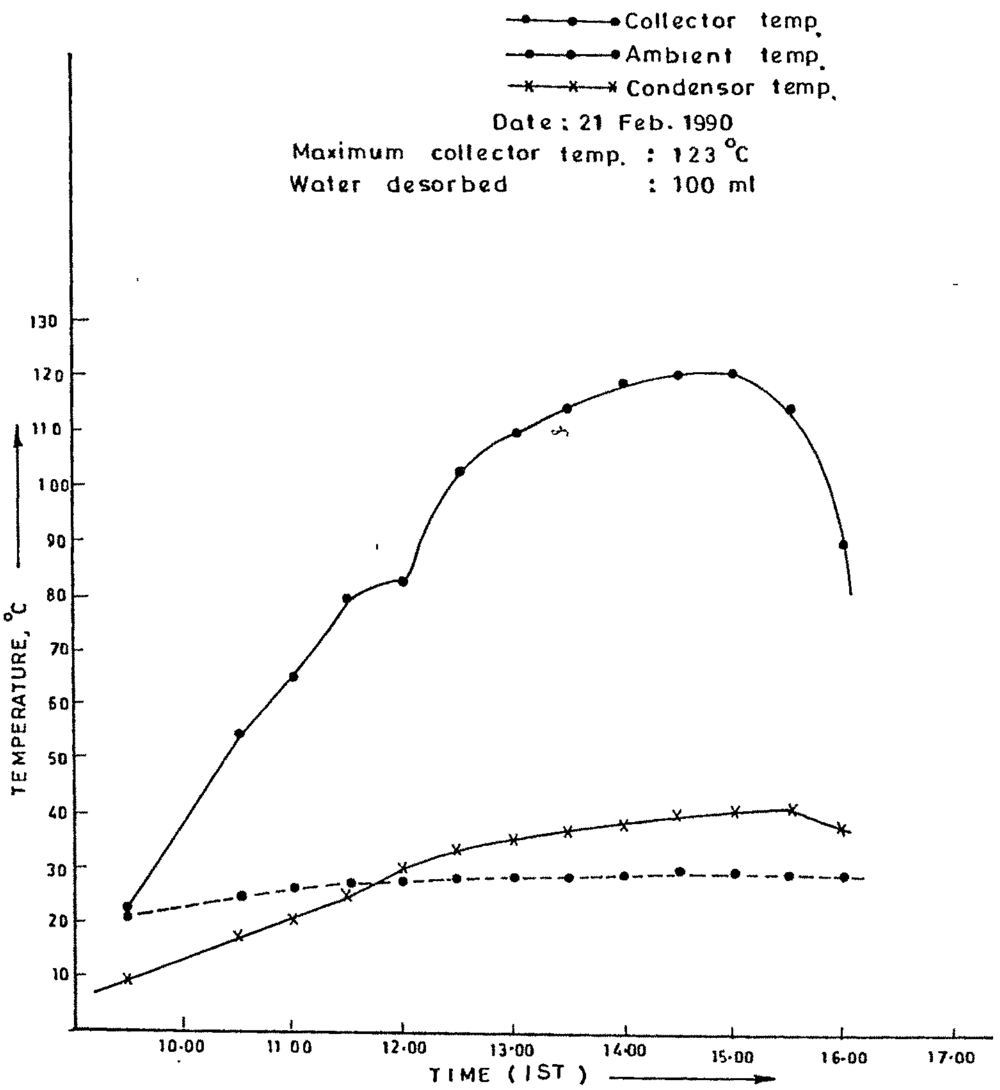

Fig. 7.11 Temperature profile during day cycle of the model

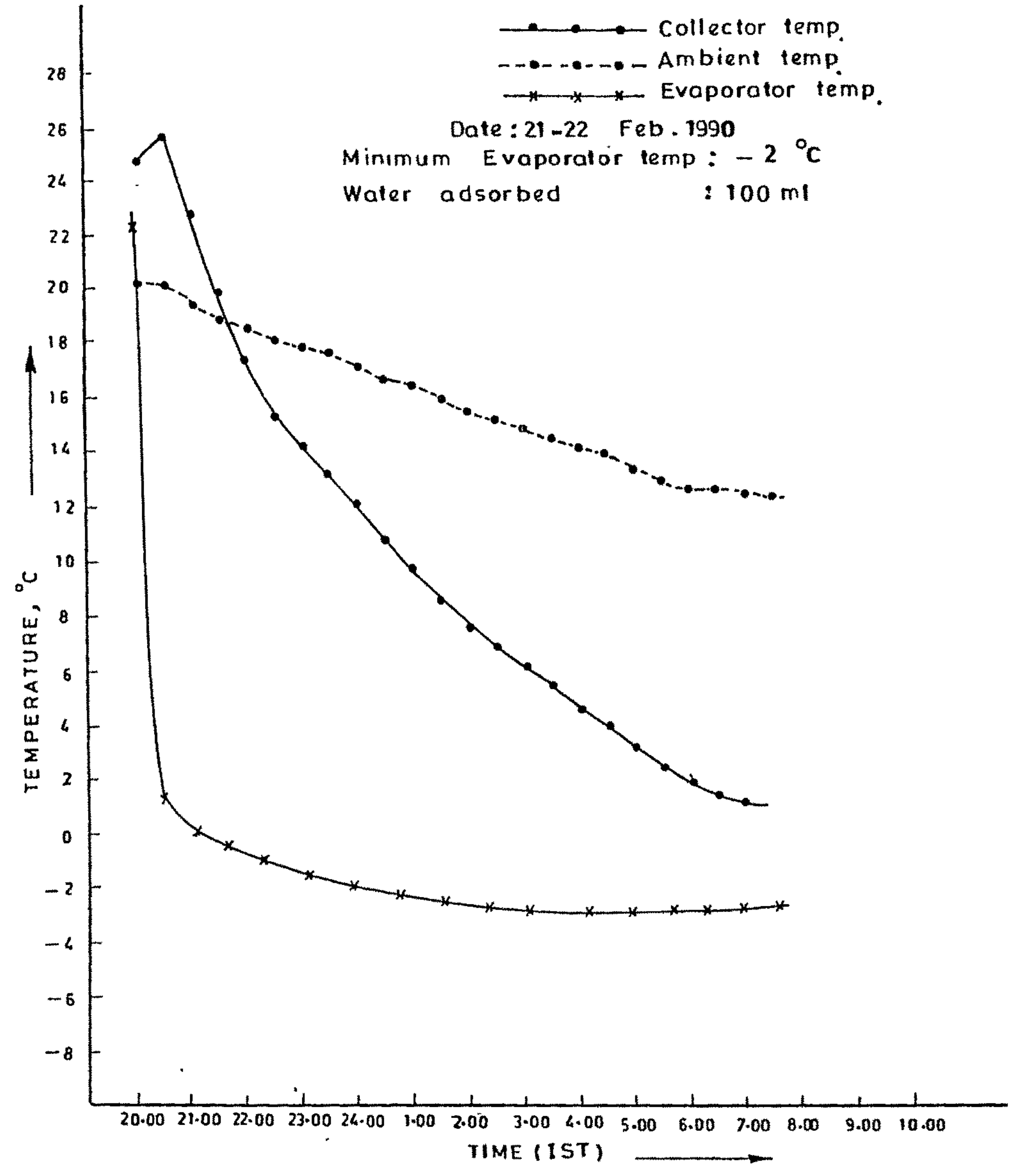

Fig : 7·12 Temperature profile during night cycle of the model

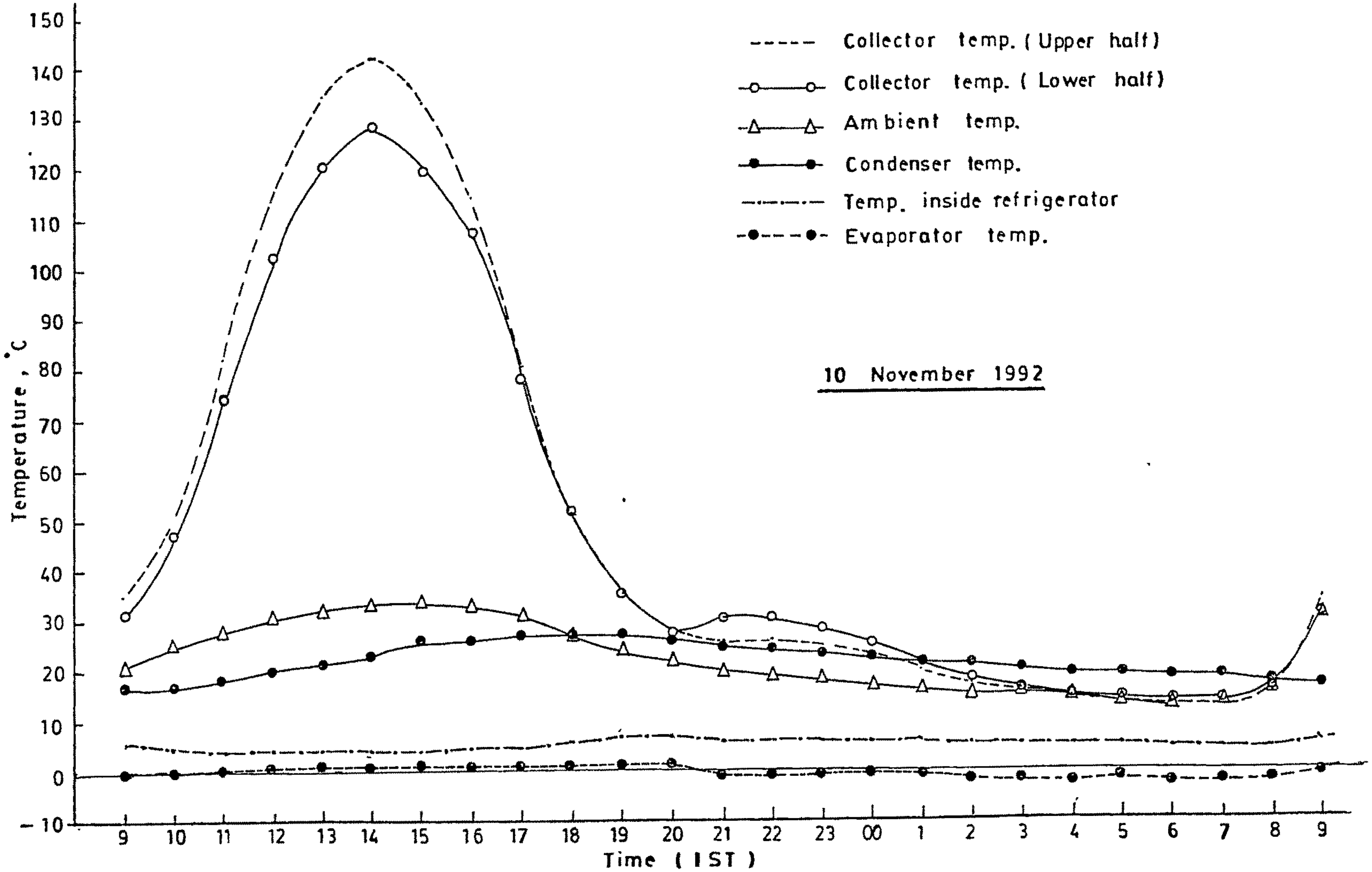

Fig . 7·13 Performance data of 25 L Zeolite Refrigerator

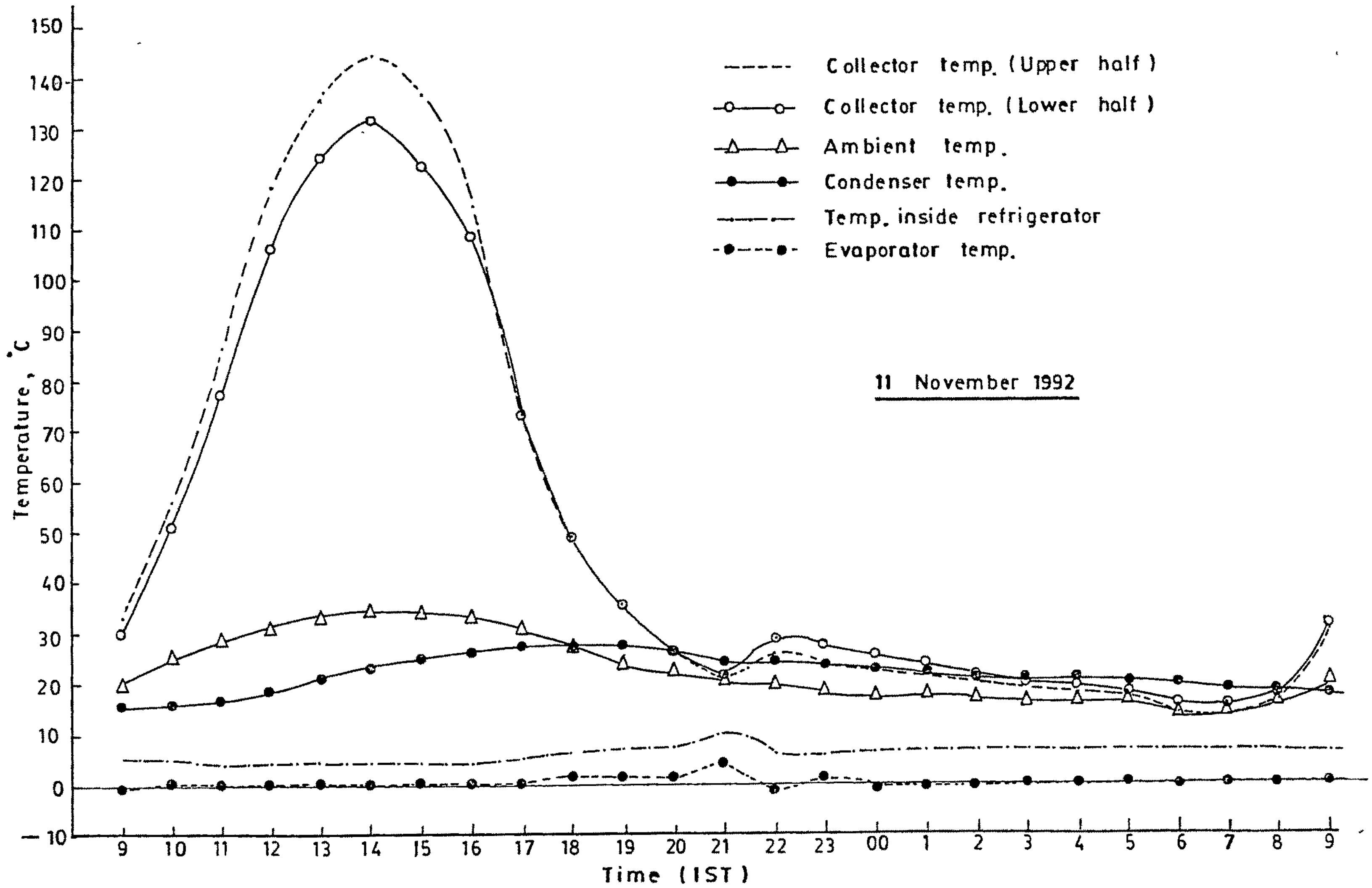

Fig. 7.14 Performance data of 25 L Zeolite Refrigerator.

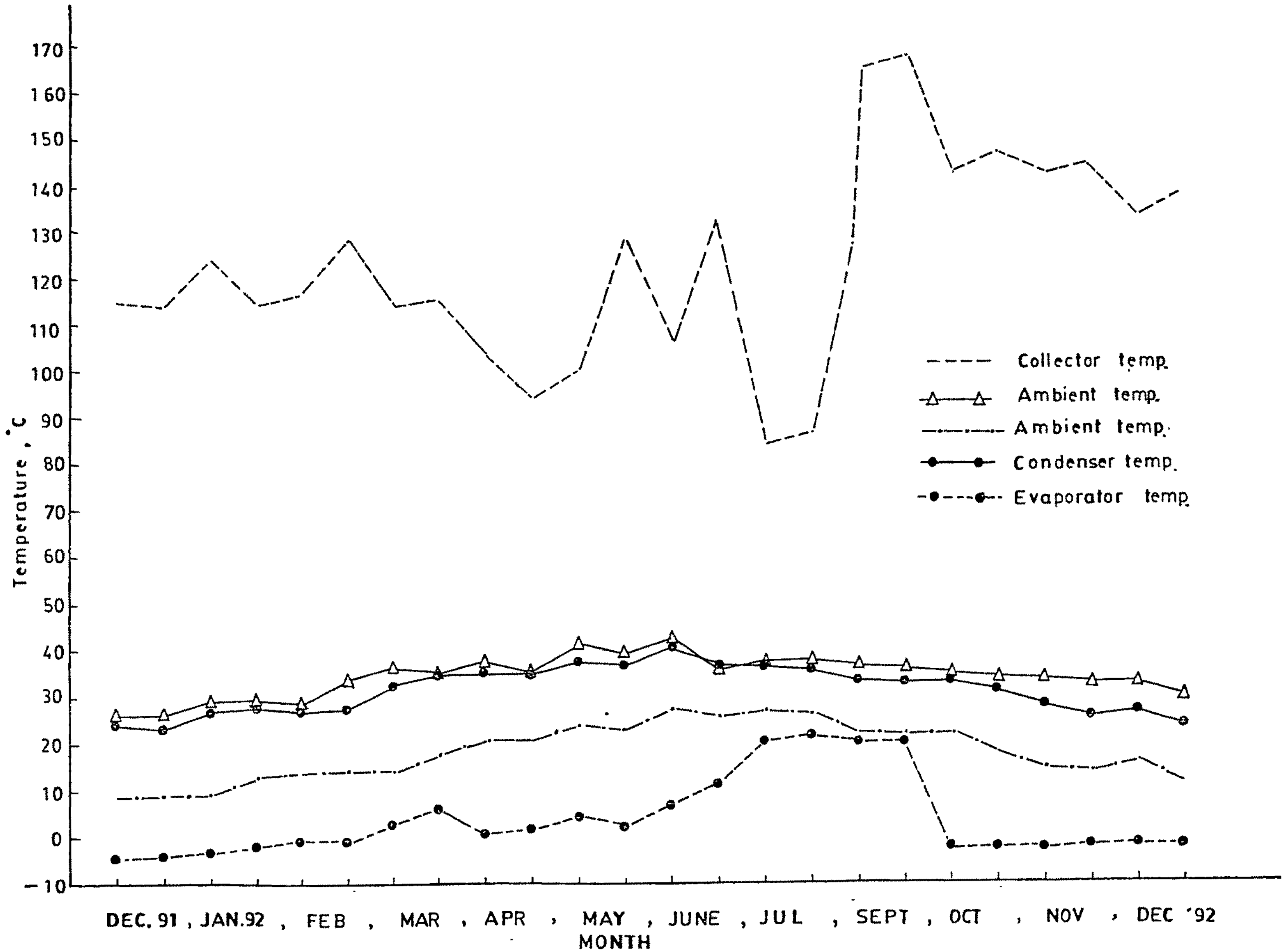

Fig. 7.15 Monthwise Performance of the 25 L Zeolite Refrigerator

satisfactory throughout this period except for the monsoon period. During monsoon due to the low collector temperature the system did not perform well.

The initial testing of the system was done without load, but the system was loaded with 500 gms of clinical load in December 1992. It was observed that this load did not affect the system performance in any way. The temperature profile of the system for one day with load is shown in Fig. 7.16.

The engineered model of the zeolite refrigerator was commissioned in December 1992. After satisfactory initial trial runs, the regular performance monitoring of the system was started from January 1993. The system performance was monitored continuously for one year and the performance was found to be satisfactory and in agreement with the first prototype.

The 24 hour performance for one day is given in Fig. 7.17. The collector temperature ranged between 120 and 140 degree C depending on the weather conditions. The evaporator temperature was found to reach below 0 degree C and the cold box temperature was within the acceptable limits.

The two prototypes developed and tested have clearly indicated the feasibility of the sold adsorbtion intermittent refrigerator working on solar energy. The performance of the system was comparable to the results obtained in the laboratory experiments. The 3.5% desorption

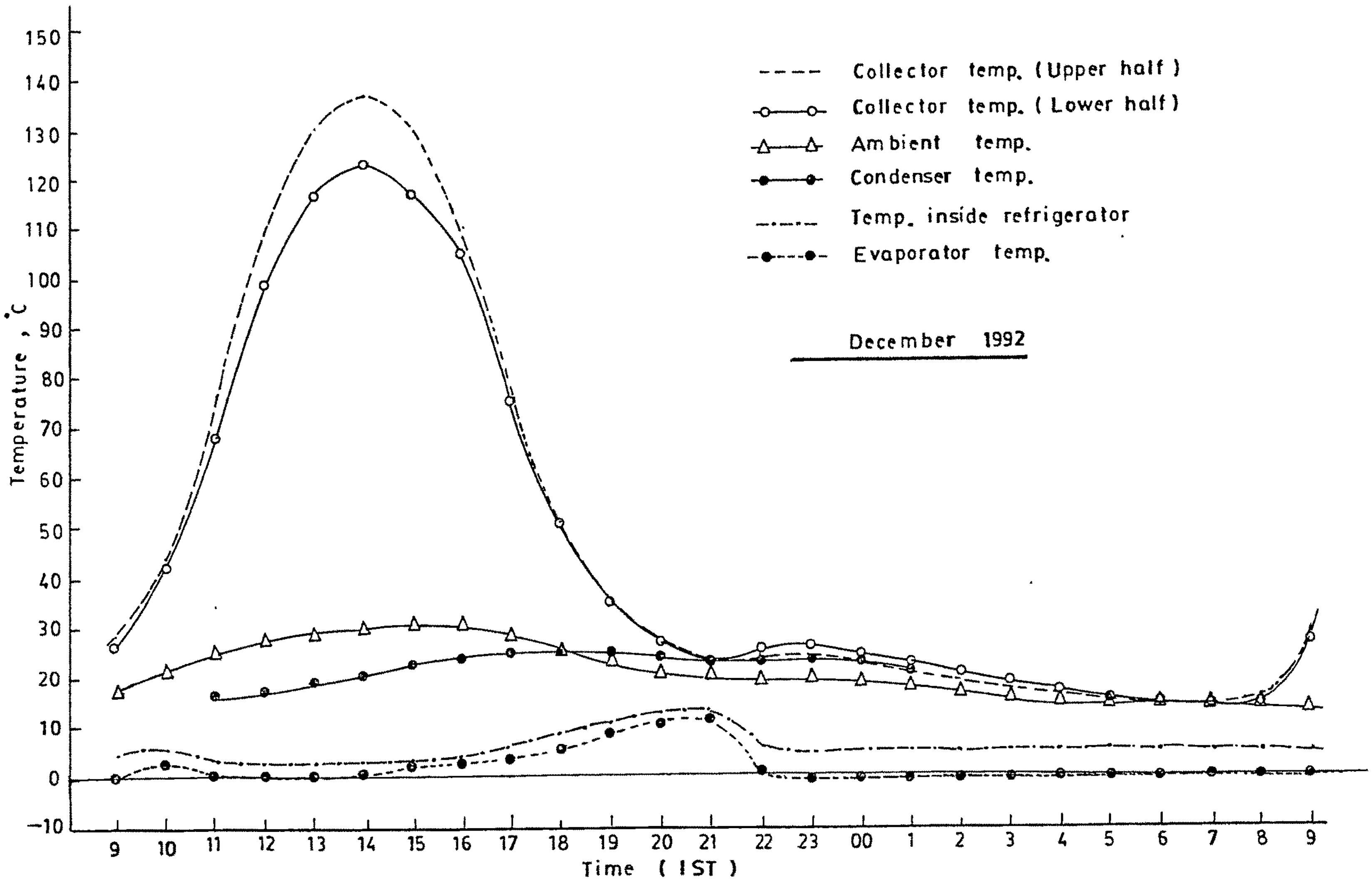

Fig. 7.16 Performance data of 25 L Zeolite Refrigerator with 500gms load

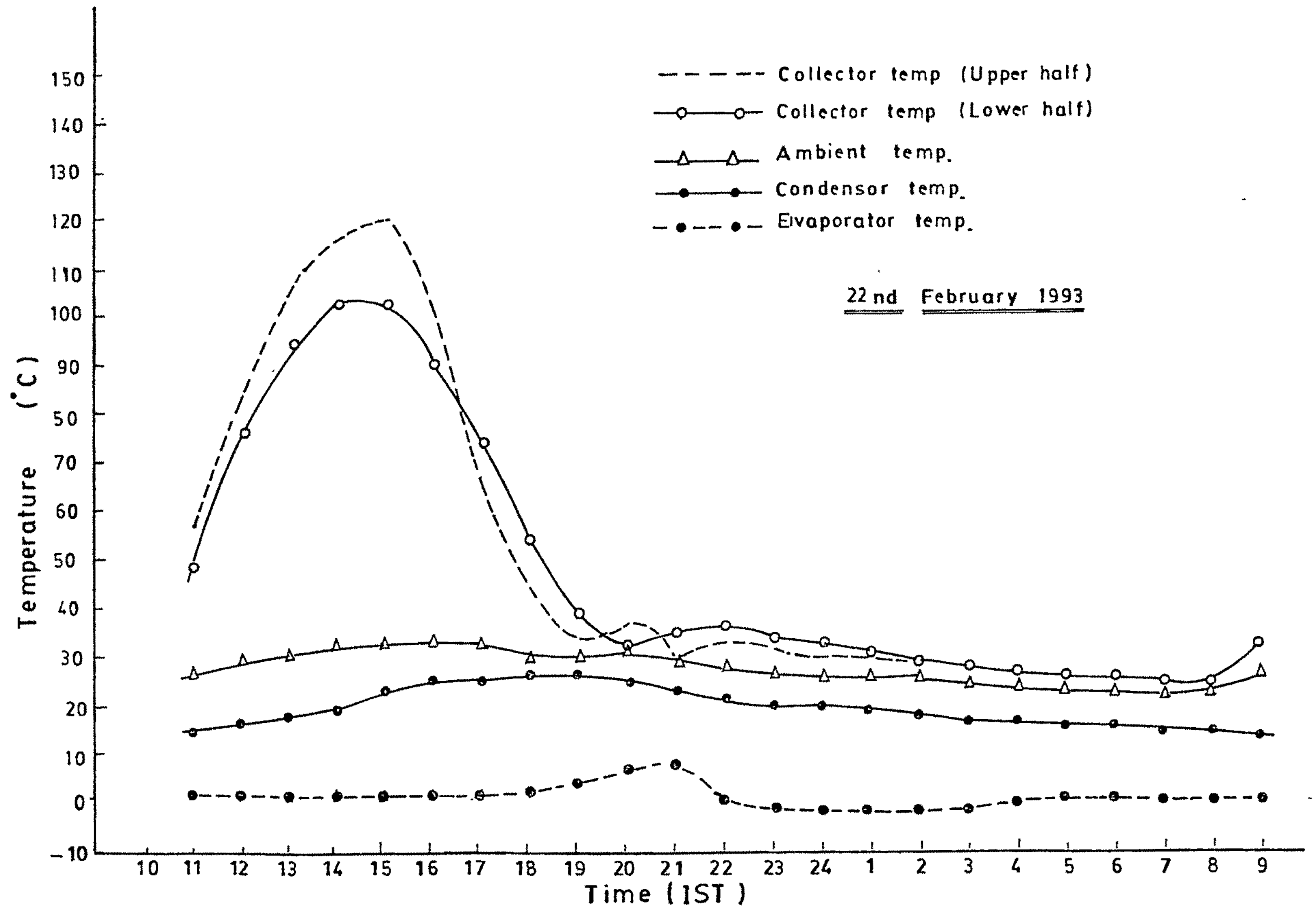

Fig. 7.17 Performance data of 25 L engineered zeolite refrigerator

rate obtained in the laboratory experiments was the basis of the 150 ml desorption assumed in the design of the prototypes. Production of 1 kg of ice and achieving sub-zero temperatures in the evaporator clearly indicate that the system performance has been as expected.

The system performance was found to be within the desirable limits for vaccine storage during most part of the year. The system did not function properly during the monsoon season because of the low collector temperature. This is a limitation of all solar energy devices and can be overcome only through a back up heating source for the collector.

The zeolite molecular sieves 13X has been found to be very stable under normal operating conditions. Five year old zeolite is continuing to work satisfactorily in the refrigerator system.

REFERENCES :

1. Development of a Solar Refrigerator using Zeolite for Rural Areas, Project Report, SPRERI, 1991.

2. Solar Engineering of Thermal Processes, Duffie, J.A. and Backman W.A., John Wiley and Sons, 1980.