EFFECT OF CORRUGATED ABSORBER PLATE ON THE PERFORMANCE OF COLLECTOR–CUM–STORAGE TYPE SOLAR WATER HEATER.

MD. MORAD HOSSAIN MOLLAH

M.Sc. Engineering (Mechanical)

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA.

AUGUST 1995.

EFFECT OF CORRUGATED ABSORBER PLATE ON THE PERFORMANCE OF COLLECTOR–CUM–STORAGE TYPE SOLAR WATER HEATER.

BY

MD. MORAD HOSSAIN MOLLAH

A Thesis submitted to the Department of Mechanical Engineering in partial fulfilment of the requirements for the degree of Masters of Science in Engineering (Mechanical).

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA.

AUGUST 1995.

RECOMMENDATION OF THE BOARD OF EXAMINERS

The Board of Examiners hereby recommends to the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology, Dhaka, the acceptance of the Thesis on "Effect of Corrugated Absorber Plate on the Performance of Collector-Cum-Storage Type Solar Water Heater", submitted by Md. Morad Hossain Mollah, in partial fulfilment of the requirements for the degree of M.Sc. Engineering in Mechanical Engineering.

Dr. Md. Abdur Razzaq Akhanda
Professor & Head
Mechanical Engineering Department
BUET, Dhaka.

Chairman

Dr. A. M. Aziz-Ul Huq
Professor
Mechanical Engineering Department
BUET, Dhaka.

Member

Dr. Md. Abdur Rashid Sarkar
Associate Professor
Mechanical Engineering Department
BUET, Dhaka.

Member

Professor Dr. Musharof Hossain Khan
(Ex-Member, University Grants Commission
Sher-E-Bangla Nagar, Dhaka.)
Vice-Chancellor
Ahsanullah University of Science & Technology
20, West Testuri Bazar Road
Tejgaon, Dhaka-1215.

Member

CERTIFICATE OF RESEARCH

This is to certify that the work presented in this thesis is an outcome of the investigation carried out for the first time by the author under the supervision of Dr. Md. Abdur Razzaq Akhanda, Professor and Head, Mechanical Engineering Department, Bangladesh University of Engineering & Technology, Dhaka.

Md. Abdur Razzaq Akhanda

Porf. Md. Abdur Razzaq Akhanda
Supervisor

Md. Morad Hossain Mollah
Author

ACKNOWLEDGEMENT

The author is deeply grateful to his supervisor Prof. Dr. Md. Abdur Razzaq Akhanda for his guidance, supervision and constant help. His continuous encouragement invaluable suggestions enabled the author to finish his work in time.

The author also express his sincere gratitude and indebtedness Prof. Dr. A. M. Aziz-Ul Huq and Dr. Md. Abdur Rashid Sarkar for their help.

He would also like to acknowledge the help and cooperation extended by the office of the Department of Mechanical Engineering, Bangladesh University of Engineering & Technology (BUET) for allowing him to use the facilities of the department. He express his thanks to Mr. Md. Fakhrul Islam Hazra for the typing of the thesis report.

The author is also grateful to the authority of the Directorate of Technical Education for allowing him to pursue the M.Sc. Engineering work.

Lastly, he would like to thank his wife who persistently kept this at his work and partly relevant him of family duties until this work was finished.

ABSTRACT

This investigation was carried out to compare performances between two Collector cum-storage Type Solar Water Heaters one having flat absorber plate (CSWHF) and the other having corrugated absorber plate (CSWHC). Both the collectors of 114 litres in capacity, 1.25 m^2 of collector projected surface area and 9.2 cm in average depth were studied at Dhaka during months of November, 1994 to March, 1995. In one hour starting at 8 AM to 6 PM, the Collector-cum-Storage Flat Plate Type Solar Water Heater (CSWHF) can heat 114 litres of water to a temperature of 32°C absorbing 0.212 kW/m^2 in November, 25°C absorbing 0.106 kW/m^2 in December, 26°C absorbing 0.212 kW/m^2 in January, 32°C absorbing 0.318 kW/m^2 in February and to 41°C absorbing 0.371 kW/m^2 in March.

The Collector-cum-Storage Corrugated Type Solar Water Heater (CSWHC) can heat 114 litres of water to a temperature of 32.5°C absorbing 0.318 kW/m^2 in November, 26°C absorbing 0.212 kW/m^2 in December, 27°C absorbing 0.318 kW/m^2 in January, 33°C absorbing 0.424 kW/m^2 in February, and to 42°C absorbing 0.477 kW/m^2 in March.

From February to March the energy is increased by 17 percent but the water temperature is increased by 28 percent in Flat Plate collector. From February to March the energy is increased by 13 percent but the water temperature is increased by 27 percent in corrugated plate collector.

The monthly average heat energy absorbed by CSWHF is 0.204 kW/m^2 with 61 percent efficiency in November, 0.144 kW/m^2 with 50 percent efficiency in December, 0.2038 kW/m^2 with 63 percent efficiency in January 0.178 kW/m^2 with 46 percent efficiency in February, 0.208 kW/m^2 with 54 percent efficient in March.

The monthly average heat energy absorbed by CSWHC is 0.302 kW/m^2 with 89 percent efficiency in November, 0.201 kW/m^2 with 70 percent efficiency in December, 0.312 kW/m^2 with 95 percent efficient in January 0.305 kW/m^2 with 72 percent efficiency in February and 0.2991 kW/m^2 with 78 percent efficiency in March.

The efficiency of CSWHC is more than that of CSWHF, by 46 percent in November, 40 percent in December, 50 percent in January, 56 percent in February and 44 percent in March.

NOMENCLATURE

Symbols	Definitions	Units
A	Projected Area	m^2
C_p	Coefficient of Specific Heat of Water	kJ/kg.k
I	Solar Insolation	kW/m^2
M	Mass	kg
N	Day Length of Bright Sun Shine	hr
Q	Rate of Heat Energy	W
T	Temperature	°C
ΔT	Change of Temperature	°C
X	Solar Insolation	$cal/cm^2.day$
Y	Heat Energy	Langley/min
η	Efficiency	%
Tw_f	Mean Temperature of Water for Flat Plate	°C
Tw_c	Mean Temperature of Water for Corrugated Plate	°C
$Tw_f - Tw_i$	Temperature Difference Between Water Mean and Initial for Flat Plate	K
$Tw_c - Tw_i$	Temperature Difference Between Water Mean and Initial for Corrugated Plate	K
q	Heat Energy Absorbed	W/m^2
q_{wf}	Heat Energy Absorbed by Flat Plate	W/m^2
q_{wc}	Heat Energy Absorbed by Corrugated Plate	W/m^2
Eff_{fp}	Efficiency Flat Plate	%
Eff_{cp}	Efficiency Corrugated Plate	%

SUBSCRIPTION

W_i	Initial Water Temperature
W	Water
P	Pressure
m	Maximum
ac	Accumulated Value
av	Average Value

CONTENTS

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Solar energy will be existing as long the earth exists. There can not be any loss using solar energy. This is a renewable energy and one should look into the use of solar energy. Throughout the history of human race, major advances in the civilization have accompanied by an increased consumption of energy. Today energy consumption appears to be directly related to the populace and the degree of industrialization of the country.

Energy is an indispensable input to develop activities leading to increase in the gross national product and ultimately for quality of life. Explicitly, status of energy consumption is an indicator of the socioeconomic pattern of a country. The availability of the sources of energy seems preconditions to sustain development process, skills and techniques for utilizing the energy are also equally important to attain sustainable development (Marsh 1994). For instance, the oil rich Arab countries were not technologically developed even in the mid twentieth country; now the life style there, has been improved with the sale proceeds of fossil fuels.

Some European countries had however successfully innovated techniques matching the potential sources available to them; generation of hydro-electric power plant with water from the mountains or even electricity out of wind mills in the coast of the North Sea might be worth mentioning. Apparently both availability of energy and matching technology are inter linked for sustainable development and quality of life.

The rate of exploitation of any non-renewable sources of energy increases with time, reaches a maximum, and then ultimately reduces to zero. According to various estimates, world's production of fossil fuels and other exhaustible energy bases will last only for a limited time. For example, in Bangladesh oil will last for another 32 years, and gas 58 years (Hamid 1994). From environmental point, today's use of conventional exhaustible energy sources is leading the world to its ultimate destruction. Hence it is a matter of concern, not only for better living standard but also for very survival of the world, to device, develop, and diploy all possible techniques to extract energy from renewable energy sources. It is essential to develop methods of diversification of energy sources, reduction of energy consumption and increasing the efficiency in the utilization of energy otherwise, there will be world wide economic and political chaos.

Fortunately, the sun is an everlasting source of renewable energy. It is emitting energy at the rate of about 3.8×10^{23} kW of which only a tiny fraction of 1.73×10^{14} kW is intercepted by the Earth. Ignoring all areas of seas, the amount of solar energy received by the rest of the land area of the earth is 2.0275×10^{13} kW (or 162.2×10^{12} kWh/day, assuming eight hours of sunshine a day, or approximately 60×10^{15} kWh year) [Rai 1984].

Solar energy is clean and safe with no significant polluting effects. It exists in abundance all over the world. To utilise this energy for practical purposes it is essential to know how much of the energy is available and how much of this available energy can be collected and stored for use. Hence both theoretical and experimental data of solar radiation intensities at various locations of concern must be known.

The sources of information on solar energy are wide spread. But for Bangladesh year round practical data on solar radiation intercepted and converted into useful energy by various means are not available yet. Under this circumstances, it is necessary to record relevant data on solar radiation for scientists, engineers and for those who are interested in solar energy research and development work to enhance further studies.

With rising fuel prices and increasing development of solar collectors, solar water heaters operating at temperature below 90°C may conveniently be served by flat plate collectors.

1.2 SOLAR ENERGY COLLECTIONS

The continuous radiation of the sun intercepted by the Earth is called solar energy. According to solar energy panel of NSF/NASA, there are two collection systems of solar energy. These are:

i. Natural Collections of Solar Energy such as Wind, Waves etc. and

ii. Technological Collections of Solar Energy such as Photovoltaic, Thermal Conversions etc.

1.3 MAN AND ORIGIN OF ENERGY

There are three important problems of the world now-a-days, they are (i) shortage of energy (ii) depletion of the fuel sources and (iii) increasing pollution. People of the world, with their increasing demand of energy for their better standard of living, need energy source which should overcome the above problems. Fossil fuels are finite in quantity and have adverse effect on environment, causing air pollution. Producing hydrogen for storing and transmitting solar energy seems the proper solution to these difficulties. Hydrogen can be used as a fuel, can be used to produce electricity, can be transmitted over long distances economically, and is a clean form of secondary energy.

Strictly speaking, all forms of energy on the earth are derived from the sun. However, the more conventional forms of energy, the fossil fuels received their solar energy input eons ago and possess the energy in a greatly concentrated form. These highly concentrated solar energy sources are being used at such a rapid rate that they will be depleted in not too distant future.

There are four primary sources of conventional energy viz., petroleum, natural gas and natural-gas-liquids, coal and wood. Excepting wood, all these common sources have finite supplies. The life-time is estimated to range from 15 years for a natural gas to nearly 300 years for coal. Therefore, as these non-renewable sourses are consumed, the mankind must turn its attention to longer-term, permanent type of energy sources. The two most significant such sources are nuclear and solar energy.

Nuclear energy requires advanced technology and costly means for its safe and reliable utilization and may have undesirable side effects. Solar energy on the other hand, shows promise of becoming a dependable energy source without new requirements of a highly technical and specialised nature for its wide spread utilization. In addition, there appears to be no significant polluting effects from its use.

Modern scientific research in the utilization of solar energy commenced in 1855 when G. Guntur, an Austrian, invented a solar boiler using mirrors. In 1876 an American inventor, John Ericssion who invented several types of hot air engines prior to this date, visualized that at some time in the near future, a chain of solar power stations across North Africa, the Middle East India, Australia and Central America would be set up. In the later half of the last century and during the first half of this century, progress in the field of energy research was fairly slow. This was mainly due to availability of cheap fossil fuels.

The Waning solar energy research was revived in 1940 when Godfray cobot left a large sum of money for research projects at the Massachussetts Institute of Technology. During the recent energy panic research in the utilization of solar energy has gathered considerable momentum, especially in industrialized countries such as USA, CIS (Former USSR) France, Australia and Canada. The near future will certainly show some major break through in solar energy technology.

All countries in the world receive some solar energy. This amount varies from a few hundred hours per year as in the northern countries and the lower part of South America, to four thousand hours per year as in the case in most of the Arabian Peninsula and the Sahara Desert. In estimating the amount of solar energy falling on the earth, let us consider first of all the natural deserts of the world. This area is about 20×10^6 km^2 with average solar insolation of 583.30 W/m^2/day. Another 30×10^6 km^2 receive about 291.65 W/m^2/day. Let us ignore all the areas of sea and the rest of the land. Therefore, the amount of solar energy received by this 50×10^6 km^2 is 162.2×10^{12} kWh/day assuming eight hours of sunsine, or approximately 60×10^{15} kWh/year. Using 5%, this energy will result in 300×10^{13} KWh and comparing this with the estimated world energy demand in the year 2000 (50×10^{12} KWh/year), it can be seen that it is 60 times what the world will require then. Solar energy, which is the ultimate source of most forms of energy used now, is clean, safe and exists in viable quantities in many countries. The drawbacks in using solar radiation as energy, as have been pointed out, are that it cannot be stored and it is a low grade energy. This is however, an outdated argument since the energy can be stored by producing hydrogen, or by storing in other mechanical or electrical storage devices, the energy can be concentrated in solar furnaces for example, which can achieve temperatures in the region of 5000°C.

1.4 SOLAR THERMAL COLLECTORS

Depending on the methods of collector technology, all solar collectors can be classified into three classes, namely,

i. Flat plate collectors
ii. Concentrating or focusing collectors and
iii. Intermittently turned concentrating collectors.

1.4.1 Flat Plate Collectors

Flat plate collectors operate without concentration. It is simple, technically feasible and economically viable for obtaining temperature below 100°C. The basic technology involved is to place a dark surface in sunshine to absorb solar energy to heat up the plate and to transfer this energy into fluid in contact with it. To reduce the reflected and convected heat loss from the absorber plate, to the atmosphere, one or two sheets of glass or polythene are placed over the abosrber. This type of collectors may further be subdivided into three classes. These are

i. The plain sheet collectors,
ii. The plain sheet and tube collectors,
    a. Tubes bonded above absorber plate collectors
    b. Tubes in-line with absorber plate collectors
iii. The corrugated sheet collectors.

The storage tank may be combined with the collector in a single unit. Alternatively, the storage tank and the collector may be built separately as two different units.

In the plain sheet and tube collectors, if the tube and sheet are not welded together or poorly welded, the thermal resistance between the tube and the sheet would increase leading to poor performance, [Whiller 1964]. In the plain sheet and corrugated sheet collectors, absorbed solar energy is transfered as fluid sensible heat through direct contact and hence, from the view point of heat transfer, the advantage is evident.

A typical liquid heating flat-plate collector in its simplest form comprises the following five components.

i. Collector plate and storage tank

ii. Surface covering

iii. Fluid

iv. Insulation and

v. Casing

These collectors have been extensively studied by Garg et. al. [1973, 68, 72, 67], Gupta [1967], Desa [1964], Morse [1961], Bliss [1959], and Hottel et. al. [1942].

Domestic solar water heater using natural circulation is gaining popularity in different countries like Australia [Morse, 1970], Israel [Yellet et. al. 1964], and USA [Hawkin, 1947]. Large size solar water heaters, designed for community, have been developed by Garg [1973] and Morse [1970].

The materials used for collectors in decreasing order of cost and thermal conductivity are copper, aluminium and steel. Willier et. al. [1964] have found that steel pipes are as good as copper pipes. If the temperature difference between the collector and the ambient air exceeds 6.5°C, one layer of glass cover is justified. Two layers of glass covers are requested when it exceeds 30°C and three layers if it temperature exceeds 75°C [Eggers et. al. 1979].

Glass wool is most widely used in collectors as insulation materials because of its law thermal conductivity and moderate cost. Plastic foam may be used and can add to structural strength when moulded integrally between the collector and the collector case [Eggers et. al. 1979].

Glass fibre reinforced plastics are used as cases instead of steel sheets, because they are strong, lighter, water proof, weather resistent and do not corrode [Eggers et. al. 1979].

Prior to 1955, black paint was the coating that was usually employed for solar collectors. It is possible to produce highly efficient black coatings for solar collectors by electrolytic and chemical treatments like Nickel-black and copper oxide [Eggers et. al., 1979].

These coatings possess high values of solar radiation absorptance and low value at longwave emmitance.

Built-in-Storage type solar water heater, proposed by Tanishita [1961], is considered to be an improvement over conventional collectors because of its reduced overall size, cost, loss of heat, etc. It is given in detail in chapter-2.

An experimental study of corrugated steel sheet solar water heater was proposed by WANG SHING-An. He concluded that the flat plate solar collectors are simple solar utilization equipments which transfer solar radiant energy to the fluid. They have the advantages of using direct and diffuse solar radiations, not requiring orientation toward the sun, and requiring little maintenance.

They are mechanically simpler than the concentrating collectors and of low cost. Therefore, wide application of the flat plate solar collectors is found in solar water heating system, and their potential uses, including building heating, air conditioning and power production are under study.

In the design and use of the solar collector, it is very important to determine the thermal performance. In this field, a number of investigators have made a lot of contributions towards the analysis of the thermal performance [H.C. Hottel and B.B. Wortz (1942), B.B. Hetyxob (1957) and Wiley (1974)] Whiller [1965], Simon [1976] and others have also presented some indoor test procedures. In recent years, the ASHRAE'S approach to the solar collector test standard was presented [J.I. Yellott-1976] and the test procedure proposed by Shanghai Mechanical Engineering Institute was also presented in by China Wang-Shing-An (1978).

Wang-shing-An (1978) proposed in his paper, a study of heat balance and heat transfer process in corrugated steel sheet solar water heater and a simplified testing procedure for determining the collector efficiency equations was presented.

In the tube and sheet collector, solar energy is absorbed mainly by the sheet. It the tube and sheet are welded together, the thermal resistance between tube and sheet would be increased, and the performance would sharply decline as proved by Whiller [1965].

In the corrugated sheet collector, the corrugated black solar energy absorbing surface transfers the absorbed energy to a fluid by direct contact. Therefore from the view point of heat transfer the advantage is evident.

1.4.2 Concentrating or Focussing Collector

This type of collector is designed to produce very high energy density and high temperature at the receiver (absorber) by means of accurate focusing devices and continuous tracking of the sun's motion. In fact it is a special type of flat plate collector modified by introducing a reflector or refracting surface between solar radiation and the absorber which increases the energy density by a factor of 1.5 to 10000 or over. The absorber may be convex, flat or concave and may be convered or unconvered. French solar furnace at Odeillo, Tromble (1973), has achieved temperature over 3000°C. The operating and collector cost has restricted the utility of concentrating collectors. However, new materials and better engineering technology may make them of practical importance.

1.4.3 Tracking Type Concentrating Collectors

Between the above two extreme groups, with energy density increasing by a factor of 1.5 to 10, is the third group, called intermittently turned concentrating collectors. They are either fixed or occasionally turning to track the sun and have no sharp focussing devices.

1.5 PROSPECT OF HARNESSING SOLAR THERMAL ENERGY IN BANGLADESH

Bangladesh with an area of 150000 km^2 and a population of about 120 million people is one of the most populous countries in the world. But its position is the lowest interms of commercial fuel use.

Industrialization and mechanization of agriculture with increasing demand of electricity would continuously aggravate the energy scene creating serious problem in the energy sector and the future economic development of the nation. With the rise of demand of energy, the research and development related with new energy sources are primary requirement. Bangladesh is more vulnerable than any other country. Hence it is vital to explore alternative energy sources like solar energy.

Statistical review of world energy (Rapp 1991) estimated that only 19 percent of the world energy is consumed by the developing countries and rest by the developed world. Obviously, the consumption of energy in Bangladesh is very low. World Bank predicted in 1991 that energy consumption per capita (Kilogram of oil equivalent) in Bangladesh stood at 57, India's was 337, Pakistan's 243 and Sri Lanka's 177 (Shahjahan 1993). This indicated the weak socioeconomic structure of Bangladesh. Strengthening of such structure may require the utilization of available energy resources in the country.

In Bangladesh about two million tons of crude oil and petroleum products are imported in each year and it accounts for around 9 percent of the total imports and 15 percent of the export earnings. Diesel is widely used in the IC engines in rural Bangladesh for the irrigation pumps. Diesel is also burnt in the engines used for rice husking machines, power tillers and country boats. Above all, most of the river crafts (Launches) and road transports require huge amount of diesel. Incidentally most of the diesel engines used for these applications are smaller in capacity (<100 kW) but are very important in national development activities.

The conventional energies are getting exhausted alarmingly and the world is to face a massive fuel crisis in the near future. The current projected demand in energy supply may not be sufficient to support the desired level of economic growth needed by the developing countries as well as for large consumption of energy by the industrial world in the years ahead. This becomes evident in Niebaus and Willians' illustration (Wohlmeyer 1987) that fossil fuels are to get declined rapidly and the excessive dependency on non-fossil energy sources are to occur. Rapid decline of fossil fuels is to cause it price to rise; as a consequence sustainability of energy technology is to experience a great shock. Most of the third world countries including Bangladesh may not have their purchasing power for importing these fuels. Sudden increase in oil price in the 1970's resulted in a perceptible fall in economic growth in industrial Countries (Wohlmeyer 1987). At the same time development of the oil importing countries of the third world came to an abrupt halt resulting virtually in the stagnation of the economic growth. Apart from economic stress, use of diesel pollutes the environment by emitting carbon dioxide, carbon mono-oxide, etc. which help producing green house effect, acid rains and so forth; thus diesel substitution is further emphasized.

Bangladesh, located between 24° 26' and 26° 20' latitude and 80°01' and 92°24' longitude, is endowed with an abundance of sunshine during most of the year and blessed with sufficient amount of indigenous non-deplectable resources of solar energy. The average incident rate of solar energy in Bangladesh was about 3000 times its consumption rate [Hossain, 1980].

The mean monthly average daily total solar radiation in Dhaka is 0.376 kW/m^2 and in Bangladesh 0.365 kW/m^2. The maximum and monthly average daily radiation in Bangladesh are found to be 0.373 kW/m^2 and 0.292 kW/m^2 during months of April in Dhaka and January in Jessore respectively [Helali, 1985].

The yearly total diffused radiation in Dhaka is considerable. It is about 72 percent of the total radiation [Helali, 1985]. This aspect should be taken into consideration at the time of focusing collectors. It is obvious that the known resources of fossil fuels in the world are depleting very fast and by the turn of the contury, man will have to increasingly depend upon renewable resources of energy. Apart from its free availablity in nature of such forms of energy, they are also pollution free and can be used in a decentralised manner, reducing the cost of transmission and distribution of power.

Sun is a primary sources of energy, and all forms of energy on the earth are derived from it.

The solar energy can be harnessed either by deriving energy directly or from sunlight or by indirect methods. The solar energy can be harnessed directly by:

i. Solar thermal technology, i.e. harnessing of solar heat into useful energy using collectors.

ii. Photovoltaic energy conversion technology. This is the most useful way of harnessing solar energy by directly converting it into electricity by means of solar photovoltaic cells. When sunshine is incident on solar cells, they generate D.C. electricity without the involvement of any mechanical generators. the electrical energy output from solar P.V. cells depends upon the intensity of sunlight incident on it, its conversion efficiency and temperature of operation. It is a highly versatile approach, since the generated electrical power can be used conversantly for various diverse purposes at the site of use.

iii. Solar hydrogen gas production technology. It is still at an embryonic stage.

The indirect method is in the form of wind. Biomass and bio-gas and through tides.

CHAPTER 2
LITERATURE SURVEY

2.1 REVIEW OF SOLAR THERMAL ENERGY

Not much is known about the first practical application of solar energy. However, in prehistoric times, in Iraq, polished golden vessels were used to ignite fire by means of the sun. Around 1455 B.C., in Egypt, `Sounding Status' were found, the sound being caused by escaping air which had been heated by the rising sun falling on them. In china, the Han-dynasty (202 B.C) used concave mirrors to light torches for sacrifices.

Modern application of solar energy started probably in 1855, A.D.C. Guntur, an Australian, invented a solar boiler using mirrors. The first major solar energy installation is probably the water distillation plant in Chili, built in 1872, covering at area of 4800 m^2 producing 2300 litres of distilled water a day. Shuman et. al., in 1912-13, built the world's largest solar water pump of 37 to 40 kW to pump water from the Nile for irrigation. In October 1973, the Arab members of OPEC temporarily stopped the export of oil which led to severe energy panic and subsequent realization of the importance of research and development of alternative energy sources without delay.

Industrialized countries, such as CIS (Former USSR), Japan, France, Germany and Canada are very advanced in solar energy technology and offer higher level teaching at their universities. Australia and Isreal have contributed notably to solar science and technology with thousands of apartments enjoying solar water heaters. Brace Research Institution in Canada has done extensive research works covering almost all fields of solar energy.

Although, solar energy has been successfully utilized on space crafts, heating or cooling of buildings, solar water heaters, driers, cookers, pumps, refrigerators, furnaces, and photovoltaic conversions, the current developments in solar energy represents a mile stone on the way to large-scale use of this inexhaustable source of energy in the future.

2.2 COLLECTOR-CUM-STORAGE TYPE SOLAR WATER HEATERS HAVING FLAT ABSORBER PLATE (CSWHF)

The Built-in-storage type solar water heater is the one in which the collector and storage tank are combined in one unit where water is heated and stored. The advantages of a built-in-storage type of solar water heater are absence of intricate mechanism to follow the sun and the ability to absorb both beam and diffuse components of solar radiation.

A comparative evaluation of the performances of three built-in-storage type water heaters of equal volume was carried out by Ecevit et. al. [1990]. They found that the triangular heater without baffle plate was most efficient (46 percent). The rectangular and the triangular one with baffle plate heaters were 43 percent and 40 percent efficient, respectively. Ecevit et. al. [1989] studied three built-in-storage type solar water heaters with different volumes and found that the rate of heating rises as the heater tube diameter decreases, producing enhanced natural convection and thus resulting in better performance during heating period. Vaxman et. al. [1985] found the maximum bulk efficiency of triangular heater with baffle plate to be 53 percent from 9 to 11 AM and 15 percent at the end of 24 hours cycle due to no radiation. Sokolov et. al. [1983] also showed that the performance of the rectangular and triangular one with baffle plates was same. Garg [1975] carried out year round performance test on rectangular heater of capacity 90 litres and showed that it can supply 90 litres of water at a mean temperature of 50 to 60°C in winter and 60 to 75°C in summer. Chinnappa et. al. [1973] studied pressurized built-in-storage type heater and found that 30-50 gal of water could be supplied a day at 120°F (48.89°C) and the efficiency was 46 percent. The pioneer works on this type of heater were done by many researchers like Chauhan [1976], Tanishita [1970], Close et. al. [1967], Richards et. al. [1967] and Tanishita [1964]. Hamid [1993] developed a Built-in-Storage Type Solar Water Heater (BSWH), 115 litres in capacity 1.25 m^2 of collector surface area, and 92 mm in depth and studied, at Dhaka, during the months of January, February and March 1992.

2.3 COLLECTOR-CUM-STORAGE TYPE SOLAR WATER HEATERS HAVING CORRUGATED ABSORBER PLATE (CSWHC)

In this type collector-cum-storage-type solar water heater corrugated absorber plate is used instead of flat plate. A sandwich type collector construction has been described by Khanna (1982). It consists of blackened corrugated G.I. Sheet with a plain GI sheet to form parallel water channel running the entire length of the corrugated sheet. The sheets were held together at many points by riveted joints. The edges were Jointed by welding.

Another solar water heater combining collection and storage was tested in Srilanka by Chinnappa and Gnanalingam (1973). The heater consists of a coil of square cross section pipe painted black to absorb solar energy (equivalent dia. 7.5 cm), 13.5 m in length fixed in a wooden box with two glass covers and insulation at the bottom. The pipe in addition to being costlier than plain metal sheet has to be in many sections, joined together by welding or elbow connections to provide 90° bends. The collection efficiency, based on glazed area was ascertained to be about 46 percent at water temperature of about 50°C.

In Allhabad, India, a collector was, made from, corrugated GI sheet (Bhardwaj, 1967). Another heater was constructed in USA by Klensch where at different flows the temperature of the water obtained was higher than 170°F it being averaged over eight hour period (Sides, 1905). Here a box of sheet metal the top of which was corrugated to present a series convex of surfaces, is used as solar heat absorber. Water is circulated at the bottom of the box absorbing heat.

Experiments were carried out at Dhaka in Bangladesh by Desa (1964). In these experiments, corrugated sheet, flat plate collector was found to be inexpensive and satisfactory solar water heater.

Arrangement for heating water with solar energy for supplying the domestic needs for a small family in Delhi, using easily available and inexpensive construction materials (Galvanize iron) was constructed by Mathur (1959). Trial indicated that the domestic unit would recover initial cost in less than one year. The conventional flat plate construction using a copper sheet with a copper pipe soldered on it was replaced by comparatively inexpensive arrangement consisting of a corrugated, galvanized iron sheet to form compact sandwich in which water would flow between the plain sheet and corrugation, Mathur (1961). Another water heater was constructed where a storage tank is connected to a flat plate collector exposed to the sun in a vertical or inclihed position, the collector having of two corrugated plate in a box covered with glass or plastic; provided with an air space by Thomson (1928).

An analysis of the heat transfer processes in a corrugated steel plate solar water heater and a simplified test procedure for determining the collector efficiency equations were represented by Wang-Shing-An (1979) of Shanghi Mechanical Engineering Institute China. The efficiency of the collector was over 94% and the space temperature was higher than the collector temperature by 7°. The corrugated plate solar collectors are widely used in China. In the corrugated plate solar energy absorbing surface transfers the absorbed energy to a fluid by direct contact. Therefore, from the point of view of heat transfer, the advantage is evident.

2.4 SCOPE OF PRESENT WORK

The present work provides a systematic investigation of the performance characteristics of two collector-cum-storage type solar water heater having a flat absorber plate (CSWHF) and a corrugated absorber plate (CSWHC). The test was carried out in Dhaka during the months of November, 1994 to March, 1995. The results of the experimental study were compared with available information in the literature.

Technologies are available for harnessing solar energy as indicated in the preceding literature survey. This work is an exception in the sense that corrugated sheet is used as absorber plate of the collector. Corrugated sheet has got good heat transfer charactieristics and available everywhere in our country. This can reduce the overall cost to a great amount since the corrugated sheet acts as an absorber as well as channels for the water to flow.

A lot of research works have been carried out all over the world on flat plate collectors. Sufficient information and experimental data have been provided for analysing the performance characteristics. But the work on corrugated collector-cum-storage type solar water heater and CSWHF still is in its infancy. Researchers of this country have carried out only limited work on solar collector and the experimental data available are quite inadequate for analysing the performance characteristics. Whereas, the geographical position of this country shows that this country is blessed with sufficient amount of solar energy throughout the year, as mentioned in Chapter-1.

It is expected that the major part of energy requirements in this country in the future may be met from solar energy source. This suggests the scope to study and work on a corrugated collector-cum-storage type solar water heater and CSWHF at Dhaka. It was thus decided to study corrugated collector-cum-storage type solar water heater and CSWHF here to show the performance characteristics. Accordingly, an extensive performance test of a corrugated collector-cum-storage type solar water heater and CSWHF was carried out in months of November-December, 1994, January-March, 1995. Both final mean water temperature and initial water temperature were recorded on hourly basis from 8 AM to 6 P.M everyday. Solar insolations at Dhaka were taken from the work of Helali (1985). Heat energy and efficiency of the collector were calculated. The results were compared with the available information in the literature.

CHAPTER 3

EXPERIMENTAL APPARATUS AND TEST PROCEDURES

3.1 GENERAL DESCRIPTION OF THE APPARATUS

The experimental apparatus and measuring devices are shown diagramatically in Fig. 3.1(a) and 3.1(b). It consists of two collector-cum-storage type solar water Heaters in which one absorber plate is flat and the other one is corrugated and measuring equipments (Digital Milivoltmeter and Selection Switch), and cold junction (Ice Box). Solar energy in the form of heat is absorbed by the absorber plates of collectors and is transferred to the water of the collector-cum-storage tank of collectors and CSWHF. Five 36 SWG Chromel-Alumel thermocouples per-heater installed in the storage tank at different depths are used to measure water temperature. The thermocouple setting measurements of both heaters from top to bottom are 0.725 cm, 1.75 cm, 1.75 cm, 1.75 cm, 1.75 cm and 0.725 cm. The larger pipe diameter is 1.905 cm and smaller pipe diameter is 4 mm. These thermocouples are connected to the Digital Milivoltmeter (DVM) through the selector switch. The Digital Milivoltmeter (DVM) is used to measure water temperature in terms of e.m.f. generated in the thermocouples. Finally these e.m.fs. were converted into temperature with the help of K type New Reference Tables.

3.2 FABRICATION OF A COLLECTOR-CUM-STORAGE TYPE CORRUGATED SOLAR WATER HEATER AND CSWHF

The collector-cum-storage type solar water heater using corrugated plate as absorber and CSWHF are illustrated schematically in detail in Figs.3.1(a) to 3.5 respectively. The details and of the corrugated type solar water heater and CSWHF fabrication are given below:

3.2.1 Corrugated Absorber Plate Solar Collector and Flat Absorber Plate Solar Collector

The storage tank and the solar collector were combined, and built as one unit. Its external dimensions are 137.16 cm x 91.44 cm x 9.21 cm with a capacity of 114 litres. It consists of two 16 Gauge GI Sheets, one at the bottom which is plain and the other at the top which is corrugated. For CSWHF both 16 Gauge GI sheets are plain. The top surface of the absorber plate was blackened with a dull paint in order to increase the absorptance of shortwave solar radiation. The wooden frame made, by 'Gorjon Wood', supports the plate and, to avoid leakage of water, rubber gasket was used in between the frame and the G.I. Sheet, securely tightened with nuts and bolts all around, as illustrated in Fig. 3.3(a). For measurement of temperature of water at different depths, 5 Chromel–Alumel thermocouple probes were inserted per heater inside the tank as illustrated in Fig. 3.3(b) and 3.4. Two G.I. pipes of diameter 19.05 mm and length 45.72 cm were fitted one for cold water inlet at the front and the other one for hot water outlet at the back-side of the collector per unit.

Collector is the heart of solar water heater and is shown in fig. 3.2. The design of collector needs much more care. The performance of the collector indicates the performance of the solar water heater. A solar collector absorbs the solar radiation falling on it and uses this energy to heat water flowing through collector which is a flat plate type absorber plate and corrugated type absorber plate.

3.2.2 Absorber Plate

Absorber plate as shown in fig. 3.2 absorbs the incoming solar radiation and transfers this resulting heat to the working fluid. Factors that determined the choice of absorber materials are:

i. Thermal conductivity (since heat is transferred to the fluid mainly by conduction);
ii. Durability;
iii. Ease of handling;
iv. Availability; and
v. Cost.

Thermal conductivities of various materials are investigated. Corrugated iron sheet and GI sheet has thermal conductivity of 62.72 W/m°C which is lower than those of copper and aluminium. But this is compensated by the good heat transfer characteristics of corrugated sheet (Wang Shing-an, 1979). Moreover, the thermal expansion of iron is much more lower than commonly used copper and aluminium. This property of the iron will prevent the bulging of corrugated sheet from the absorber plate at high temperature. The corrugated iron sheet is less costlier than that of commonly used materials. Since for household purposes, corrugated sheet serves as an important element of roofing, it is available in our country. Its price is too low where as cost of copper is high. So corrugated sheet is used in the absorber plate and its utility is briefly discussed in review of literature. This corrugated sheet is placed over plain GI Sheet. Corrugation may increase losses caused by natural convection between the absorber plate and glass cover, but it increases the effective light absorption of the surfaces by bouncing the light more than once as it enters the grooves. So the net effect of corrugated absorber plate is to increase efficiency (Anderson). The two sheets are held together by some Nut-Bolt joints and wood. As far as possible use of Nut-Bolt joints was avoided to prevent leakage tendencies. Two pipes (inlet and outlet) were fitted to the opposite sides of tank by thread, gasket and glue.

The top portion of the absorber plate facing the sun is painted black since black body is the best absorber as well as the best emitter. The good quality paint. Berger/Elite is used, special surfaces called selective surfaces have been developed which are good absorbers of solar radiation and yet poor radiation of heat. This surfaces are prepared by chemically treating the plate. But they are more expensive than black paint surfaces and are generally only used when high temperatures are required from the collector i.e., when it is important to keep the heat losses as low as possible. Since this is not for high temperature application, Berger/Elite paint can serve well.

3.2.3 Glass Cover Plate (Glazing)

A transparent cover plate (glazing), as shown in fig. 3.3, is usually used on solar collector to reduce the rate of heat loss from the absorber plate to the environment and thus to increase collector output. The glazing produces Green House effect. This must be highly transparent to the wavelengths of the incoming sunlight; and it is best if it also is opaque to the longer heat wave lengths that are being reradiated by the absorber plate. The functions of the glazing is to trap heat. This is always better to use low iron content glass to reduce the absorption of solar radiation. One sheet of 0.32 cm glass transmits from about 82-90 percent of the visible light striking it. Locally made glass has high iron content and this leads to significant absorption of solar radiation. For this reasons a 3mm sheet of local window glass may only transmits 80-84 percent of the radiation falling on it. Low iron glass can be imported and used on flat plate collectors. With this glass upto 92 percent of the solar radiation may be transmitted. Cost reason generally favours the use of local window glass with its high absorption of solar radiation. Here 4 mm window glass is used.

The air gap between the absorber plate and the glass cover is an important factor. The small air gap 1 to 4 cm between plate and glazing suppresses direct convective losses due to wind, and the glazing opacities to infrared radiation traps heat inside the collector box for low temperature application, a spacing of 2.50 cm is about the optimum [Rai, G.D., Solar Energy Utilization, 1989]. Here mentioned the air gap of 2.50 cm was kept in solar water heater for obtaining better performance.

The question may arise that why plastic sheet was not used although it is a cheap material. The following Table 3.1 gives the answer.

Table 3.1: Transmissivity of Glass and Plastic Sheet.

Cover Material	Short Wave Transmissivity from Solar Radiation	Transmittance to Long Wave
Transparent Glass	0.88	0.03
Transparent Plastic	0.89	0.80

Source: Rai, G.D. (Solar Energy Utilization, 1989).

Plastics are affected by continuous exposure to solar radiation. Effects such as crazing, discolouring and brittleness may be produced which reduces both the life of the cover and the fraction of solar radiation transmitted and degrade quickly in sunlight unless treated with ultra violet inhibitors.

So, in order to admit as much solar radiation as possible as well as to reduce heat losses from the collector by re-radiation and convection to a minimum value, a glass cover of 142.24 cm x 101.60 cm x 4 mm, with optimum air gap of 25.4 mm [Eggers, 1980], is used. The glass rests on a wooden frame, made of `Gorjon' of 142.24 cm x 101.60 cm x 24.11 cm and, is secured by wooden batten of 2.54 cm x 156 cm, screwed with the wooden box, as shown in Fig. 3.4(b).

3.2.4 Insulation

Insulator is used on the back and all side of the absorber plate to prevent the heat loss by conduction from the absorber plate.

The glass-wool because of its low thermal conductivity of 0.041 W/mK, and of moderate cost, was used as insulation having thickness of 2.86 cm at the bottom surface and 25.4 mm at sides.

3.2.5 Casing (Wooden Box)

The wooden box is made of Pine wood. This is low cost compared to other woods. Weight of this wood is less which provides minimum physical effort to shift the collector from one place to other place. The `Pine' wood is not easily attacked by the wood cutting worms. The lower portion (Fig. 3.5) contains space for insulating material. The box is so designed that collector assembly can easily be detached. The external dimensions of the box are 147.32 cm x 106.68 cm x 29.21 cm.

3.2.6 Steel Stand and Structure

The supporting steel structure for the heaters consists of a frame made of angle iron bar 152.40 cm x 107.70 cm. Another steel structure of dimensions 167.64 cm x 108.92 cm was made, on which the corrugated collector-cum-storage type solar water and CSWHF are held rigidly and it has the provision of setting the collector at any desired inclination between 0° and 40° manually, as shown in the fig. 3.2.

3.3 TEST PROCEDURES AND MEASUREMENTS

Calibration of thermocouples was carried out in a hot water bath for temperatures upto 100°C and in a muffle furnace upto a temperature of 200°C. The readins were compared with a precision thermometer. The indicated e.m.f. was compared with the tabulated values for Chromel-Alumel thermocouples of British Standard No. 4938, Part 4:1973 & ASTM E 230-72.

Before starting experiment, the storage tank of the solar water heater was filled with fresh water through the gate valve attached to the collector's inlet pipe. Care was taken so that no air bubbles were trapped in the tank.

The temperature distribution along the depth of the tank was measured using 36 SWG Chromel-Alumel thermocouples. As mentioned earlier, a total of 5 thermocouples (Fig. 3.1 and 3.4) were used to obtain temperature distribution. These temperatures and the initial water temperature were recorded every hour from 8 AM to 6 PM, everyday. The results obtained had a maximum error of ± 0.2°C at a maximum operating temperature of 60°C.

3.4 REDUCTION OF DATA

The relevant parameters were calculated from the data and graphs were plotted using the computer in the Mechanical Engineering Department, BUET. The results were checked using the Desk calculator. The results and discussion are presented in Chapter-4. The working formulas and sample calculations are provided in Appendix-B.

CHAPTER 4

PERFORMANCE ANALYSIS OF THE COLLECTORS

Daily average of the total radiation for the month of November, 1984 to March, 1985 was taken from the tabulated data of Helali [1985].

The test was done over one hour interval. Fresh water was introduced in to the collectors, at every one hour interval from 8 AM to 6 PM. Inlet water temperature and water temperature at different section were measured and final mean temperature of the water in the collector was taken for calculations.

The collector was placed horizontally to compare their performance. But there have been provisions to placed at any angle between 0 to 23.5° because the constant latitude angle for Bangladesh is 23.5°.

Sample calculation of the collectors is given in the Appendix.

CHAPTER 5
RESULTS AND DISCUSSIONS

An experimental investigation was carried out for studying performance characterisitcs of two collector-cum-storage-type solar water heaters, one having corrugated absorber plate (CSWHC) and the other having flat one (CSWHF) in Dhaka during months of November, 1994 to March, 1995. Both heaters were filled with fresh water at atmospheric temperature at every hour starting from 8 A.M. and readings were taken on hourly basis until 6 P.M. Results are presented graphically from figures 4.1 to 4.45 interms of initial water temperature, final mean water temperature and heat energy absorbed.

Figures 4.1 to 4.31 show typical temperature distributions of water in the heaters during day time (8 A.M. to 6 P.M.) in the months of November, 1994 to March, 1995. It is observed from these figures that as the initial water temperature increases, the final mean water temperatures for both heaters also increase and final mean water temperatures reach maximum values at around noon every day as expected. In the afternoon both the initial and the final mean water temperatures decrease at almost the same rate, but the rise of water temperatures in the collectors is more in the forenoon than in the afternoon. This may be due to the fact that the heat energy absorbed by water during this period is faster than that absorbed by water in the afternoon and may also be due to solar path. From 8 A.M. to 6 P.M. the average initial water temperature varies from 16 to 28.5°C in November, 15 to 24°C in December, 14 to 24°C in January, 16 to 29°C in February and 19 to 36°C in March.

Typical results in terms of energy absorbed per hour at every hour are given in figures 4.32 to 4.45. It is evident from these figures that energy absorbed by water increases in both heaters upto 10 A.M., then remains almost constant upto 4 P.M. and then decreases every day. Theoretically heat absorbed in a heater would have increased even after 10 A.M. if we could supply inlet water at the same initial temperature as in the morning hours (i.e. 8 A.M.). It is also found that heat energy absorbed by CSWHC is higher than that of CSWHF by 43 percent. This is due to the fact that CSWHC absorbed more diffuse radiation than that absorbed by CSWHF everyday. This may also be due to multiple reflection and more surface area. In one hour, starting from 8 A.M., the heat energy absorbed by horizontally placed corrugated type solar water heater (CSWHC) is considerably high varying from 0.159 to 0.371 kW/m^2 ~~and~~ (by CSWHF 0.106 to 0.223 kW/m^2) in November, 0.106 to 0.318 kW/m^2 ~~and~~ (by CSWHF 0.053 to 0.212 kW/m^2) in December, 0.371 to 0.212 kW/m^2 ~~and~~ (by CSWHF 0.106 to 0.265 kW/m^2) in January, 0.106 to 0.424 kW/m^2 ~~and~~ (by CSWHF 0.053 to 0.212 kW/m^2) in February and 0.212 to 0.477 kW/m^2 ~~and~~ (by CSWHF 0.106 to 0.212 kW/m^2) in March.

During this period the Collector-cum-storage Type Solar Water Heater having flat absorber plate (CSWHF) can heat 114 litres of water to a final mean temperatures of 32°C absorbing 0.212 kW/m^2 in November, 25°C absorbing 0.106 kW/m^2 in December, 26°C absorbing 0.212 kW/m^2 in January, 32°C absorbing 0.318 kW/m^2 in February and 41°C absorbing 0.371 kW/m^2 in March. The Collector-cum-storage Type Solar Water Heater having corrugated absorber plate (CSWHC) can heat 114 litres of water to a final mean temperatures of 32.5°C absorbing 0.318 kW/m^2 in November, 26°C absorbing 0.212 kW/m^2 in December, 27°C absorbing 0.318 kW/m^2 in January, 33°C absorbing 0.424 kW/m^2 in February and 42°C absorbing 0.477 kW/m^2 in March. The average temperature differences between final mean water temperature and initial mean water temperature of the above five months are 2°C in CSWHF and 3°C in CSWHC. With the increasing of initial water temperature the heat energy absorbed by the collectors also increases but at a faster rate and then almost remains constant. Both the final mean water and initial water temperatures then decrease at almost the same rate. Due to clouds some time the energy vs time curves are not similar (the curve drops down but goes up when clouds clear up). In case of corrugated plate some time there might have remained air bubbles in the collector while filling up the collector with water on hourly basis. This air obstructed the absorption of solar heat. So the values for final water temperature, quantity of energy absorbed and efficiency must have fallen in these cases.

Figures 4.46 to 4.50 show daily efficiencies for both collectors in the months of November, 1994 to March, 1995. It is evident from these figures that the efficiency of corrugated type collector (CSWHC) is more than that of flat plate collector (CHWHF).

This may be due to the fact that corrugated collector absorbed total radiation more than that absorbed by the flat plate collector (CSWHF). This may also be due to multiple reflection of diffuse radiation and more surface area. The total surface area of corrugated collector is 1.28 times than that of flat collector i.e. CSWHC has 28 percent more surface area than that in the flat plate collector. So on area basis initial capital cost is more but gain in energy is 43 percent more in CSWHC than the CSWHF.

From table II, it is found that, the efficiency of CSWHC is more than that of CSWHF, by 46 percent in November, 40 percent in December, 50 percent in January, 56 percent in Fabruary and 44 percent in March.

Table—II

Sl. No.	Month	Flat Plate		Corrugated Plate	
		q_{av} kW/m^2	η_{av} %	q_{av} kW/m^2	η_{av} %
1	November	0.204	61	0.302	89
2	December	0.144	50	0.201	70
3	January	0.2038	63	0.312	95
4	February	0.149	46	0.2383	72
5	March	0.208	54	0.2991	78

On November 25, the efficiency was 66 percent in flat plate type and 72 percent in corrugated plate type i.e. the efficiency is increased by 6% in corrugated plate type. The efficiency has been calculated by using total surface area of the absorber plate. So the increased efficiency of corrugated plate collector is due to absorption of excess diffuse radiation. The efficiencies in flat plate collector and in corrugated plate collector are found to be 66 percent and 93 percent respectively when projected area was considered i.e. the true % efficiency is increased by 27 in corrugated type collector.

Figure 4.51 shows maximum final mean water temperature attained during day time (8 A.M. to 6 P.M.) every day in the months of November, 1994 to March, 1995 in CSWHF. It is evident from this figure that in CSWHF, this temperature varies from 29 to 36°C in November, 21 to 29°C in December, 22 to 29°C in January, 22 to 33°C in February and 28 to 41°C in March.

Figure 4.52 shows maximum energy absorbed by water in CSWHC during day time (8 A.M. to 6 P.M.) every day in the months of November, 1994 to March, 1995. It is found from this figure that, in CSWHC, this energy varies from 0.264 to 0.477 kW/m^2 in November, 0.212 to 0.370 kW/m^2 in December, 0.264 to 0.371 kW/m^2 in January, 0.264 to 0.390 kW/m^2 in February and 0.264 to 0.477 kW/m^2 in March.

Figure 4.53 gives daily average energy absorbed in CSWHC during day time (8 A.M. to 6 P.M.) in the months of November, 1994 to March, 1995. It is observed from this figure that average energy absorbed by water varies from 0.238 to 0.308 kW/m^2 in November, 0.164 to 0.285 kW/m^2 in December, 0.200 to 0.313 kW/m^2 in January, 0.164 to 0.308 kW/m^2 in February and 0.164 to 0.313 kW/m^2 in March.

Results, obtained in this work on February 11 and 19 are compared with those of Hamid [1992] and Chinnappa [1973] as shown in figures 4.54 to 4.57. (a) Hamid [1992] listed in Dhaka a collector-cum-storage type solar water heater having flat plate absorber, with surface area 1.25 m^2, average depth of 9.2 cm and single glass cover and a capacity of 114 litres, (b) Chinnappa tested a combined collector and storage type solar water heater of colombo on February 11 and 19 in 1973. This heater consisted of a square coil of 76.20 mm diameter pipe 13.50 m long, with two glass covers of 1.86 m^2 in area (c) one corrugated type solar water heater with a projected absorber area of 1.85 x 0.85 = 1.57 m^2, transparent frontal area 1.64 m^2 and two glass covers, having a capacity of 18.25 litres was tested in China (Wang-Shing An-1979).

The differences in the results may be due to: (a) different types, (b) test conducted at three different geographically located stations and (c) different years (1992 in Dhaka, 1995 in Dhaka, 1993 in Colombo and 1979 in China). Though the time of the year is the same but the year as well as the weather conditions at three different locations may have been different. But similarity of Hamid's result with the present work may be noted in figure 4.55.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

From the investigations the following conclusions can be drawn:

i. The final mean water temperature increases with increasing of initial water temperature at a faster rate and reaches a maximum value at the maximum initial water temperature around noon. Both final mean and initial water temperatures then decrease at almost the same rate.

ii. The initial water temperature increases, the final mean water temperatures for both heaters also increase and final mean water temperatures reach maximum values at around noon every day as expected. The rise of water temperatures in the collectors is more in the forenoon than in the afternoon.

iii. In one hour time from 11 A.M. the flat plate solar heater can raise the temperature of water ~~to~~ a final mean water temperature of 32°C in November, 25°C in December, 26°C in January, 32°C in February and 41°C in March and in corrugated plate ~~by~~ 33°C in November, 26°C in December, 27°C in January, 33°C in February and 42°C in March. The average temperature differences between final mean water temperature and initial mean water temperature of above five months are 2°C in CSWHF and 3°C in CSWHC.

iv. In one hour, starting from 8 A.M., the heat energy absorbed by horizontally placed corrugated type solar water heater (CSWHC) is considerably high varying from 0.159 to 0.371 kW/m^2 ~~and~~ by CSWHF 0.106 to 0.223 kW/m^2 in November, 0.106 to 0.318 kW/m^2 ~~and~~ by CSWHF 0.053 to 0.212 kW/m^2 in December, 0.371 to 0.212 kW/m^2 ~~and~~ by CSWHF 0.106 to 0.265 kW/m^2 in January, 0.106 to 0.424 kW/m^2 ~~and~~ by CSWHF 0.053 to 0.212 kW/m^2 in February and 0.212 to 0.477 kW/m^2 ~~and~~ by CSWHF 0.106 to 0.212 kW/m^2 in March.

v. The monthly average heat energy absorbed by CSWHF is 0.204 kW/m^2 with 61 percent efficiency in November, 0.144 kW/m^2 with 50 percent efficiency in December, 0.2038 kW/m^2 with 63 percent efficiency in January, 0.149 kW/m^2 with 46 percent efficiency in February and 0.208 kW/m^2 with 54 percent efficiency in March. The monthly average heat energy absorbed by CSWHC is 0.302 kW/m^2 with 89 percent efficiency in November, 0.201 kW/m^2 with 70 percent efficiency in December, 0.312 kW/m^2 with 95 percent efficiency in January, 0.2383 kW/m^2 with 72 percent efficiency in February and 0.2991 kW/m^2 with 78 percent efficiency in March.

vi. On very clear bright sunny days, the maximum efficiency of 56 percent can be obtained with a final mean water temperature of 30°C in February and 49 percent efficiency with a final mean water temperature of 40°C in March for CSWHF and 86 percent efficiency can be obtained with a final mean water temperature of 31°C in February and 75 percent efficiency with a final mean temperature of 42°C in March for CSWHC.

vii. The efficiency of corrugated type collector (CSWHC) is more than that of flat plate collector (CSWHF). The corrugated one has a collector area 1.28 times that of flat collector. So on area basis initial capital cost is more but gain in energy is 43 percent more in CSWHC than the CSWHF. The efficiency is more in CSWHC than that of CSWHF, and these values are 45 percent increase in November, 40 percent increase in December, 50 percent increase in January, 56 percent increase in February and 44 percent increase in march. So the corrugated plate collector-cum-storage type solar water heater is better than flat plate collector-cum-storage type solar water heater under the conditions tested.

6.2 RECOMMENDATIONS

Collector, the heart of the solar water heater being constructed by writer . The following recommendations are put forward on the basis of the experience gained out of this research and concerning solar heater are consider worth recording here for subsequent investigations.

i. The year round performance characteristics of the flat plate and corrugated type solar water heater for varying inclination should be studied.

ii. According to Helali [1985], the yearly total diffuse radiation in Dhaka is about 72% of the total radiation. As the diffuse radiation come from all directions substantial amount of radiation can be captured by way of exposing all the sides of the heater unit like the top surface with glass cover. For designing the solar water heater to capture radiation from all directions, the storage tank may be built separately so that the water may be drawn off from the heater after achieving the desired water temperature and stored in a storage tank.

iii. The flat plate and corrugated type solar water heater should be strong enough to withstand severe winds, storms, hailstone, etc. They should be water tight yet should have vent holes located around the corner of the upheader to prevent condensation and at the same time the collector may be set at a desired angle of inclination without spill over of water.

iv. The performance of the heater at a predetermined constant water temperature should be investigated.

v. The performance of the flat plate and corrugated type solar water heaters for different shapes of surface area of the collector with constant volume and varying inclination should be studied.

REFERENCES

1. Bhardwaj, R. K. et al., 1967; "Performance of a Flat Plate Solar Collector", Solar Energy, Vol. 2, No. 3-4, July-December, pp. 160-162.

2. Bliss R.W., 1959; "The Derivation of Several Plate Efficiency Factors useful in the Design of Flat Plate Solar Collectors", Solar Energy, 3, p. 56.

3. Chauhan R.S. and Kadambi V., 1976; "Performance of a Collector-cum-Storage Type of Solar Water Heater", Solar Energy, 18, p. 327.

4. Chinnappa J.C.V. and Gnanlingam K., 1973; "Performance at Colombo, Ceylon of a Pressurized Solar Water Heater of the Combined Collector and Storage Type, Solar Energy", 15, p. 195.

5. Close D. J. and Lof. G.O.F., 1967; "Solar Water Heaters in Low Temperature Engineering Application of Solar Energy", Ch. 6, p. 61478, ASHRAE.

6. Desa,V.G. 1964;"Solar Energy Utilization at Dhaka", Solar Energy,Vol.8, No. 3.

7. Duffie J.A. and Beckman W.A., "Solar Engineering of Thermal Processes", A Wiley- Inter Science Publication.

8. Ecevit et. al. 1990; "A Comparative Evaluation of the Performance of Three Built-in-Storage Type Solar Water Heaters", Solar Energy, 44, p. 23.

9. Ecevit A., Al-Shariah A.M. and Apaydin E.D., 1989; "Triangular Built-in-Storage Solar Water Heater", Solar Energy 42, p. 253.

10. Eggers-Lura A., 1979; "Solar Energy in Developing Countries", Vol. 1, Pergamon Press.

11. Garg H.P. and Rani V., 1982; "Theoritical and Experimental Studies on Collector/Storage Type Solar Water Heater", Solar Energy, 23, p. 467.

12. Garg H.P., 1975; "Year Round Performance Studies on a Built-in-Storage Type Solar Water Heater at Jodhpur, India", Solar Energy, 17, p. 167.

13. Garg H.P., 1973; "Design and Performance of a Large Size Solar Water Heater", Solar Energy, 14, p. 303.

14. Garg H.P. and Krishman A., 1973; "Development of a Low-Cost Solar Water Heater at Jodhpur", India and Easter Engineering, 115, p. 339.

15. Garg H.P., 1972; "Design and Performance Prediction of Low-Cost Solar Water Heater", Research and Industry, 17, p. 125.

16. Garg H.P. and Gupta C.L., 1968; "System Design in Solar Water Heaters with Natural Circulation", Solar Energy, 12, p. 163.

17. Gupta C.L. and Garg H.P., 1967; "Optimizing the Lift of Flat Plate Solar Collectors for India", J. Inst. of Engrs. (India), Pt. GE, 21.

18. Garg, H.P., 1975; "Year Round Performance Studies on a Built-in-Storage Type Solar Water Heater at Jodhpur, India", Solar Energy, Vol. 17, p. 167.

19. Hamid A.K.M.A, 1993; "Performance Studies of a Built-in-Storage Type Solar Water Heater at Dhaka in the Month of January-March", A Project Report on Master of Engineering (Mechanical), BUET, Dhaka.

20. Hawkin, H.M., 1947; "Domestic Solar Water Heating in Florida", Bulletin of the Florida Engineering Industrial Experimental Station, No. 18, p. 26.

21. Helali M., 1985; "Solar Radiation in Bangladesh", M. Sc. Thesis, BUET, Dhaka.

22. Hossain M. Anwer, 1980; "Possible Low Temperature Applications of Solar Energy in Bangladesh", Technical Journal, BUET.

23. Hottel H.C. and Woertz B.B., 1942; "The Performance of Flat Plate Solar Heat Collectors", Trans. ASME, 64, p. 91.

24. Kreith F. and Kreider J.F., "Principles of Solar Engineering", Pub. McGraw-Hill Book Company.

25. Khanna M.L., 1982; "The Development of a Solar Water Heater and its Field Trials Under Indial Tropical Conditions", M. Tech. Thesis, Mechanical Engineering Department, IIT, Kanpur.

26. Marshal E. and Adams G., 1978; "The Efficiency of Solar Flat Plate Collectors", Solar Energy, 30, p.413.

27. Morse, R. N., 1970; "Solar Energy Research and Development and Industrial Applications in Australia", ISES Conference, Melbourne, Paper 1/94.

28. Morse R.N., 1961; "Water Heating by Solar Energy", UN. Conf. New Sources of Energy, Rome, Paper 5/38, pp. 62-73.

29. Marsh, K. R.(1994). Effective Energy Management. The World Agriculture: The International Review of Agribusiness in Developing Markets. Sterling Publications Limited, Londong, W22 YW, UK.

30. Mathur, K.N., 1959; "Domestic Solar Water Heater", Journal of Scientific Industrial research, Vol. 184, February, pp. 51-58.

31. Mathur, K.N., 1961; "Solar Water Heaters", Conference on New Sources of Energy, Rome, Paper No. S/102, p. 19.

32. Prakash J., Garg H.P. and Datta G., 1985; "A Solar Water Heater with a Built-in-Latent Heat Storage", Energy Conversion. Mgnt. 25, p. 51.

33. Proctor D., 1981; "A Generalized Method for Testing all Class of Solar Collector-I, II", Solar Energy, 32, p. 377.

34. Rai G. D., 1984; "Solar Energy Utilization", 3rd Ed.

35. Richards S.J. and Chinnery D.N.W., 1967; "A Solar Water Heater for Low Cost Housing", NBRI Bull., 41, CSIR Research Report, p. 237, South Africa.

36. Sokolov M. and Vaxman M., 1983; "Analysis of an Integral Compact Solar Water Heater", Solar Energy, 30, p. 237.

37. Shajahan, M. (1993). Inaugural speech given at the International Symposium on Electrical Energy System. Jointly organized by BUET, Dhaka and Virgina Polytechnic Institute, USA, 13-15 December.

38. Sides, W.S., 1905; "Solar Heater U.S. Patent" No. 807, Dec. , p. 692.

39. Tanishita I., 1970; "Present Situation of Commercial Solar Water Heaters in Japan", International Solar Energy Congress, Melbourne, Australia, Paper No. 2173.

40. Tanishita I., 1964; "Recent Development of Solar Water Heaters in Japan, Proc. UN. Conf. on New Source of Energy", Rome 1967, 5, p. 102.

41. Thomson, J.A., "Solar Water Heater", Britain Patent No. 325, 928, December 31.

42. Vaxman B. and Sokolov M., 1985; "Experiments with an Integral Compact Solar Water Heater", Solar Energy, 34, p. 447.

43. Wang Shing-an: 1979; "An Experimental Study of Corrugated Steel Sheet Solar Water Heater" Solar Energy Laboratory, Shanghai Mechanical Engineering Institute, Shanghai, China, Solar Energy, vol. 23, pp. 333-341.

44. Whiller A., 1967; "Design Factors Influencing Solar Collectors Performance", Low Temperature Engineering Application of Solar Energy (Editor R.C. Jordan), ASHRAE.

45. Whiller A., "Thermal Resistance of the Tube Plate Band in Solar Heat Collector", Solar Energy Trans.

46. Wohlmeyer H., 1987; Biotechnology as an Opportunity for the Natural Resources and Development: A Biannual Collection of Recent German Contributions (Concerning the Exploration and exploitation of Natural Resources). Institute for Scientific Cooperation, Tubirgen. Federal Republic of Germany, Volume 26.

47. Yellot J. I. and Sobatka R., 1964; "An Investigation of Solar Water Heater Performance", Trans. ASHRAE, 70, p. 425.

APPENDICES

APPENDIX : A

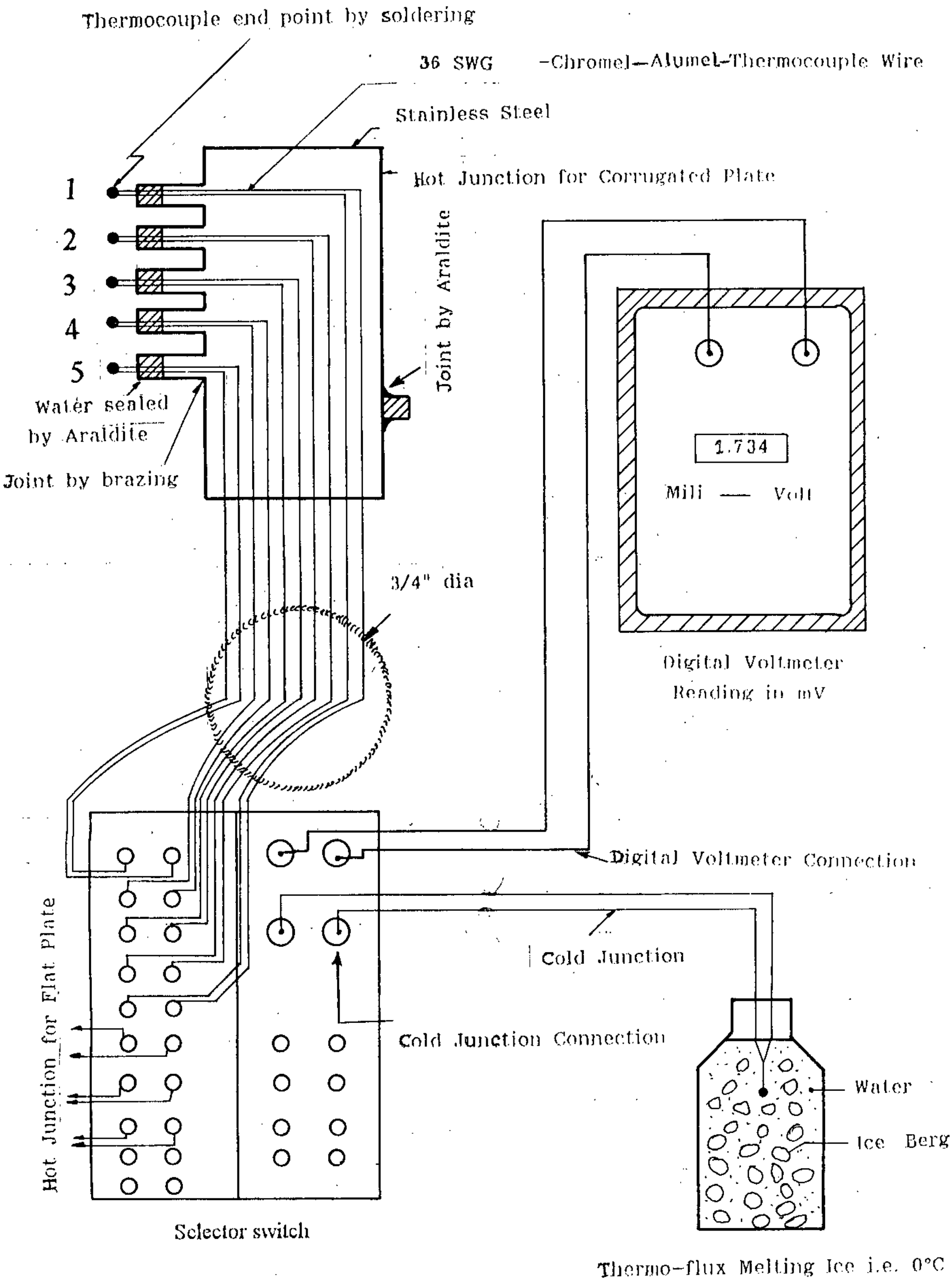


Fig. 3.1(a) Details of Temperature Measurements Instrument.

APPENDIX: A

A.1 FIGURES

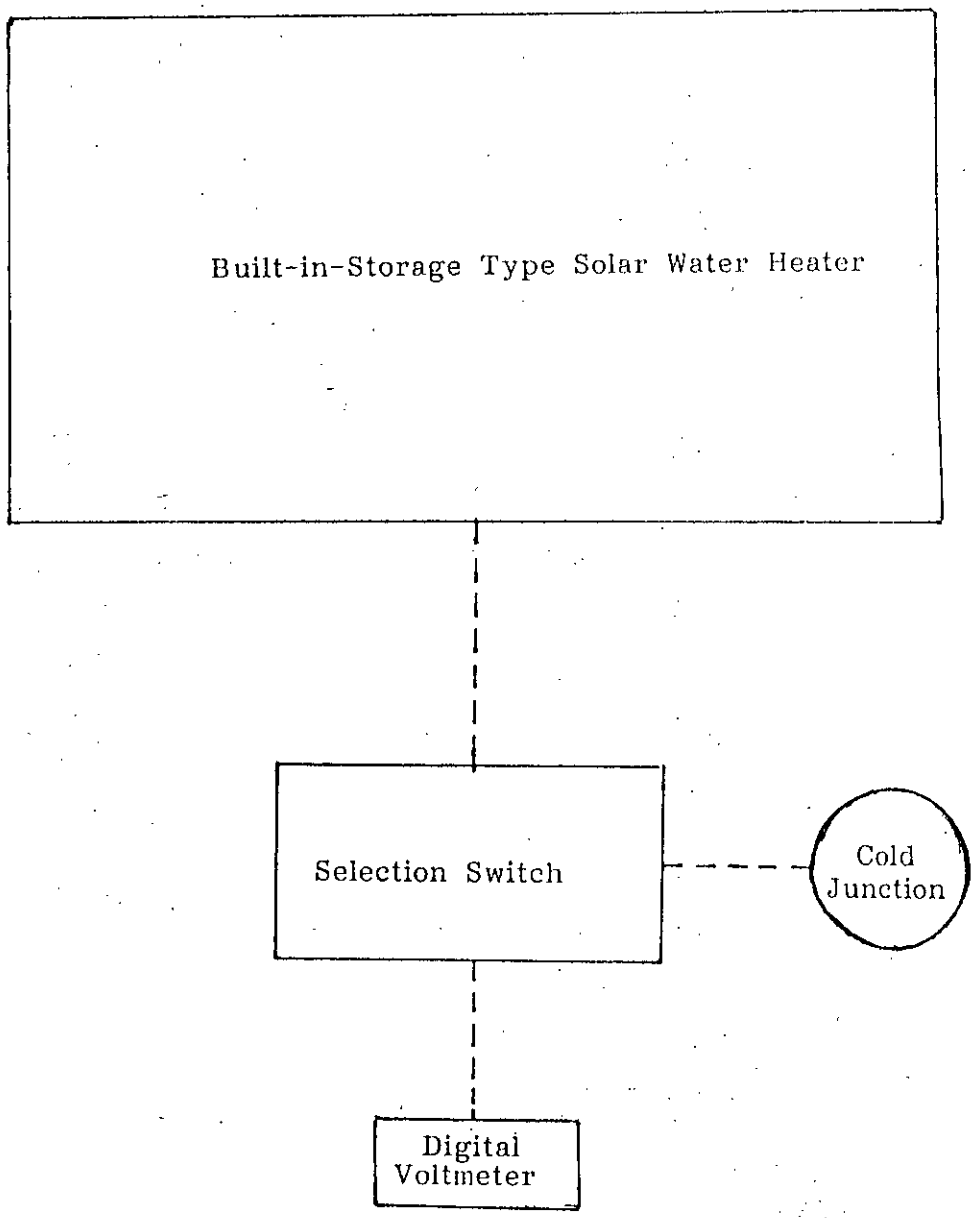


Fig. 3.1(b) The Schematic Diagram of Experimental Set-up.

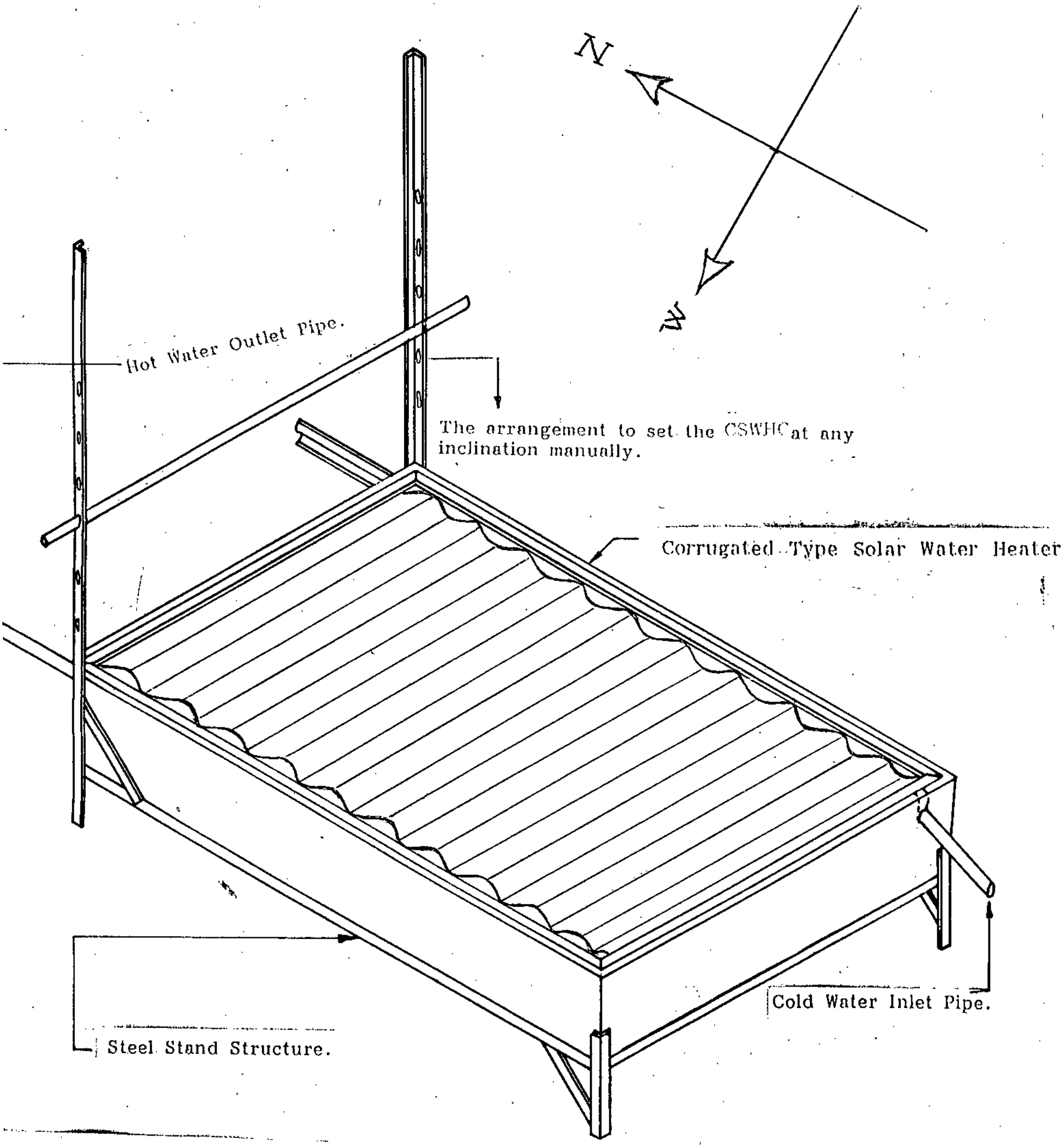


Fig. 3.2(a) The Schematic Diagram of Corrugated Type Solar Water Heater and Steel Stand Structure.

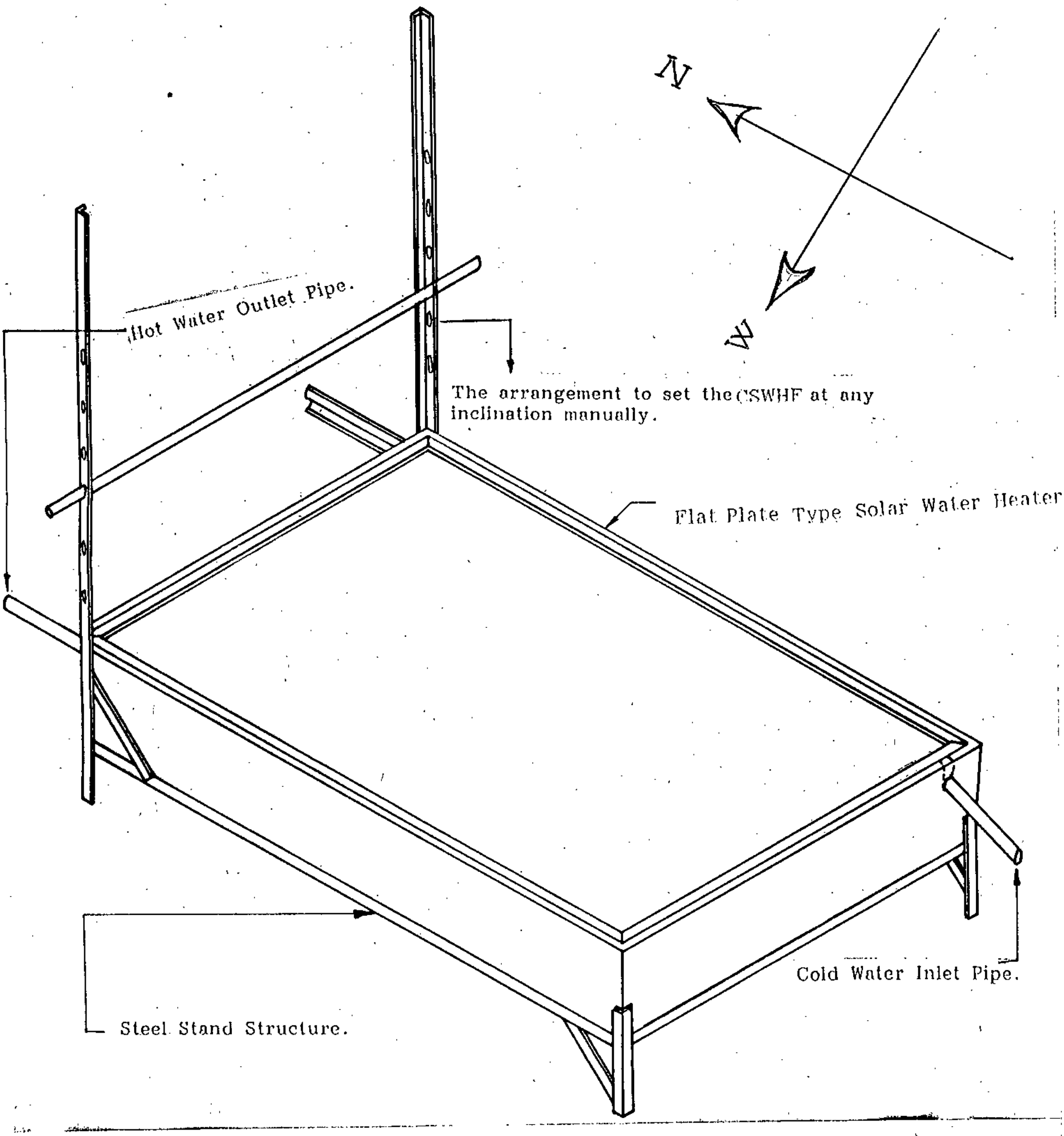


Fig. 3.2(b) The Schematic Diagram of CSWHF and Steel Stand Structure.

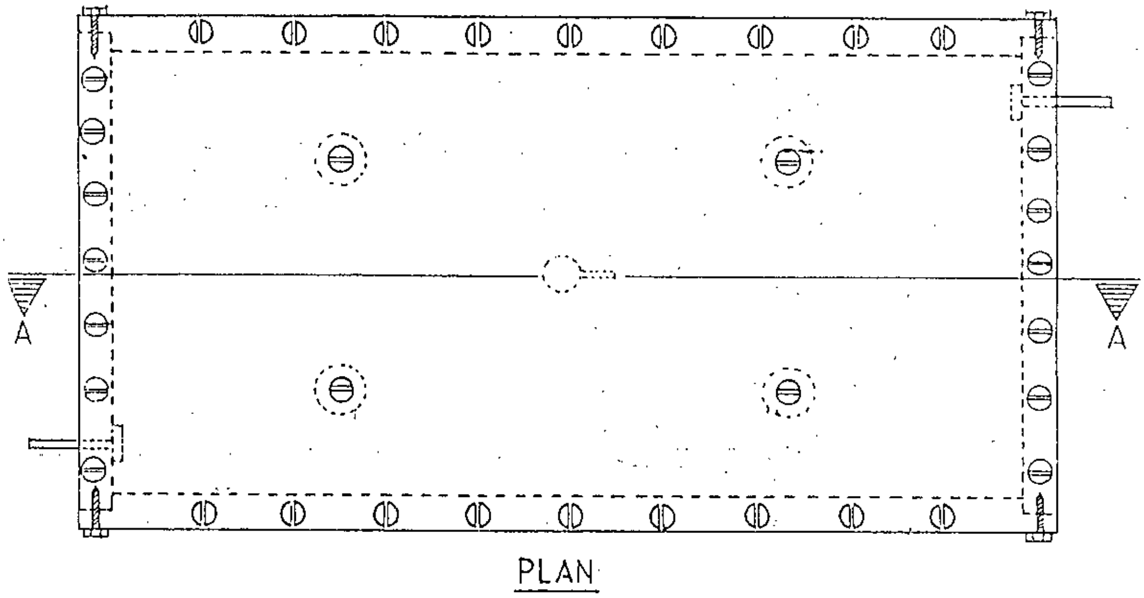


Fig. 3.3(a) The Plan View of CSWHF.

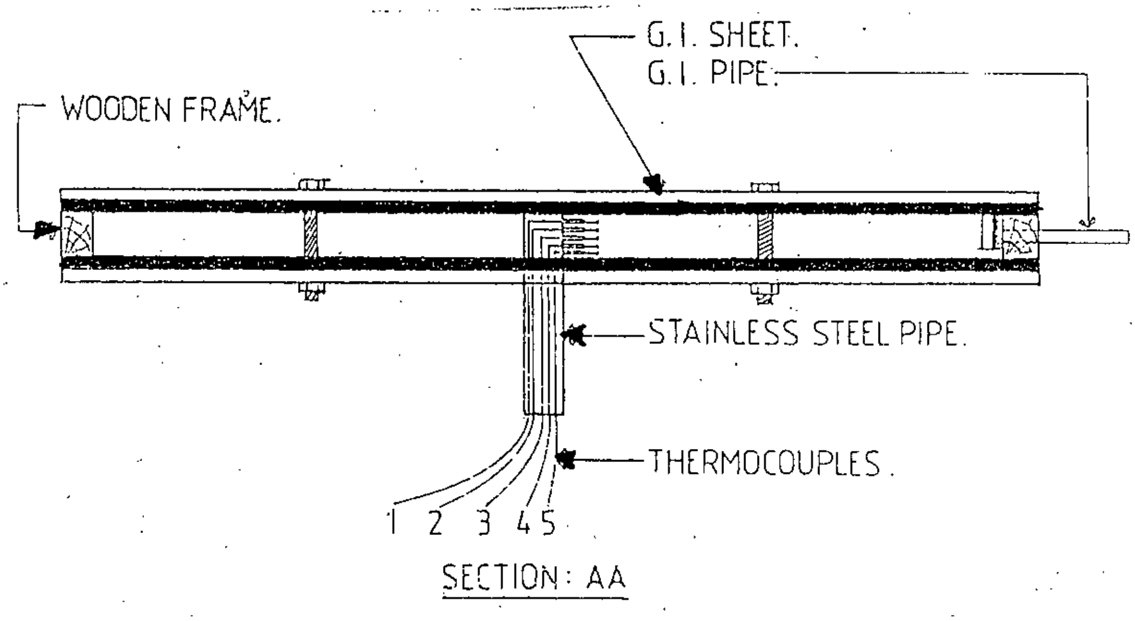


Fig. 3.3(b) X-Sectional View of CSWHF Illustrating the Set-up of Thermocouples.

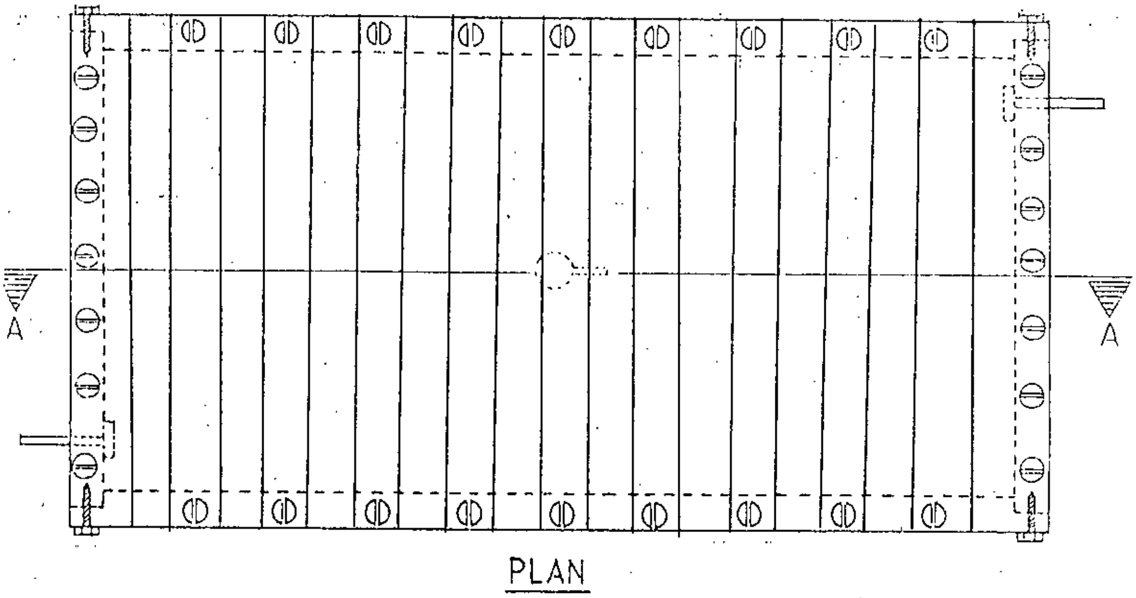


Fig. 3.3(c). The Plan View of Corrugated Type Solar Water Heater.

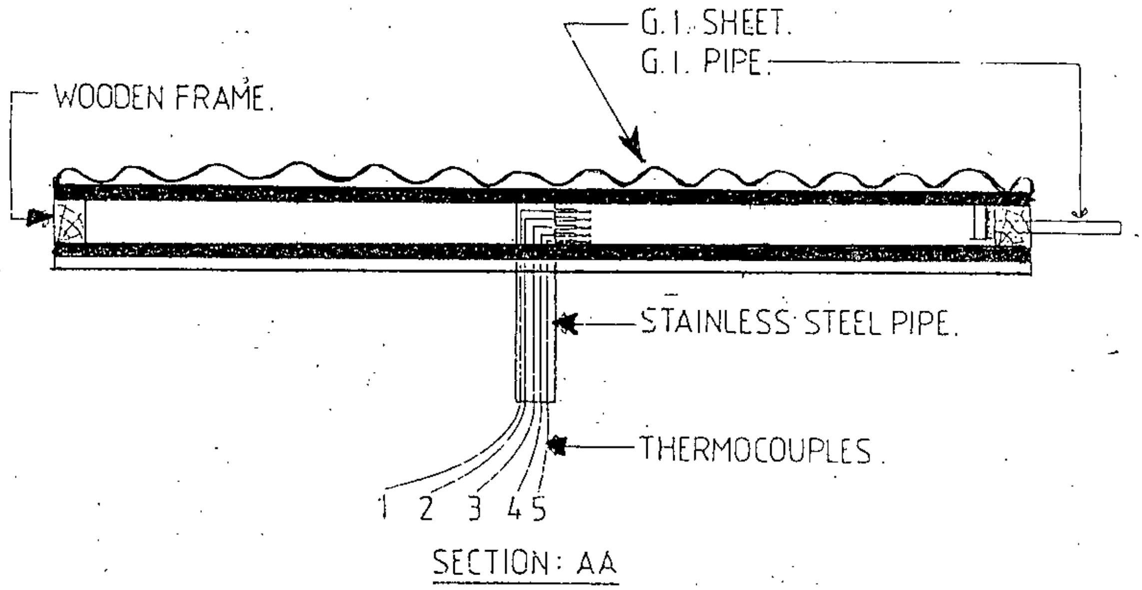


Fig. 3.3(d) X-Sectional View of Corrugated Type Solar Water Heater Illustrating the Set-up of Thermocouples.

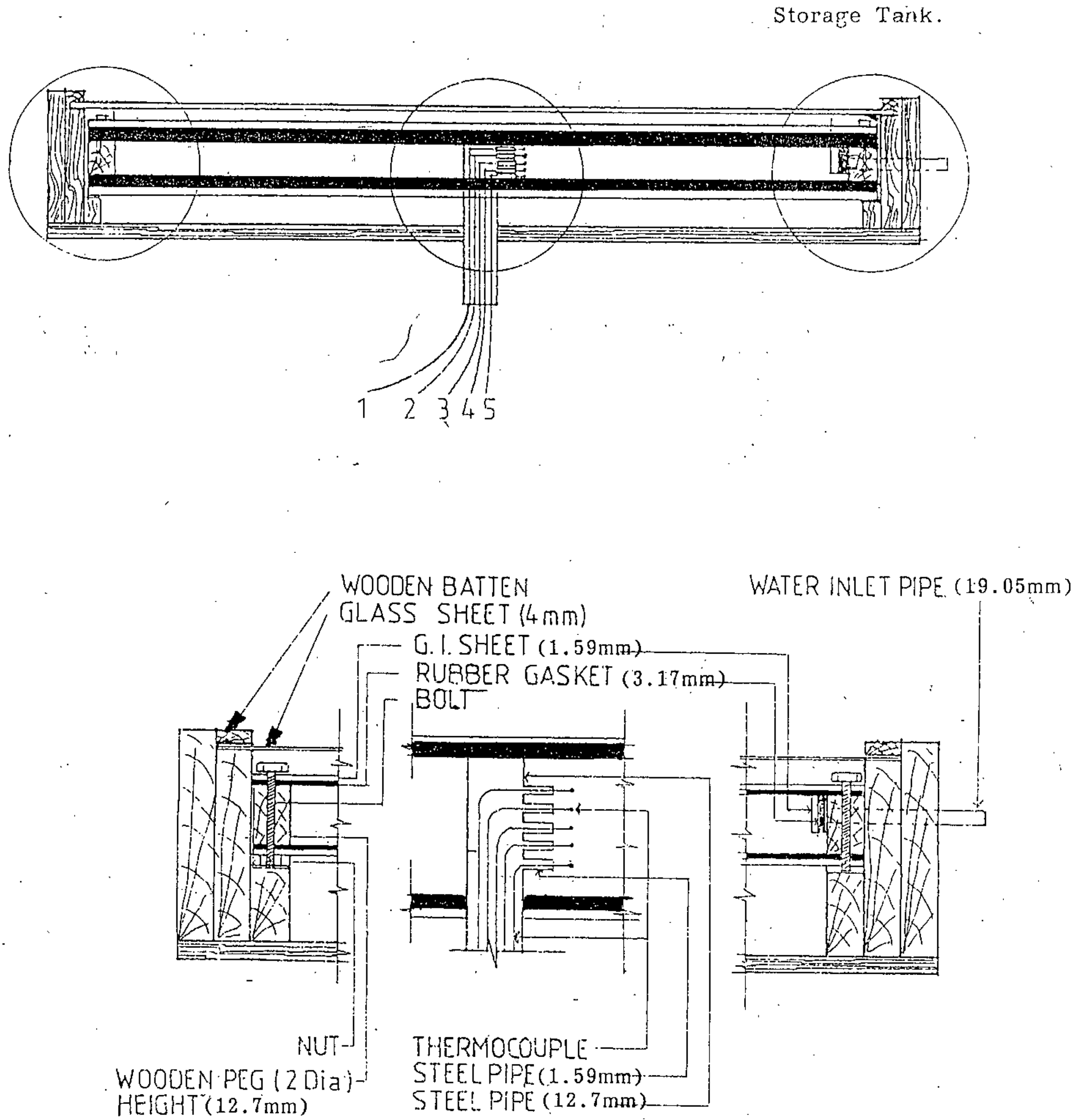
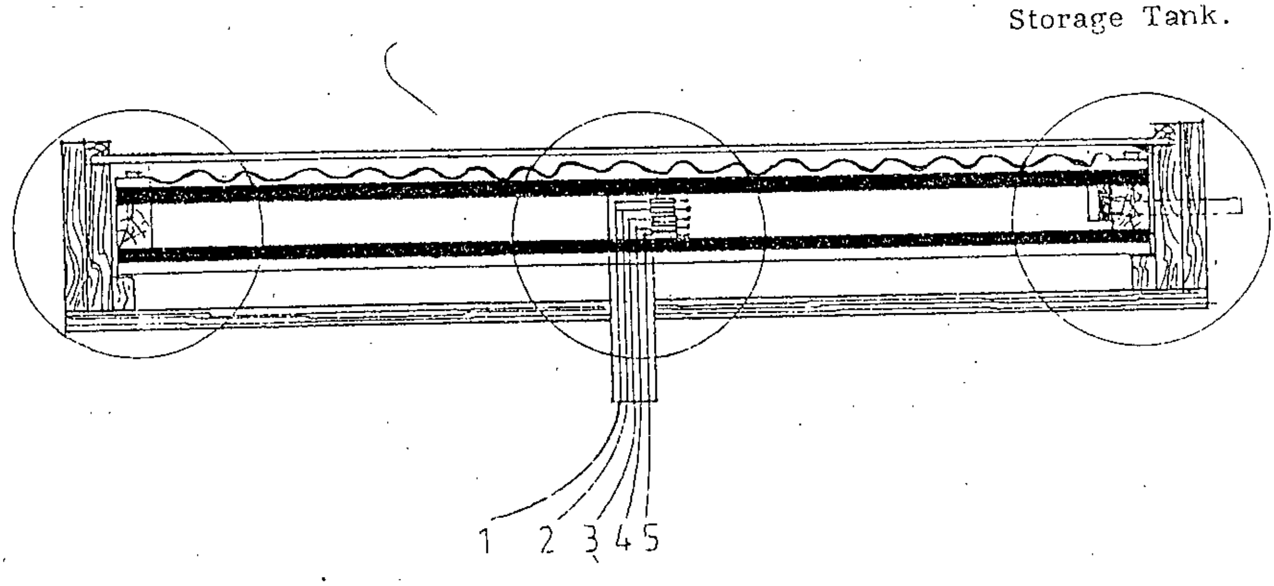


Fig. 3.4(a) X-Sectional View of CSWHF Illustrating the Interior Set-up.



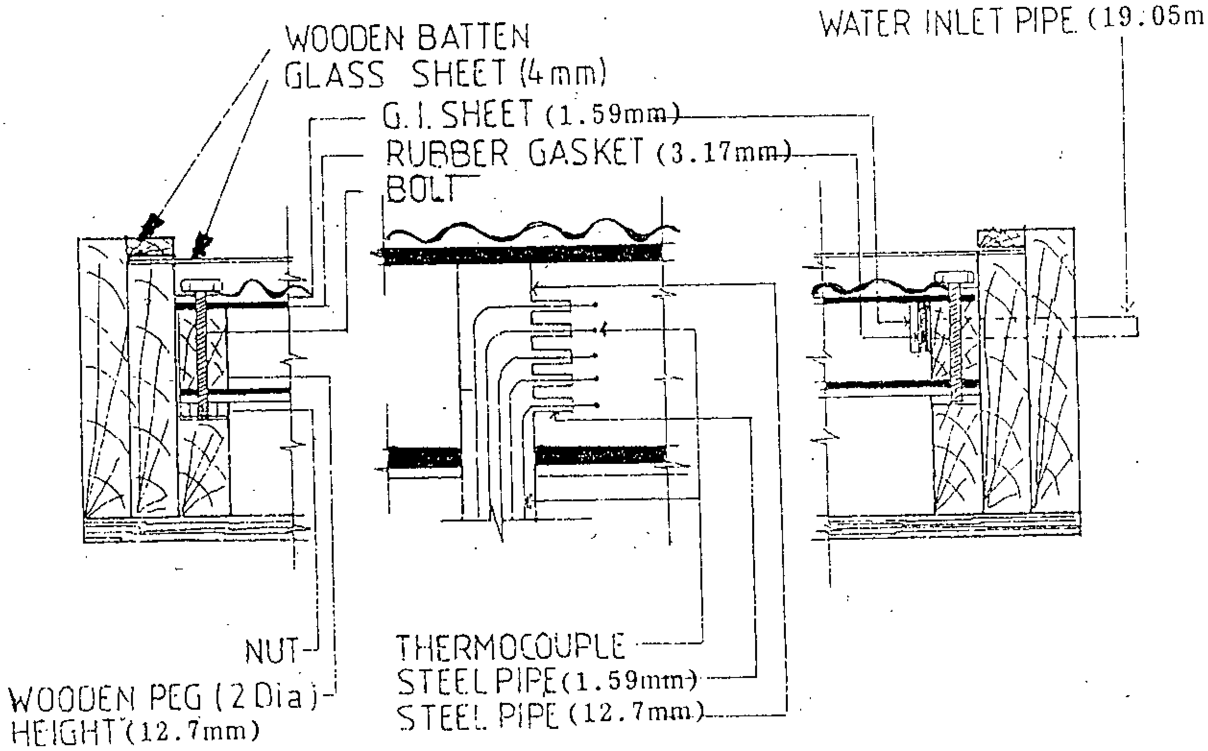
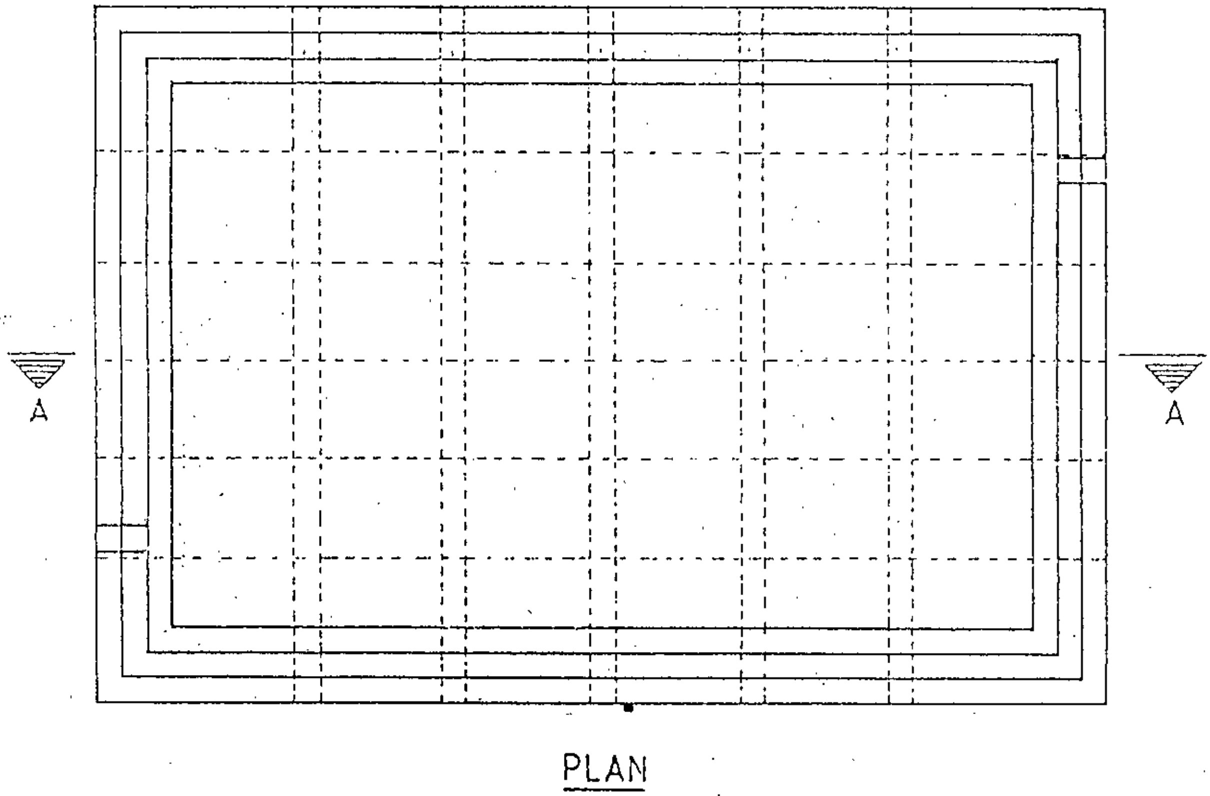


Fig. 3.4(b) The X-Sectional View of Corrugated Type Solar Water Heater Illustrating the Interior Set-up.



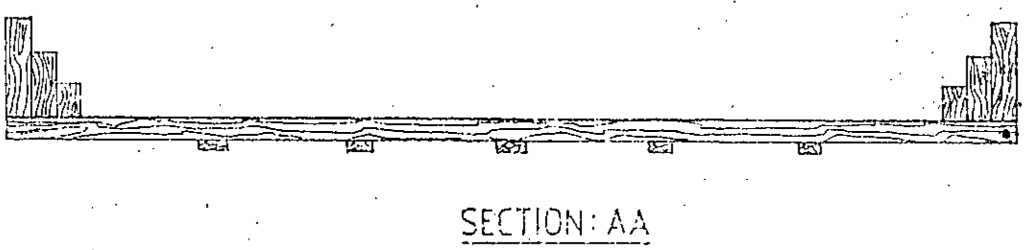


Fig. 3.5 Wooden Casing of Corrugated Type Solar Water Heater and CSWHF.

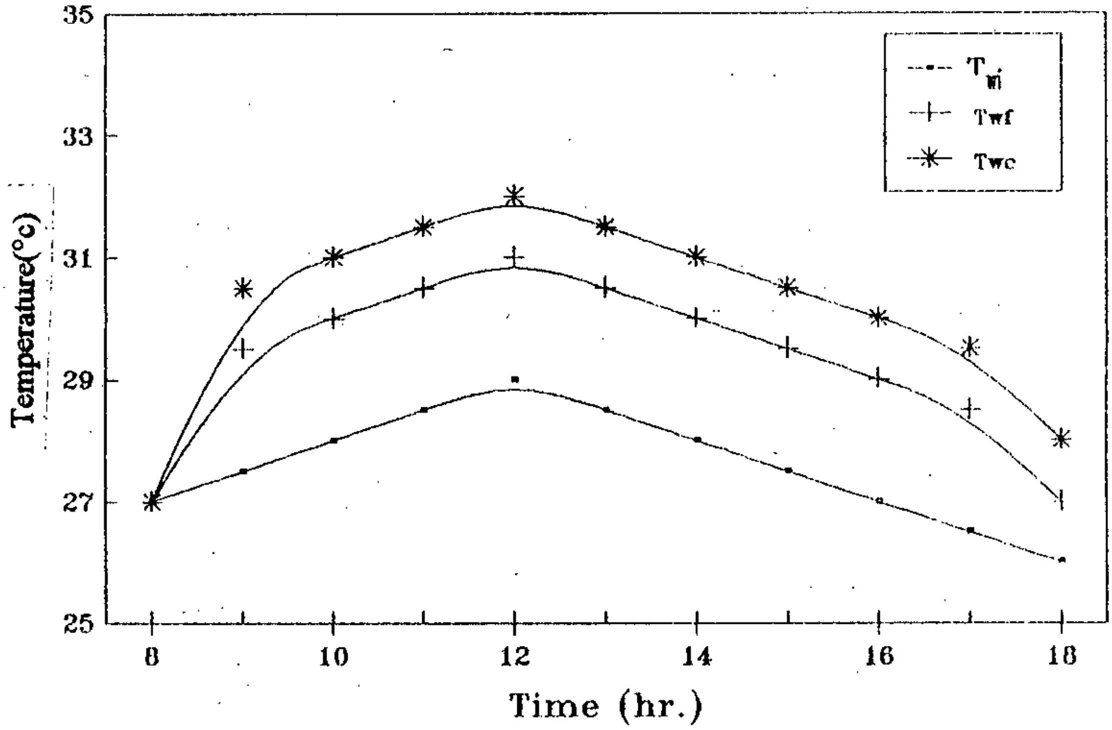


Fig. 4.1 The Initial and Final Mean Water Temperature on November 01, 1994.

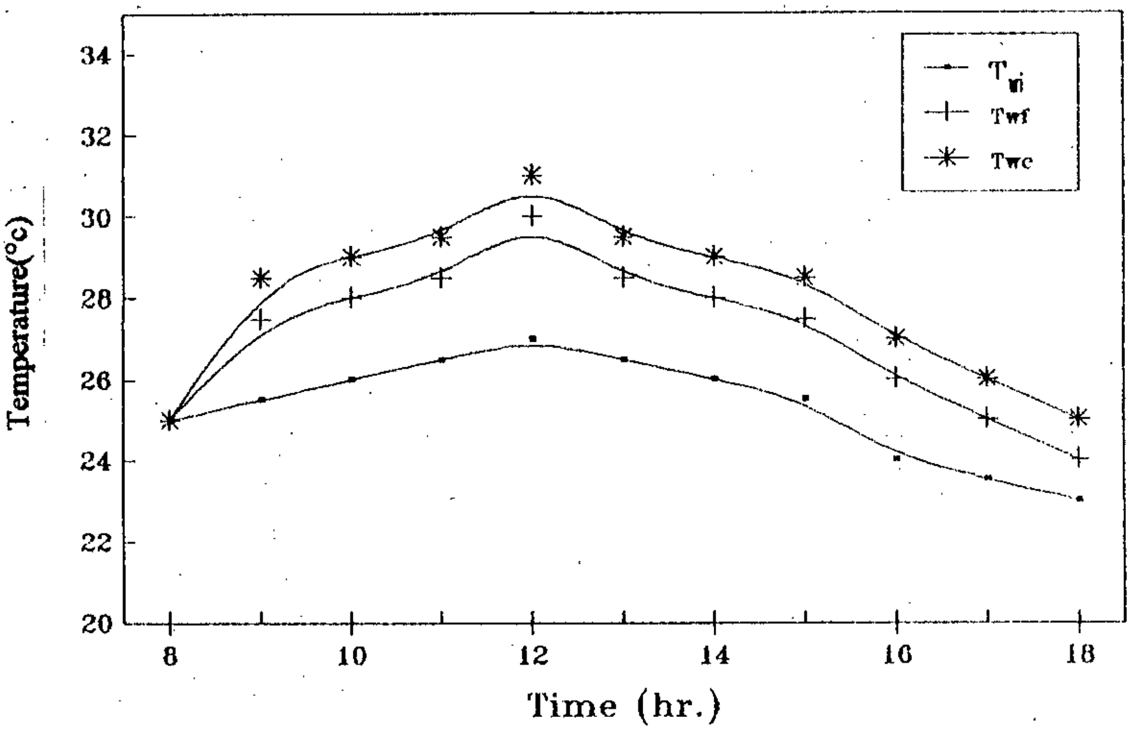


Fig. 4.2 The Initial and Final Mean Water Temperature on November 05, 1994.

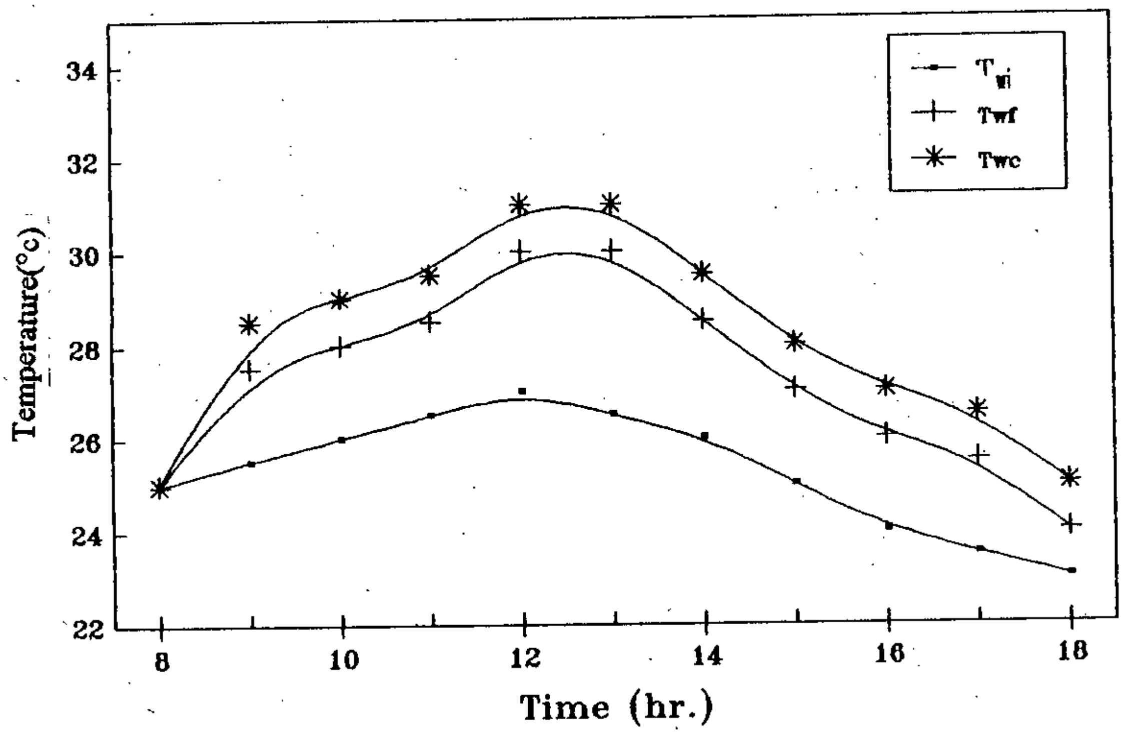


Fig. 4.3 The Initial and Final Mean Water Temperature on November 10, 1994.

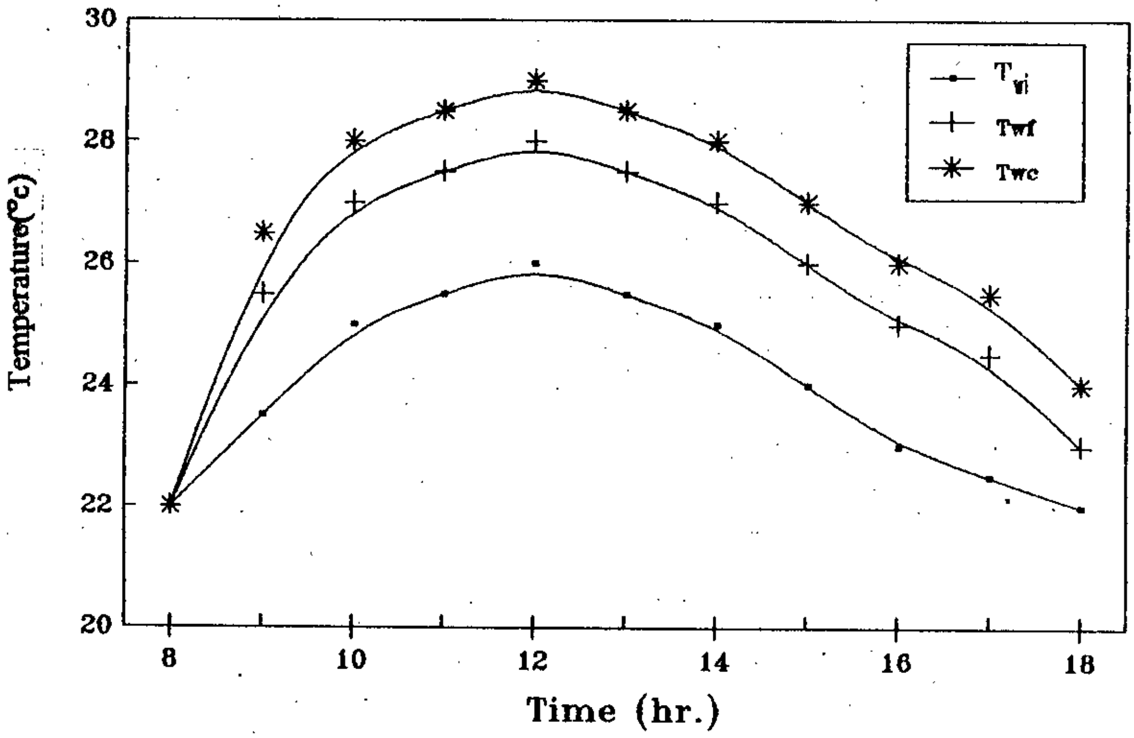


Fig. 4.4 The Initial and Final Mean Water Temperature on November 15, 1994.

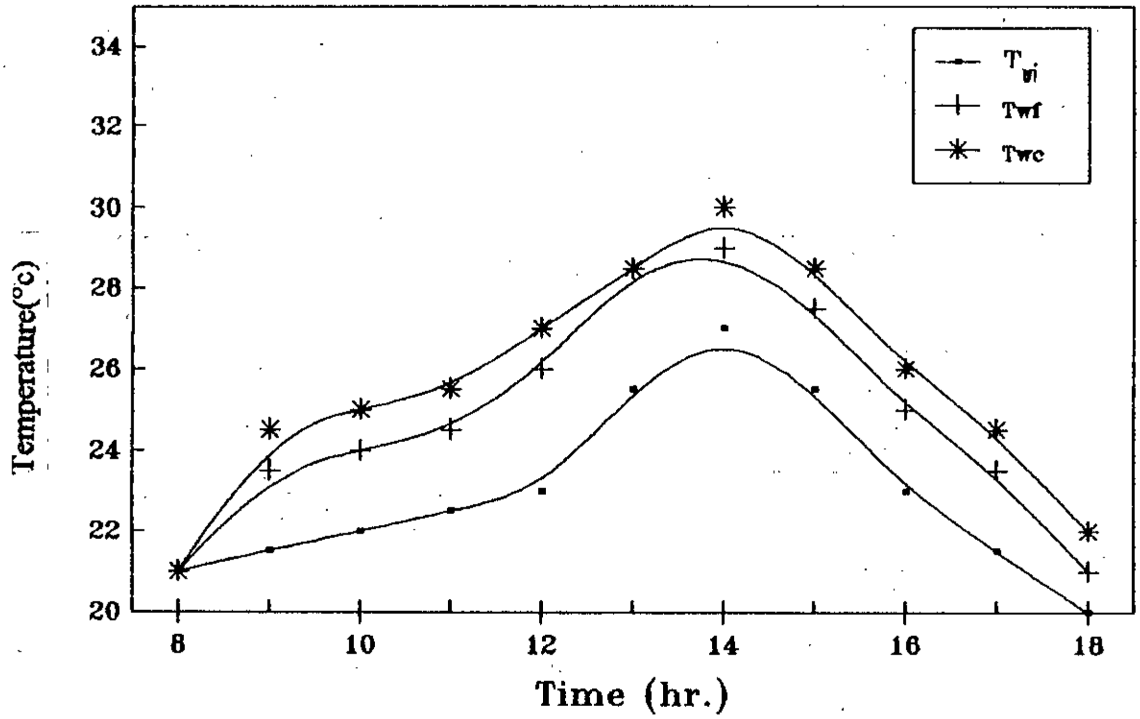


Fig. 4.5 The Initial and Final Mean Water Temperature on November 20, 1994.

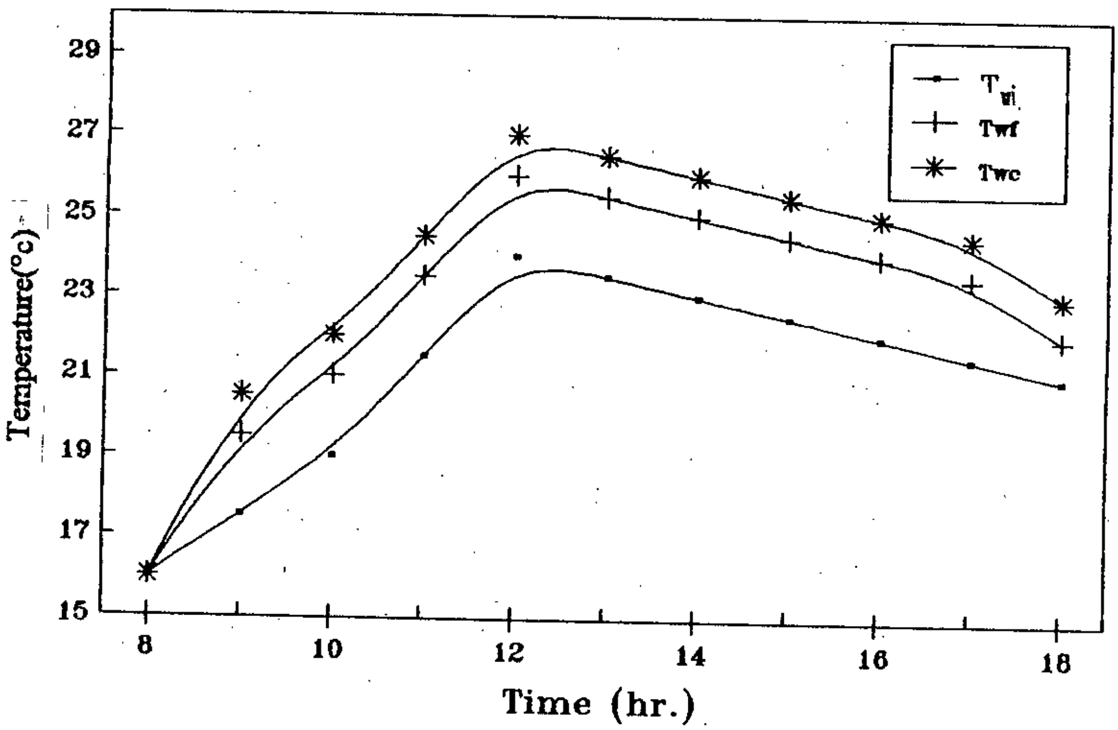


Fig. 4.6 The Initial and Final Mean Water Temperature on November 25, 1994.

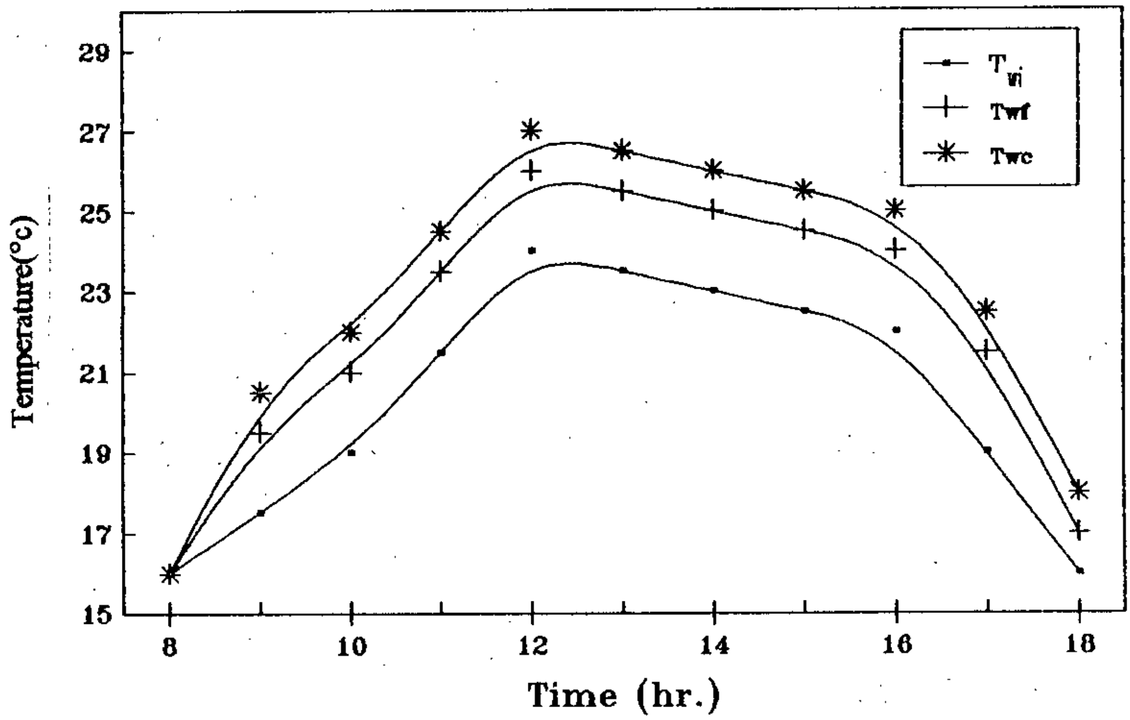


Fig. 4.7 The Initial and Final Mean Water Temperature on November 30, 1994.

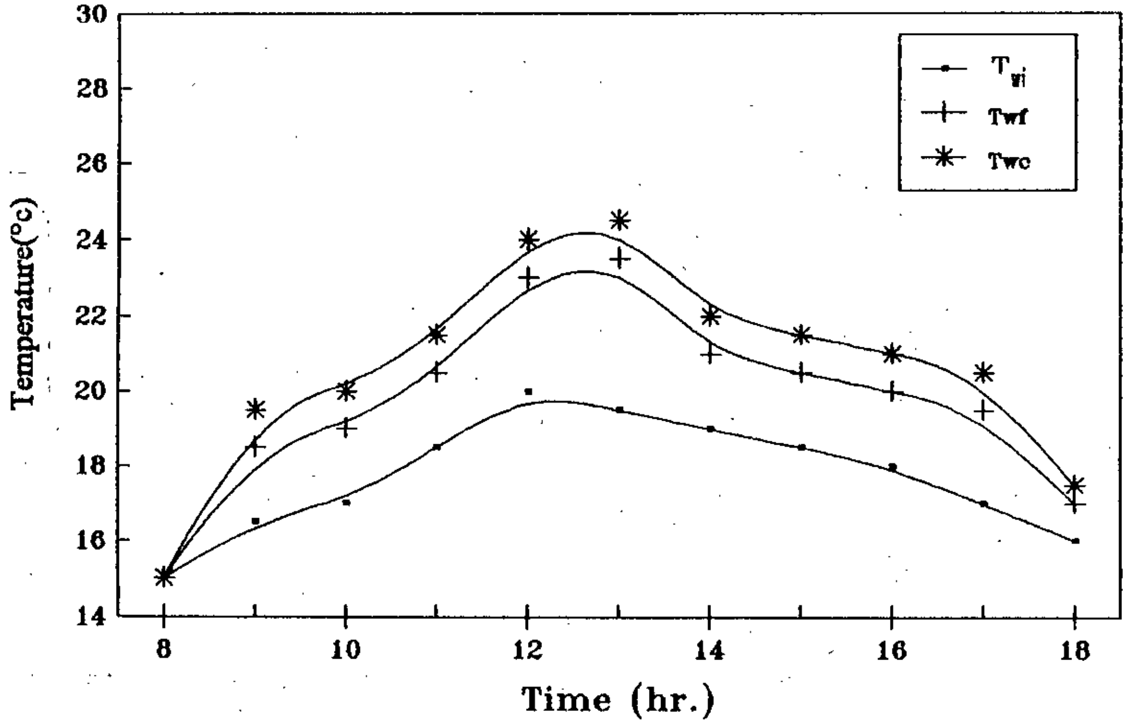


Fig. 4.8 The Initial and Final Mean Water Temperature on December 05, 1994.

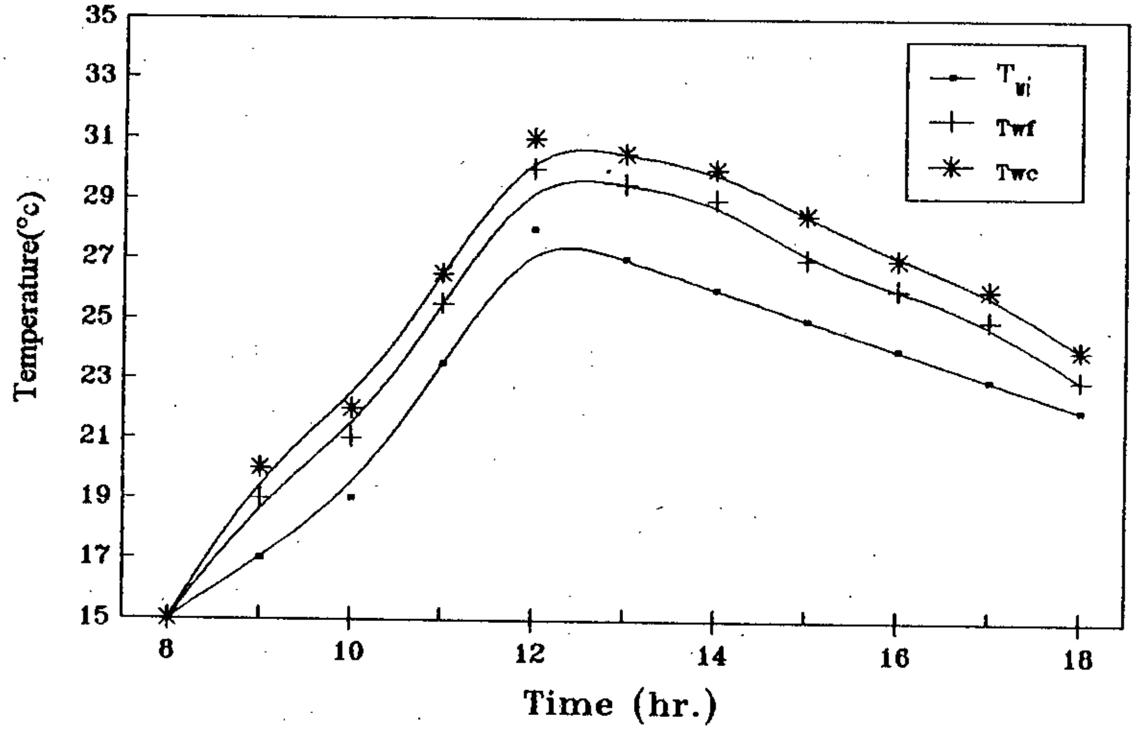


Fig. 4.9 The Initial and Final Mean Water Temperature on December 10, 1994.

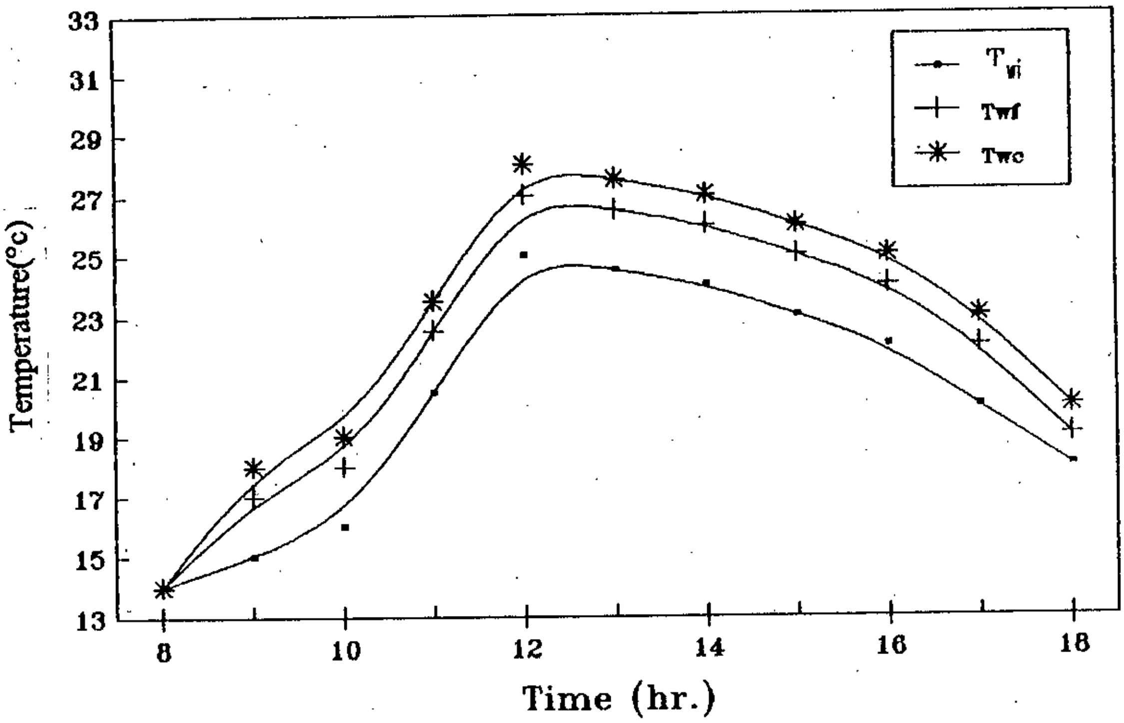


Fig. 4.10 The Initial and Final Mean Water Temperature on December 15, 1994.

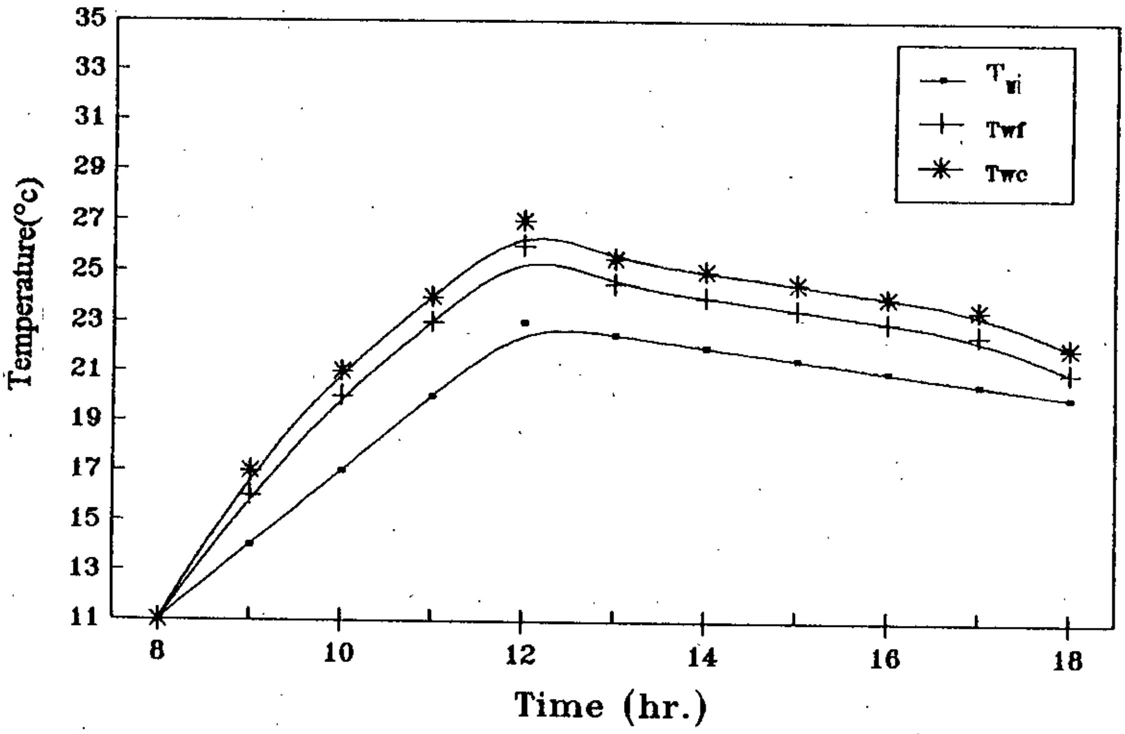


Fig. 4.11 The Initial and Final Mean Water Temperature on December 20, 1994.

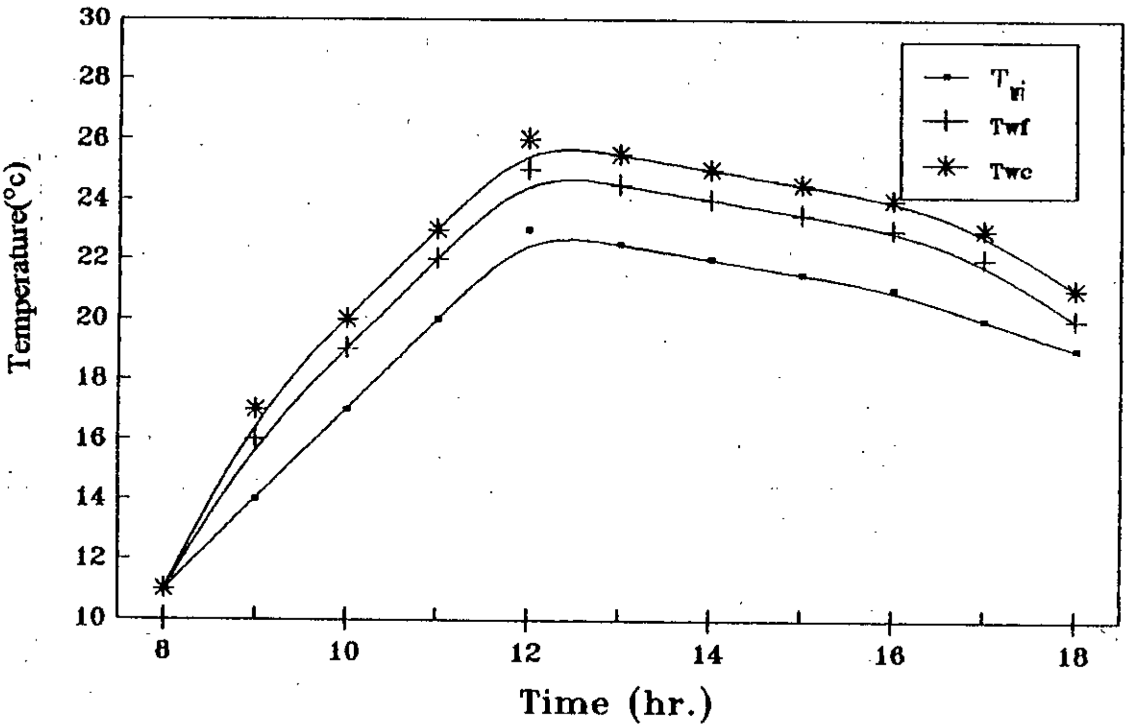


Fig. 4.13 The Initial and Final Mean Water Temperature on December 30, 1994.

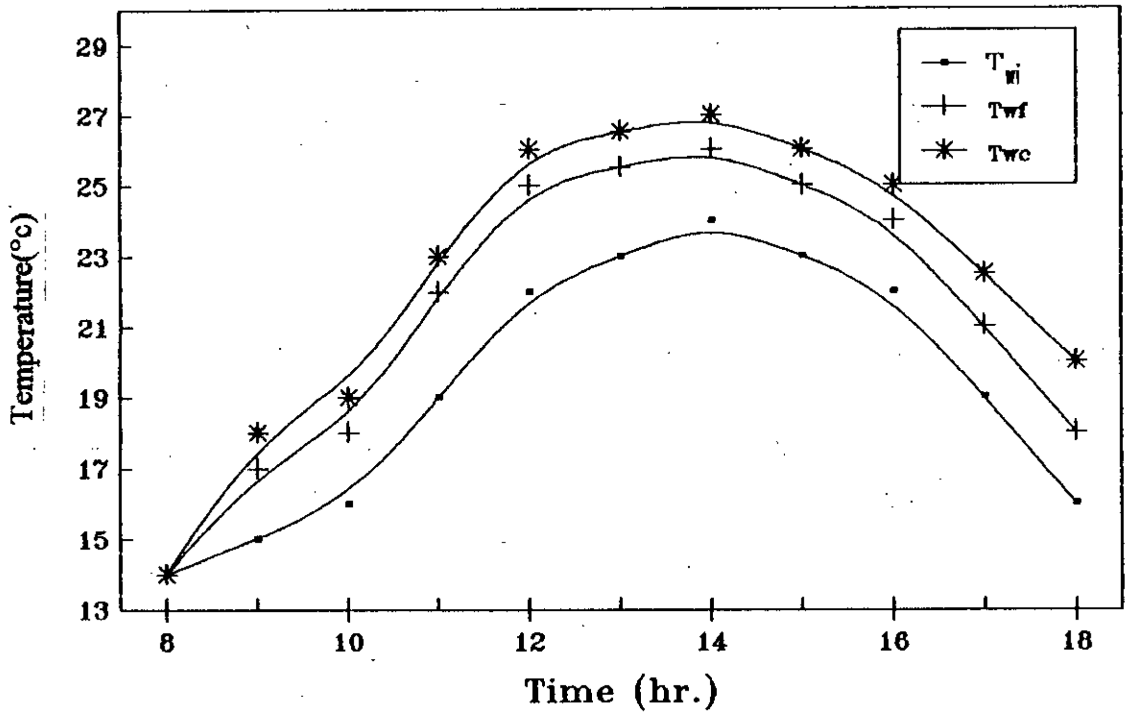


Fig. 4.14 The Initial and Final Mean Water Temperature on January 05, 1995.

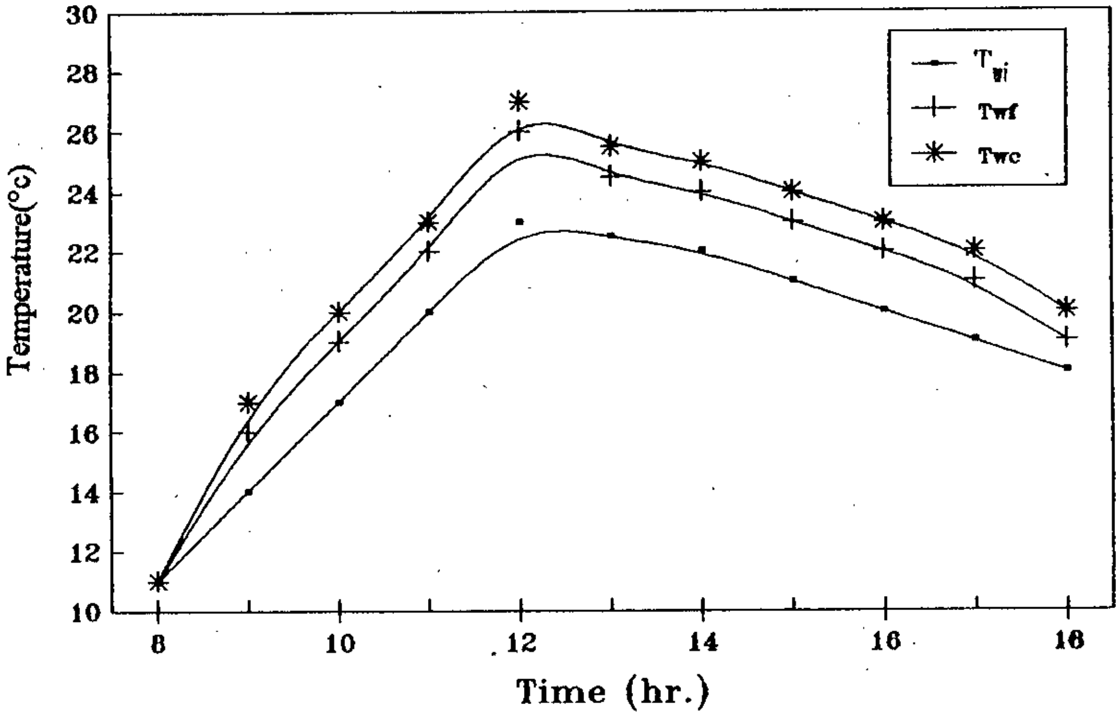


Fig. 4.15 The Initial and Final Mean Water Temperature on January 10, 1995.

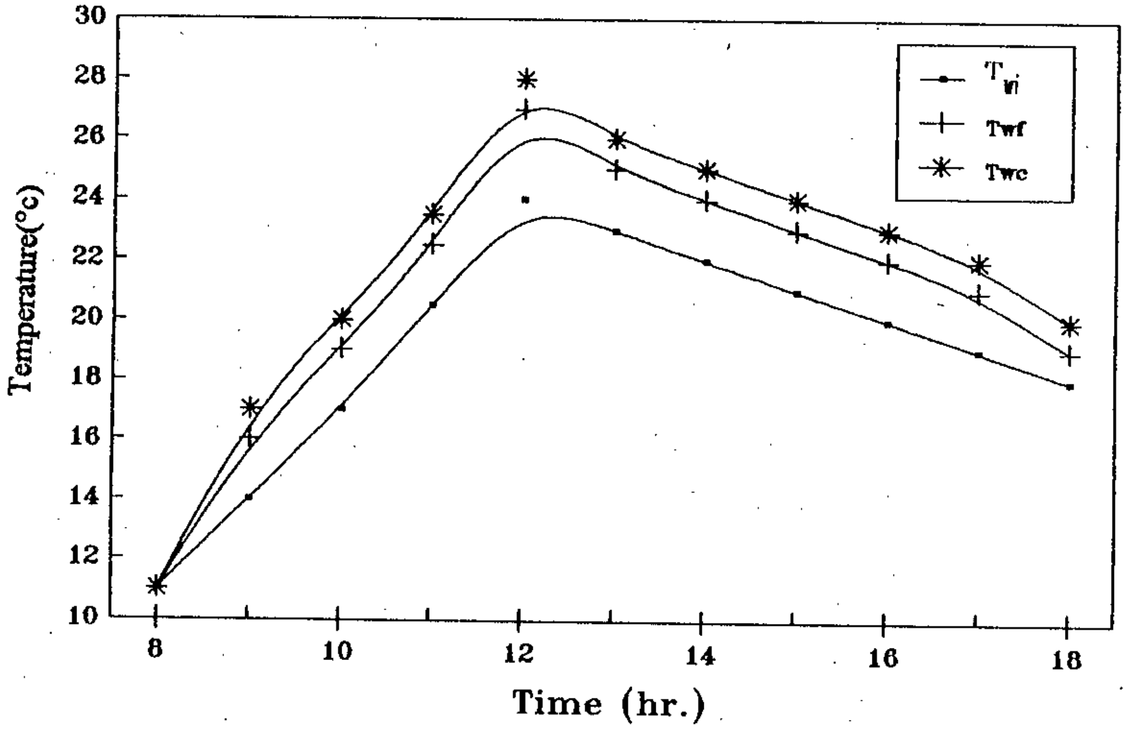


Fig. 4.16 The Initial and Final Mean Water Temperature on January 15, 1995.

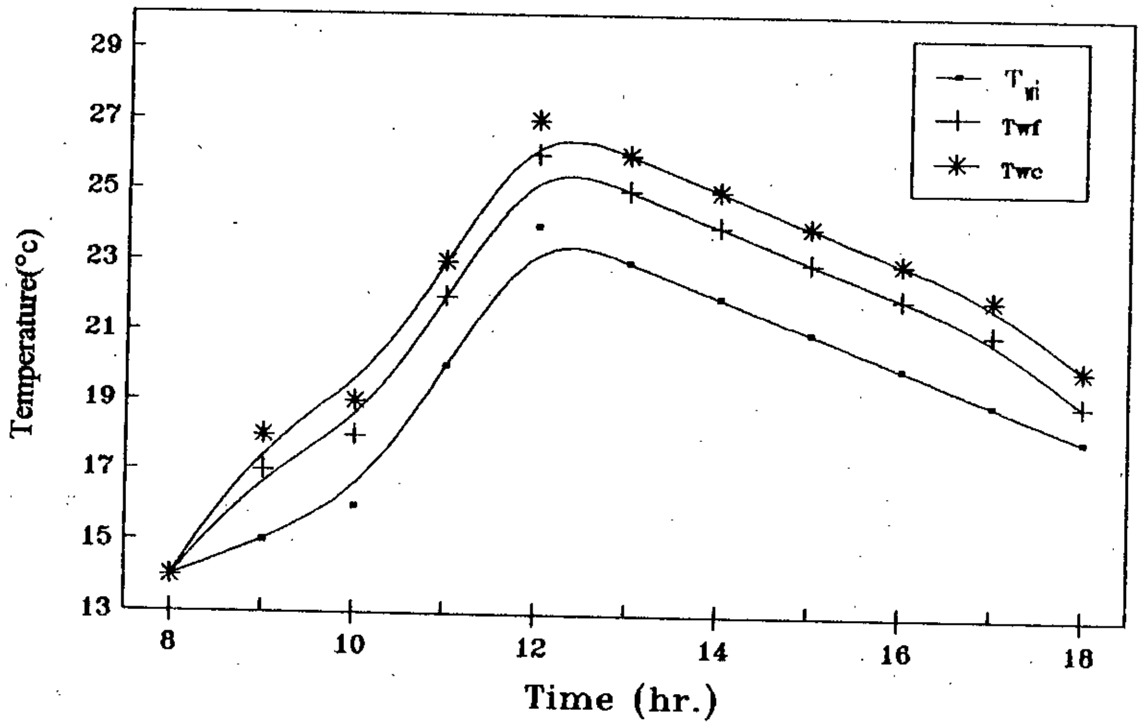


Fig.4.17 The Initial and Final Mean Water Temperature on January 20,1995.

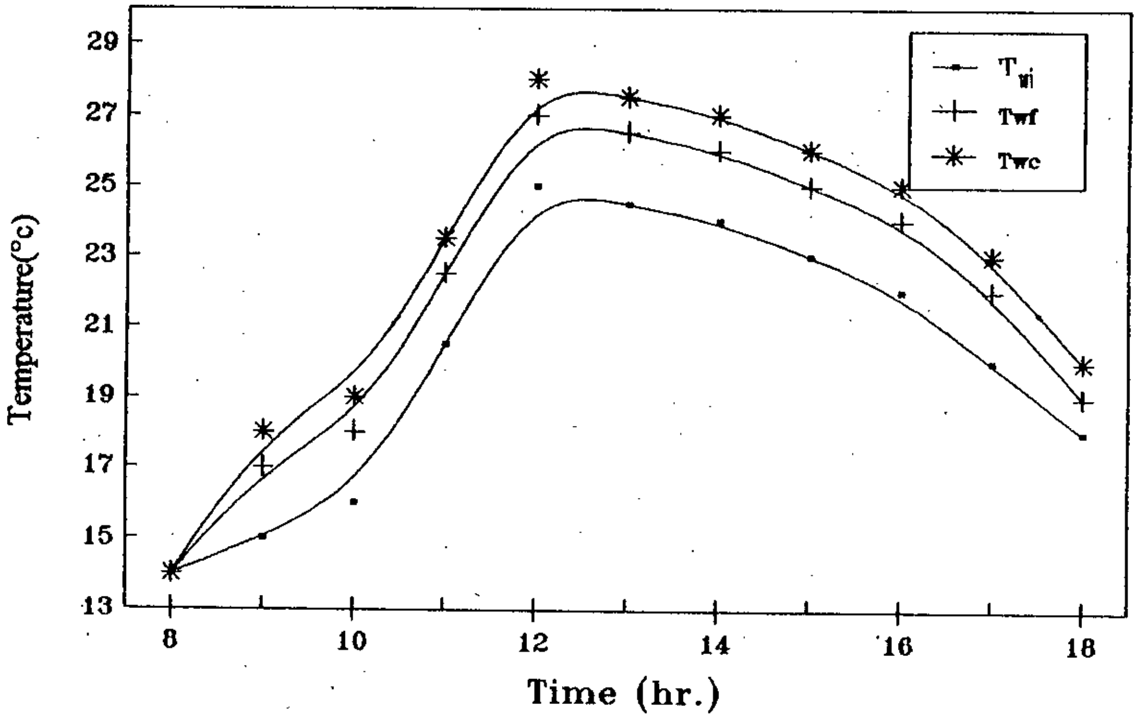


Fig. 4.18 The Initial and Final Mean Water Temperature on January 25, 1995.

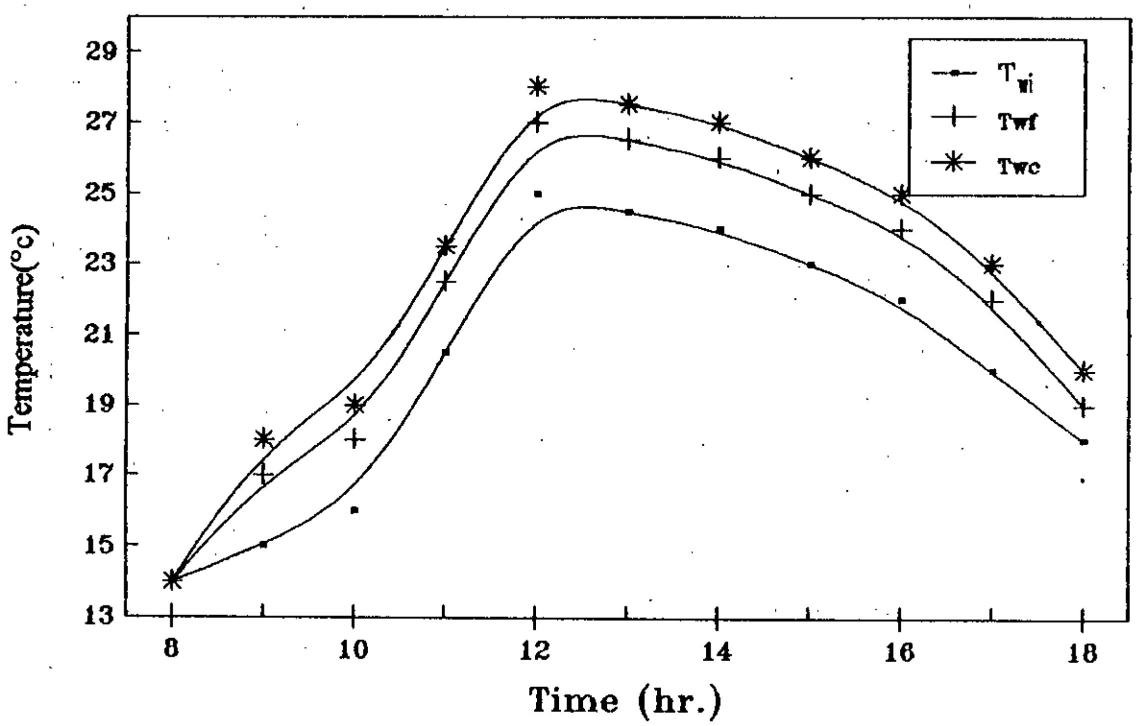


Fig. 4.18 The Initial and Final Mean Water Temperature on January 25, 1995.

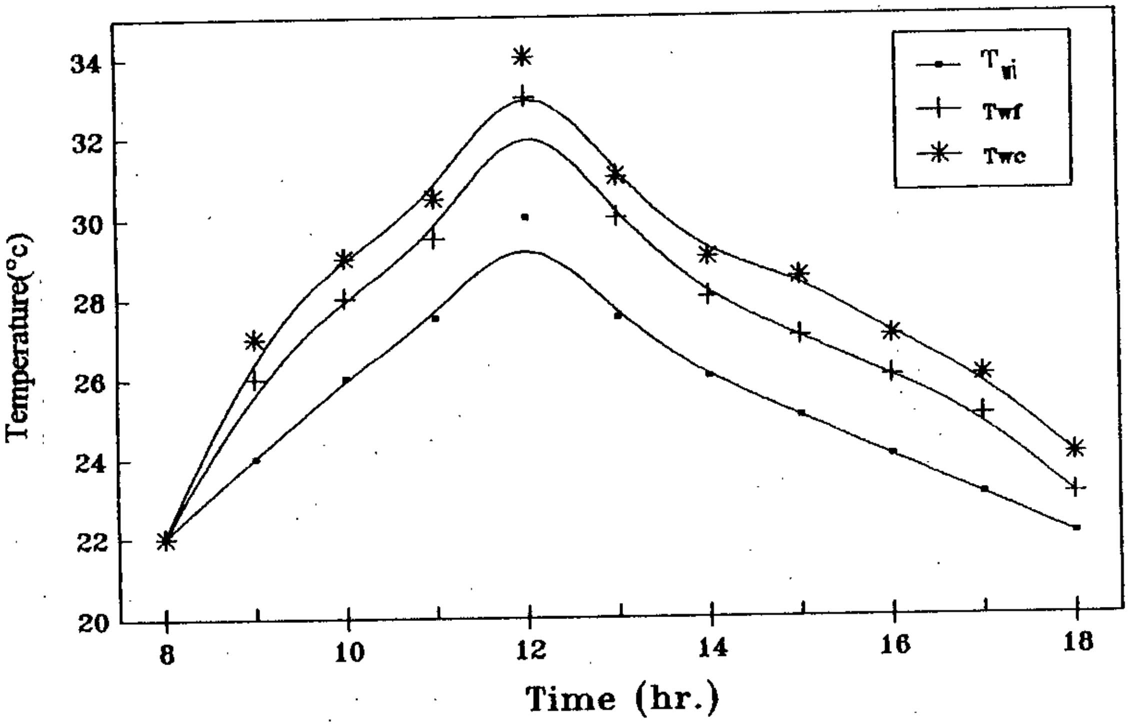


Fig. 4.19 The Initial and Final Mean Water Temperature on January 30, 1995.

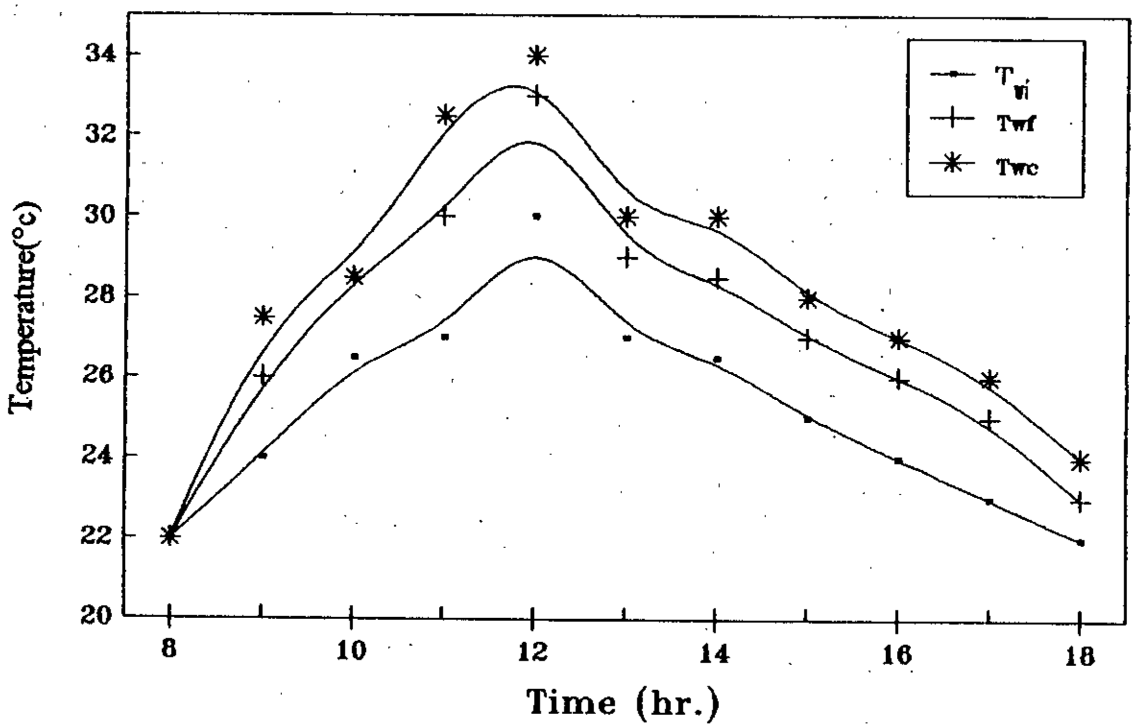


Fig. 4.20 The Initial and Final Mean Water Temperature on Febryary 05, 1995.

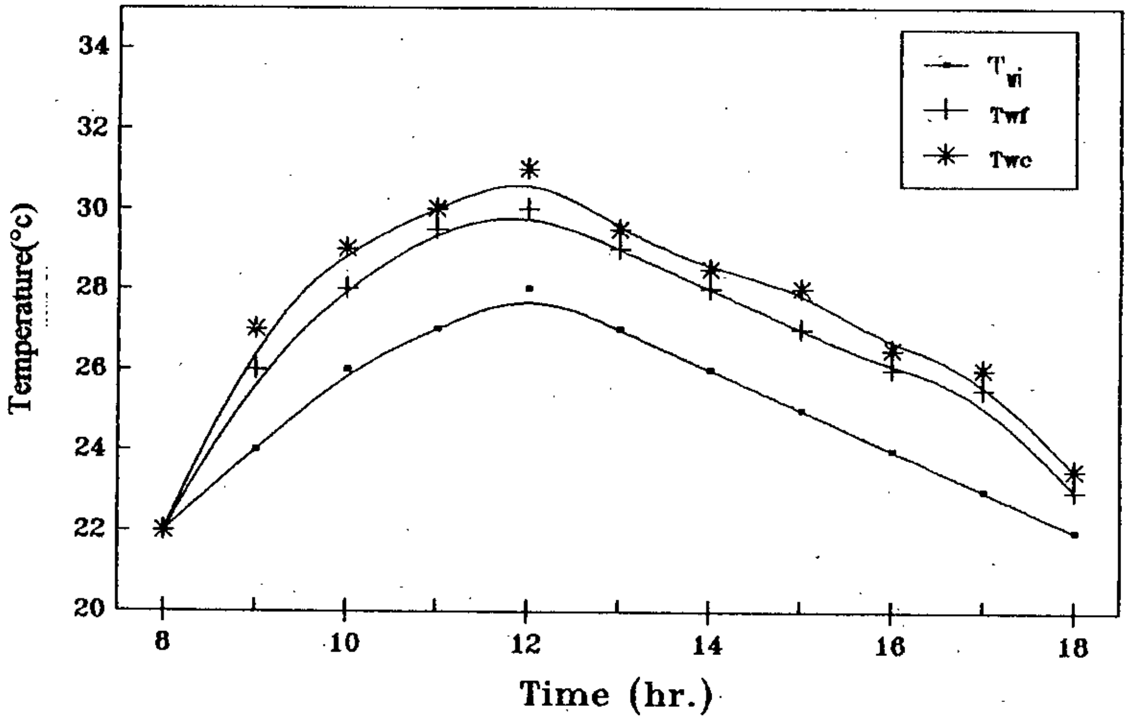


Fig. 4.22 The Initial and Final Mean Water Temperature on Febryary 15, 1995.

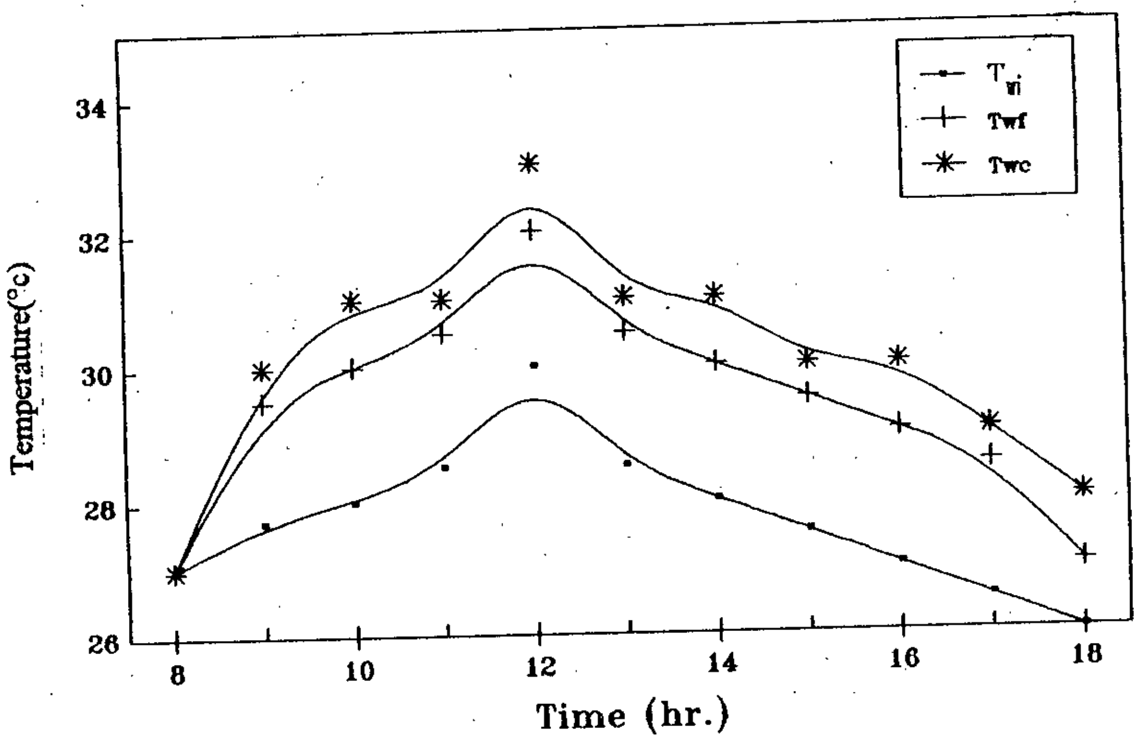


Fig. 4.24 The Initial and Final Mean Water Temperature on Febryary 25, 1995.

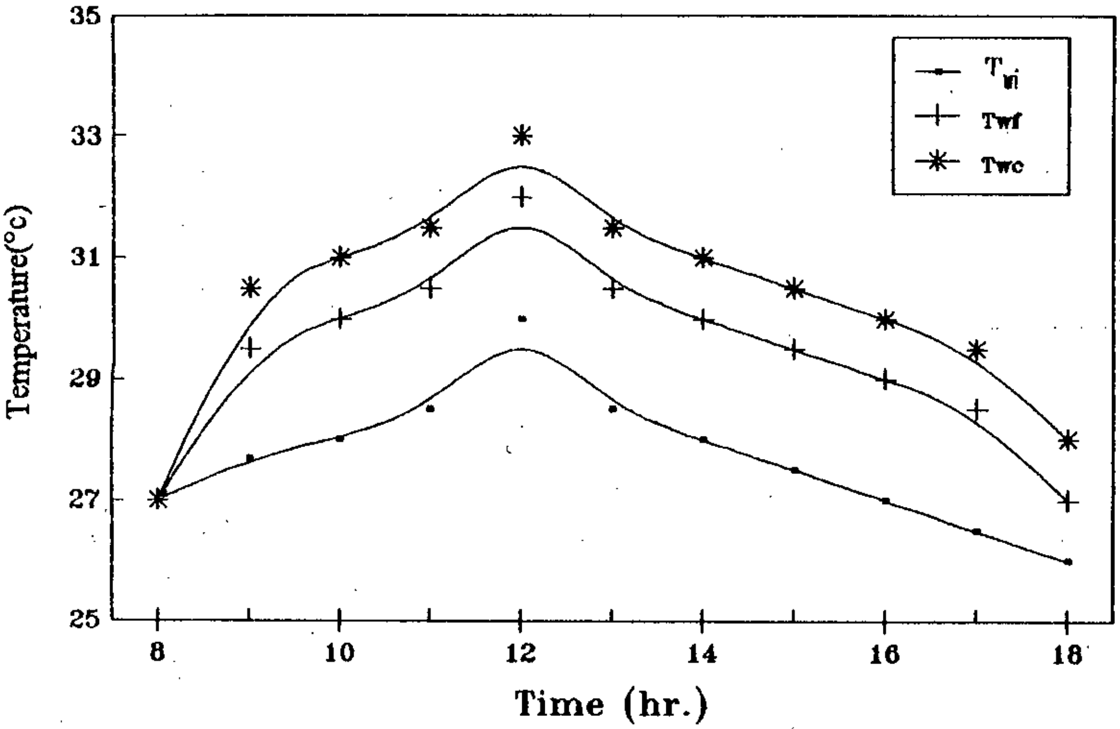


Fig. 4.25 The Initial and Final Mean Water Temperature on Febryary 28, 1995.

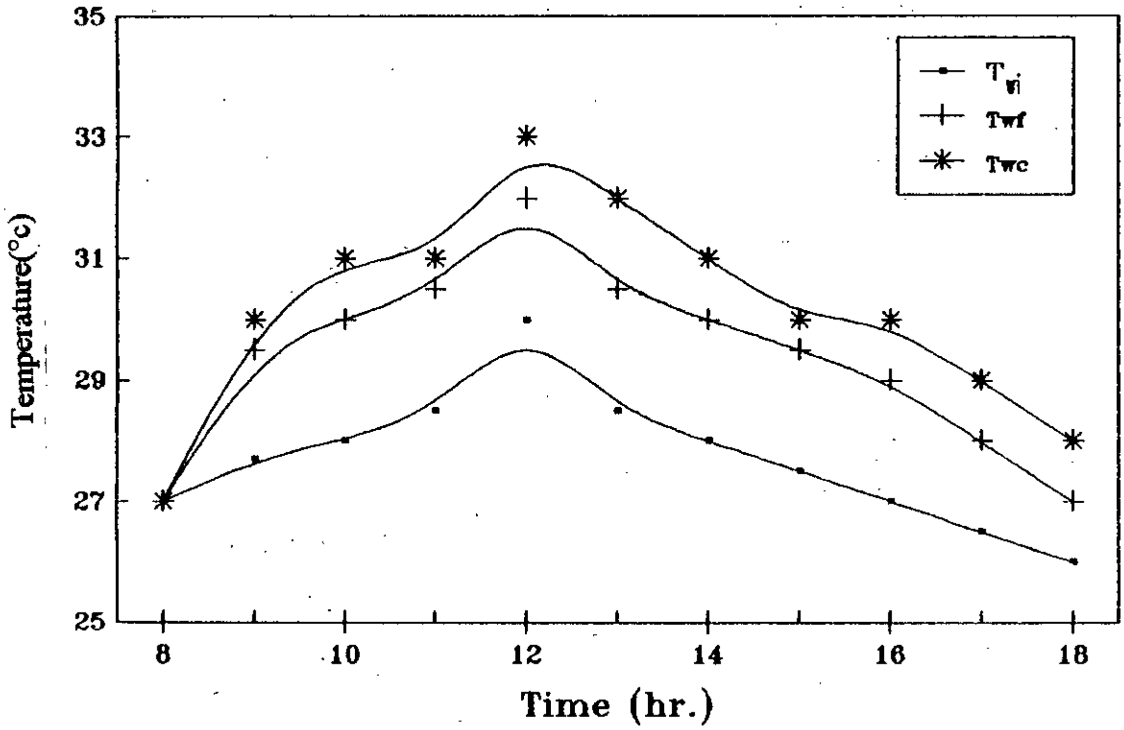


Fig. 4.26 The Initial and Final Mean Water Temperature on March 05, 1995.

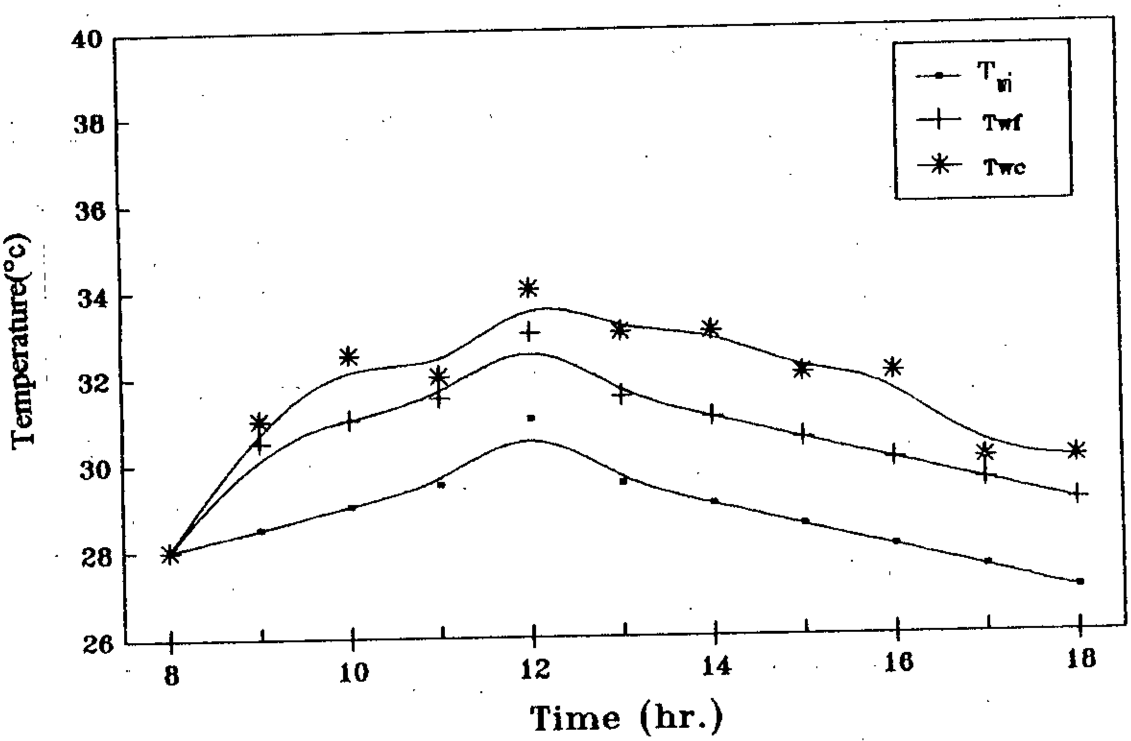


Fig. 4.27 The Initial and Final Mean Water Temperature on March 10, 1995.

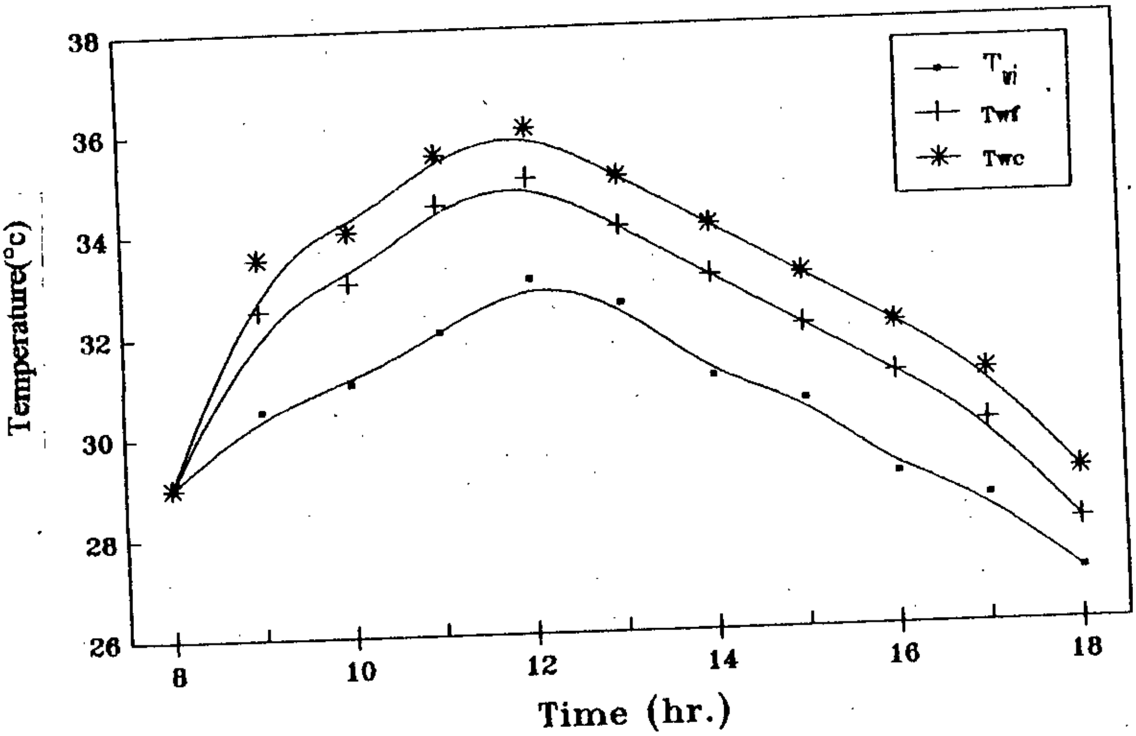


Fig. 4.28 The Initial and Final Mean Water Temperature on March 15, 1995.

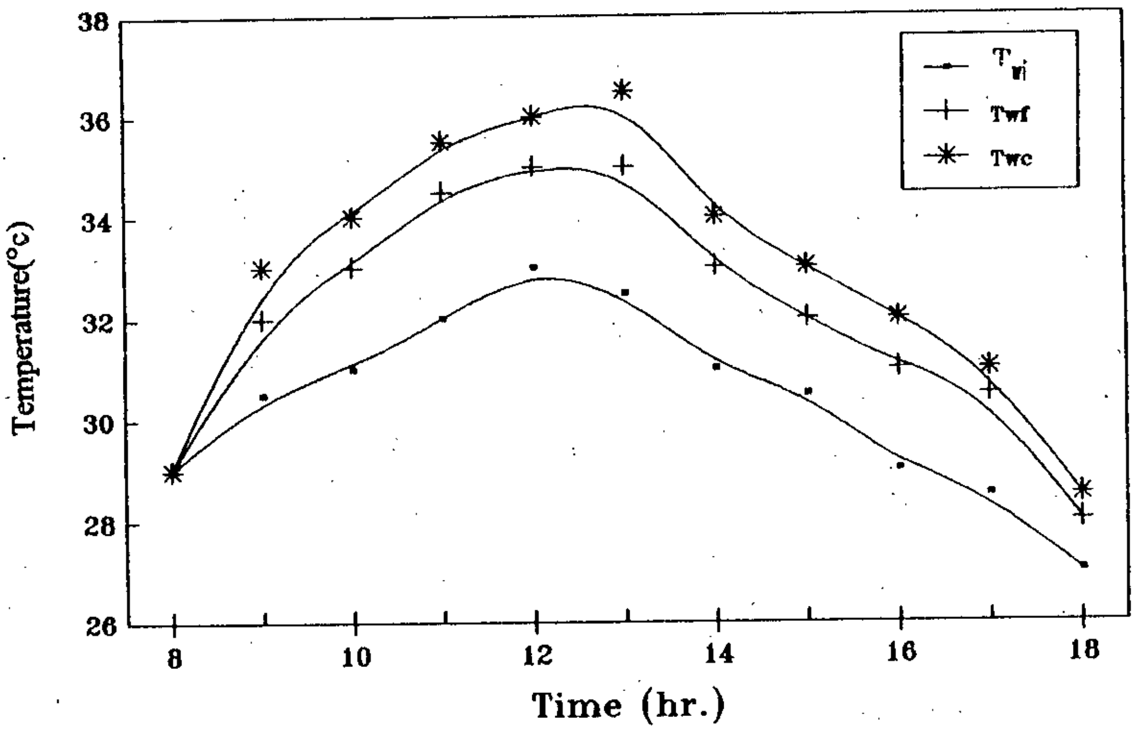


Fig. 4.29 The Initial and Final Mean Water Temperature on March 20, 1995.

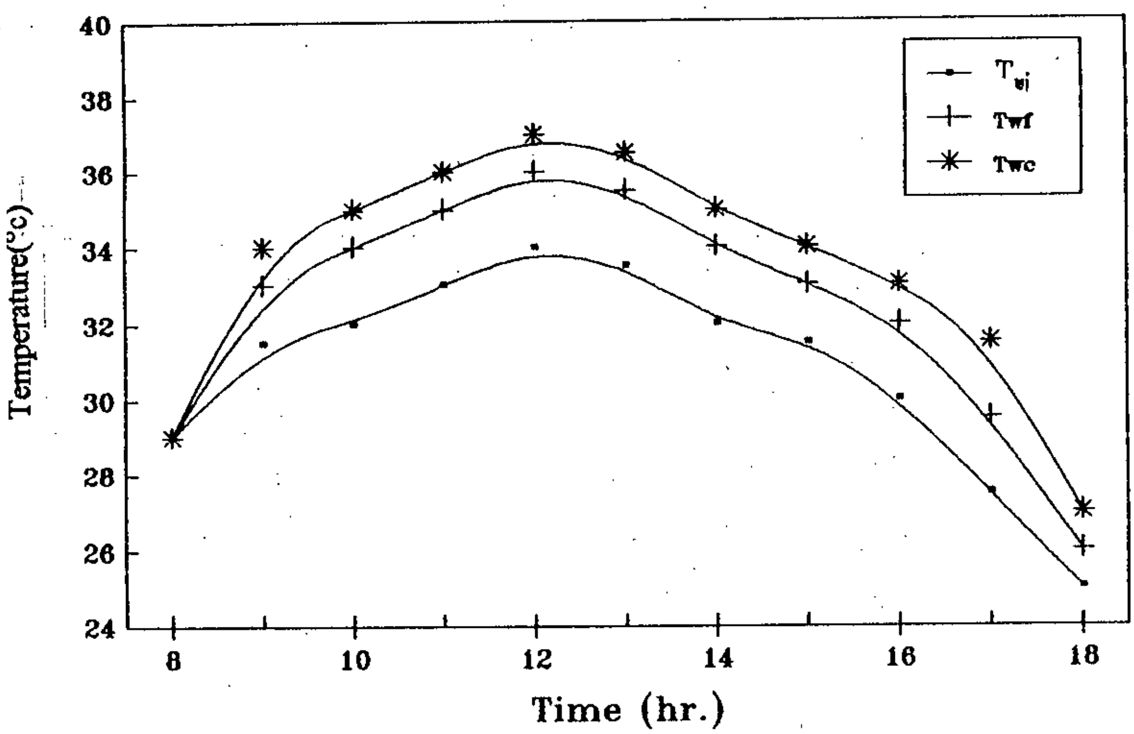


Fig. 4.30 The Initial and Final Mean Water Temperature on March 25, 1995.

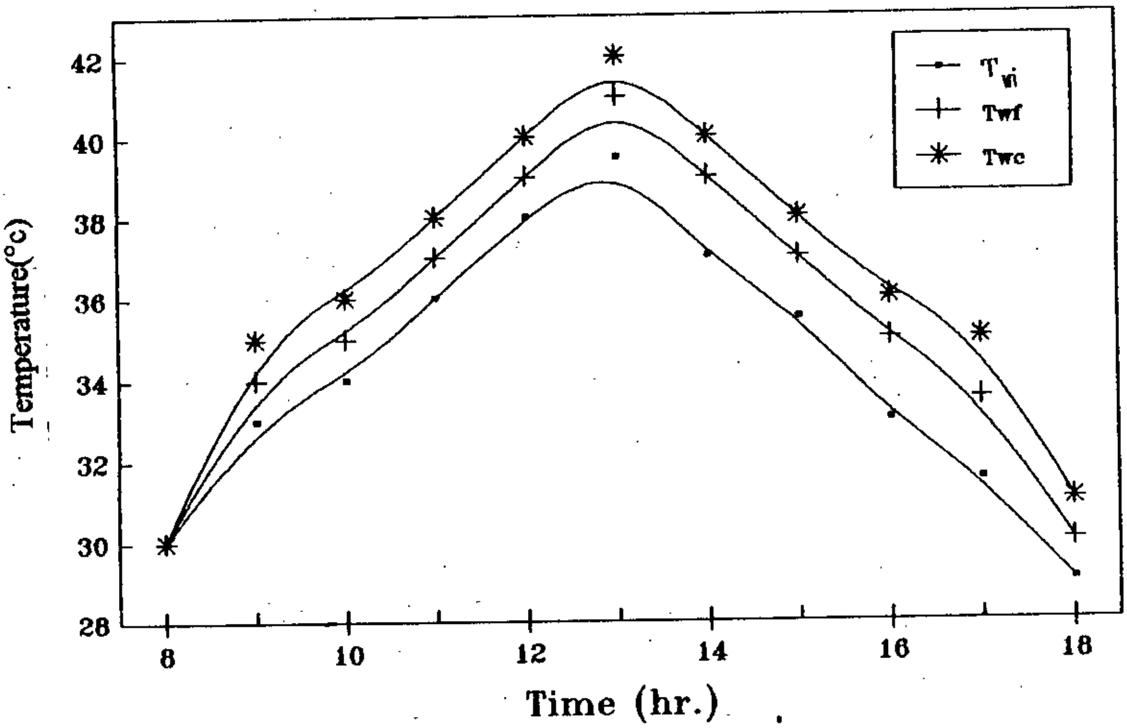


Fig. 4.31 The Initial and Final Mean Water Temperature on March 30, 1995.

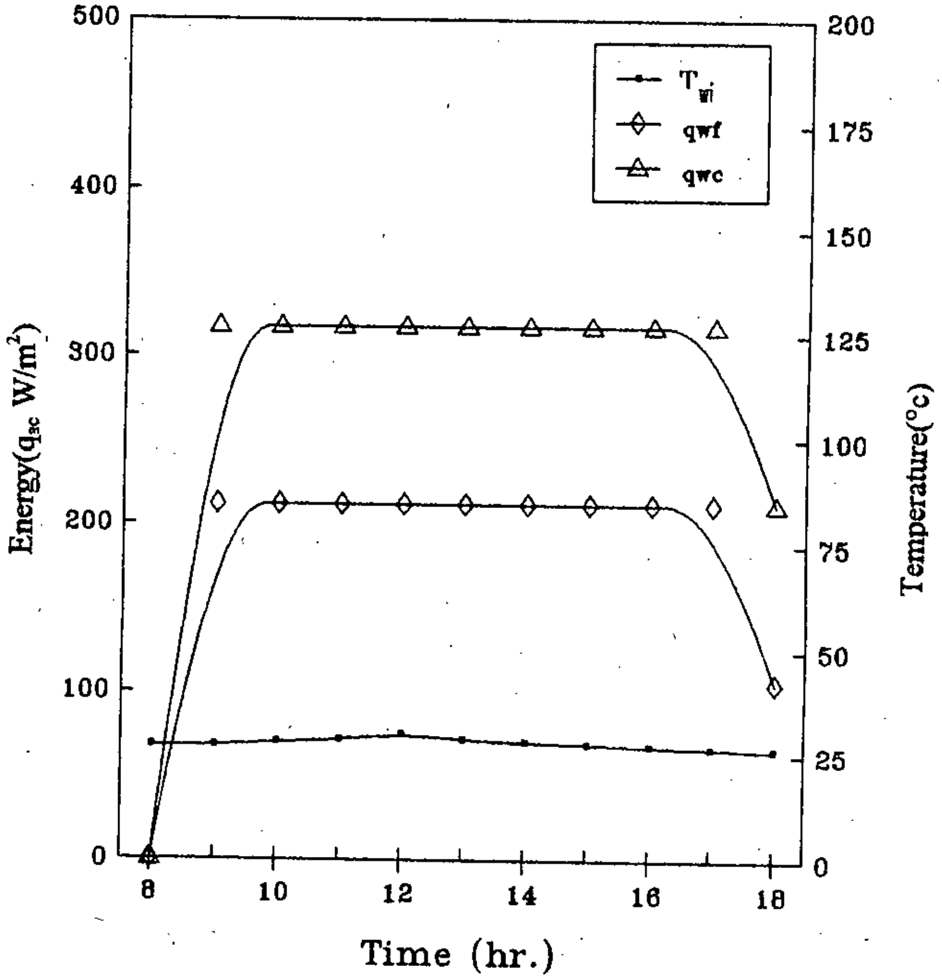


Fig. 4.32 The Heat Energy Absorbed and Initial Water Temperature on November 01, 1994.

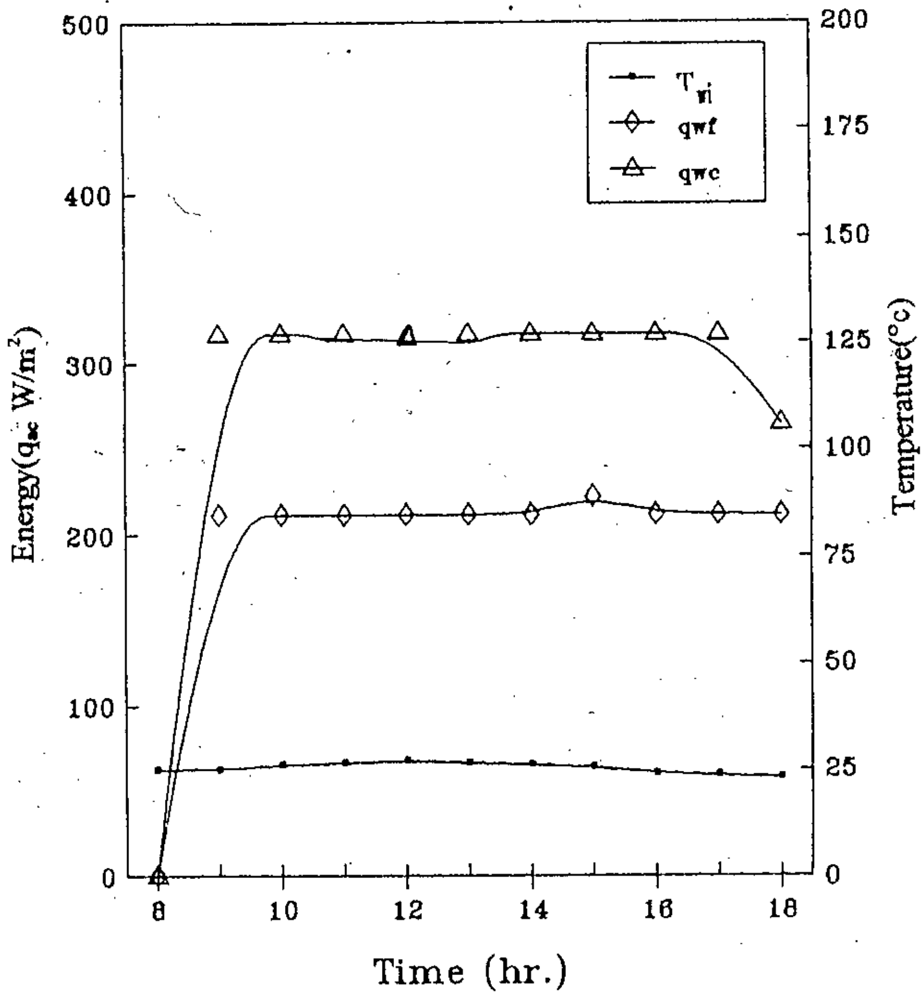


Fig. 4.33 The Heat Energy Absorbed and Initial Water Temperature on November 05, 1994.

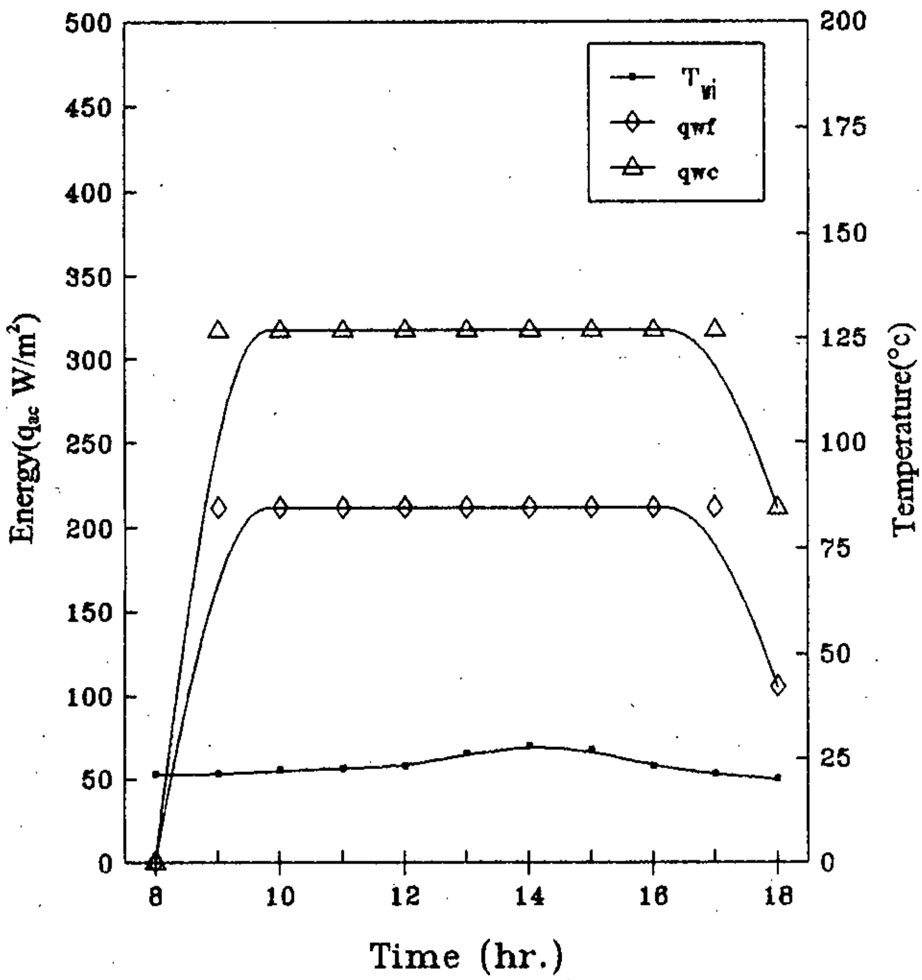


Fig. 4.34 The Heat Energy Absorbed and Initial Water Temperature on November 20, 1994.

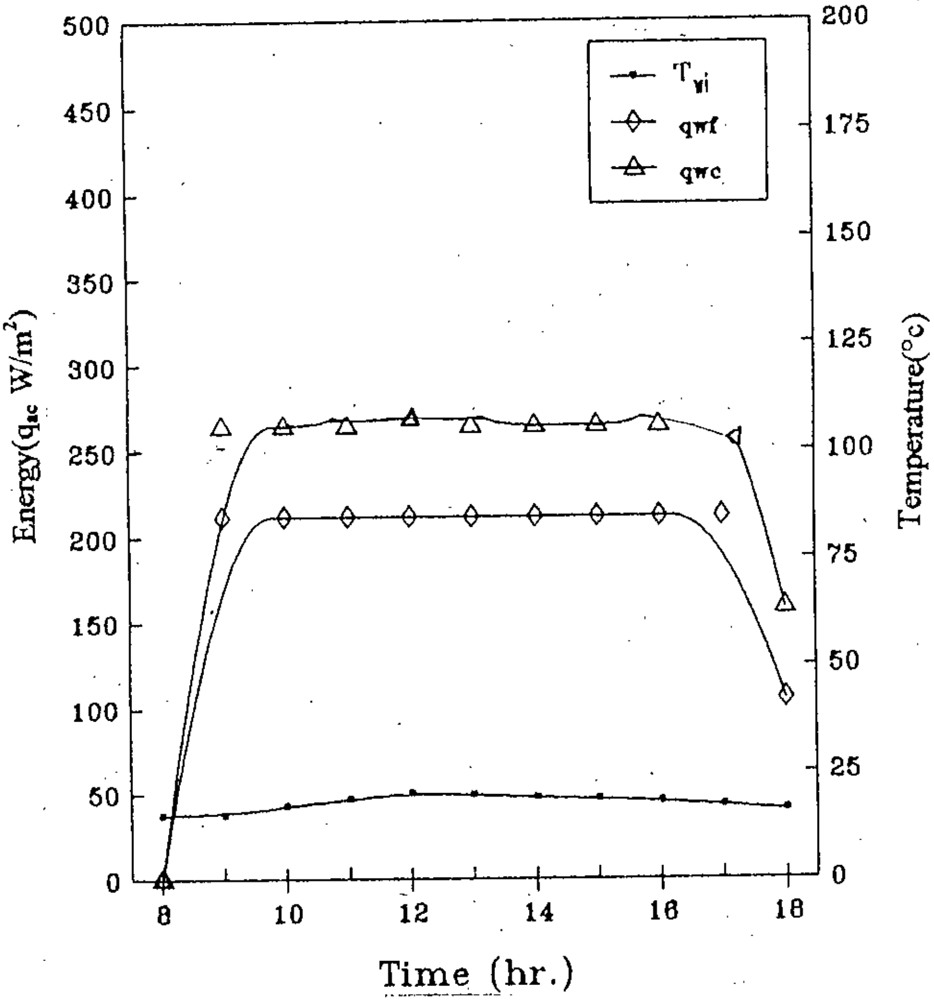


Fig. 4.35 The Heat Energy Absorbed and Initial Water Temperature on December 05, 1994.

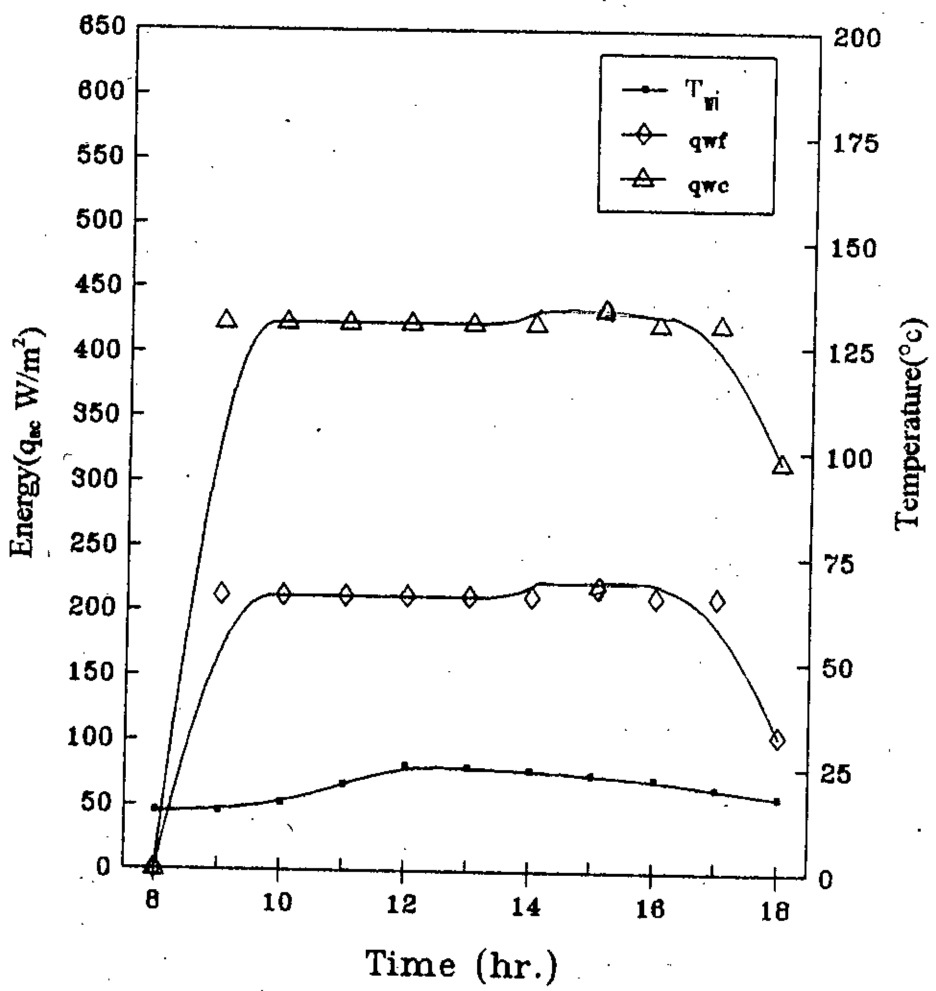


Fig. 4.36 The Heat Energy Absorbed and Initial Water Temperature on December 15, 1994.

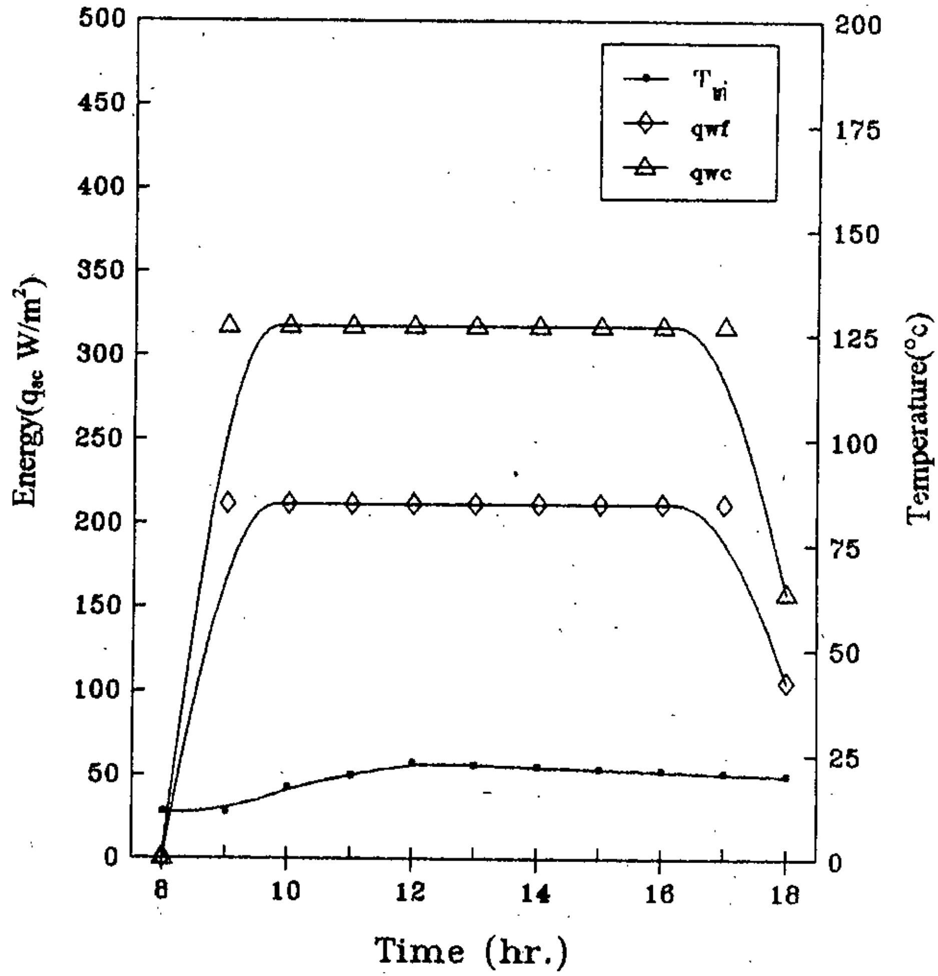


Fig. 4.37 The Heat Energy Absorbed and Initial Water Temperature on December 20, 1994.

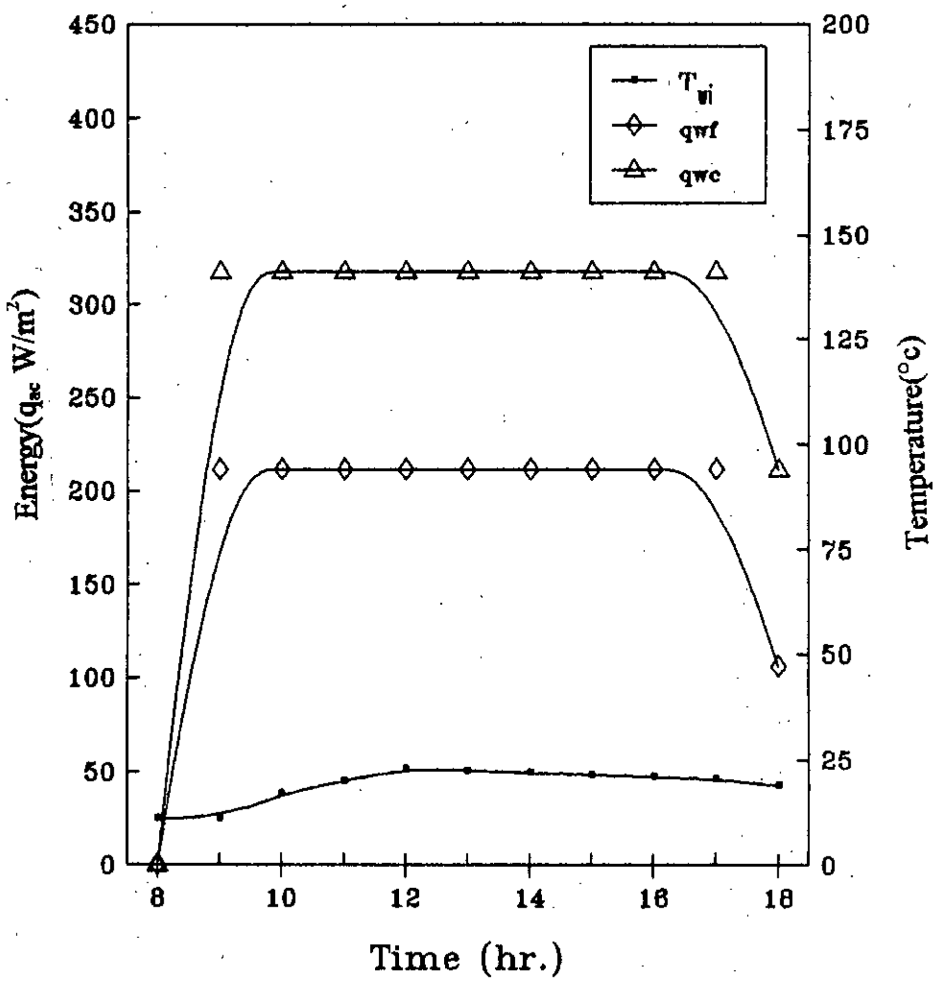


Fig. 4.38 The Heat Energy Absorbed and Initial Water Temperature on December 30, 1994.

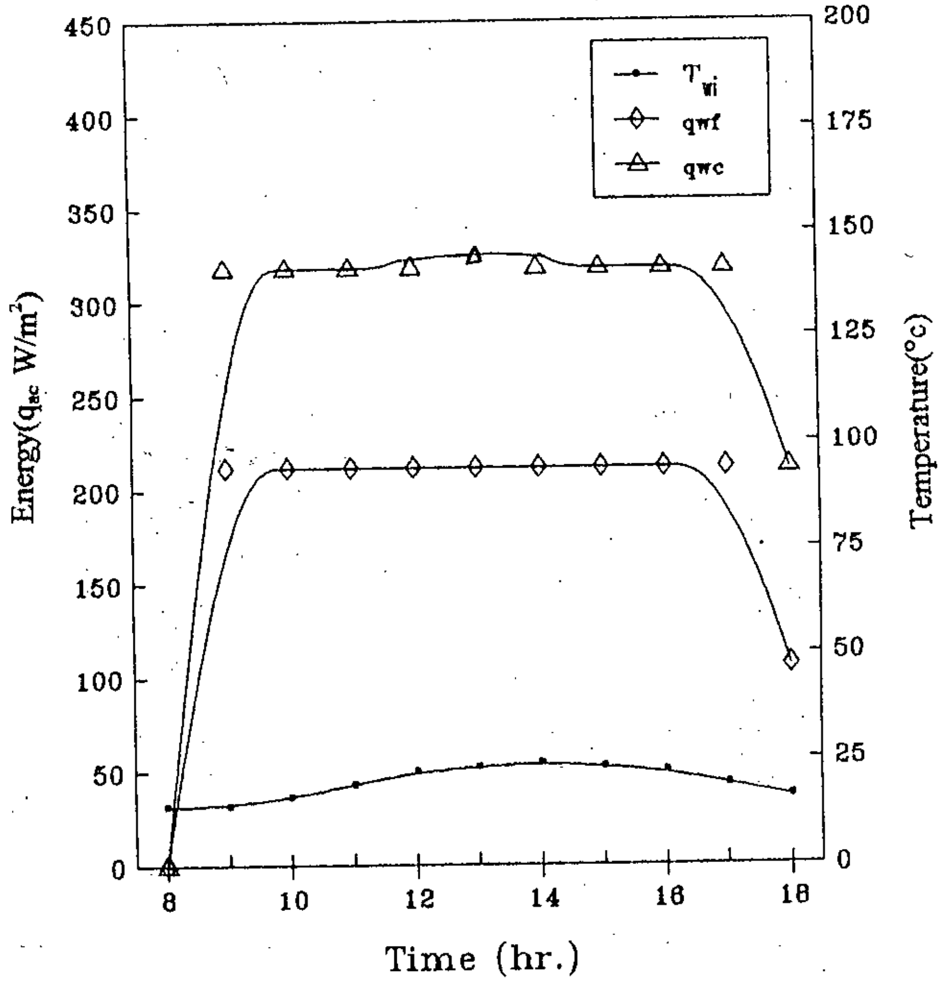


Fig. 4.39 The Heat Energy Absorbed and Initial Water Temperature on January 05, 1995.

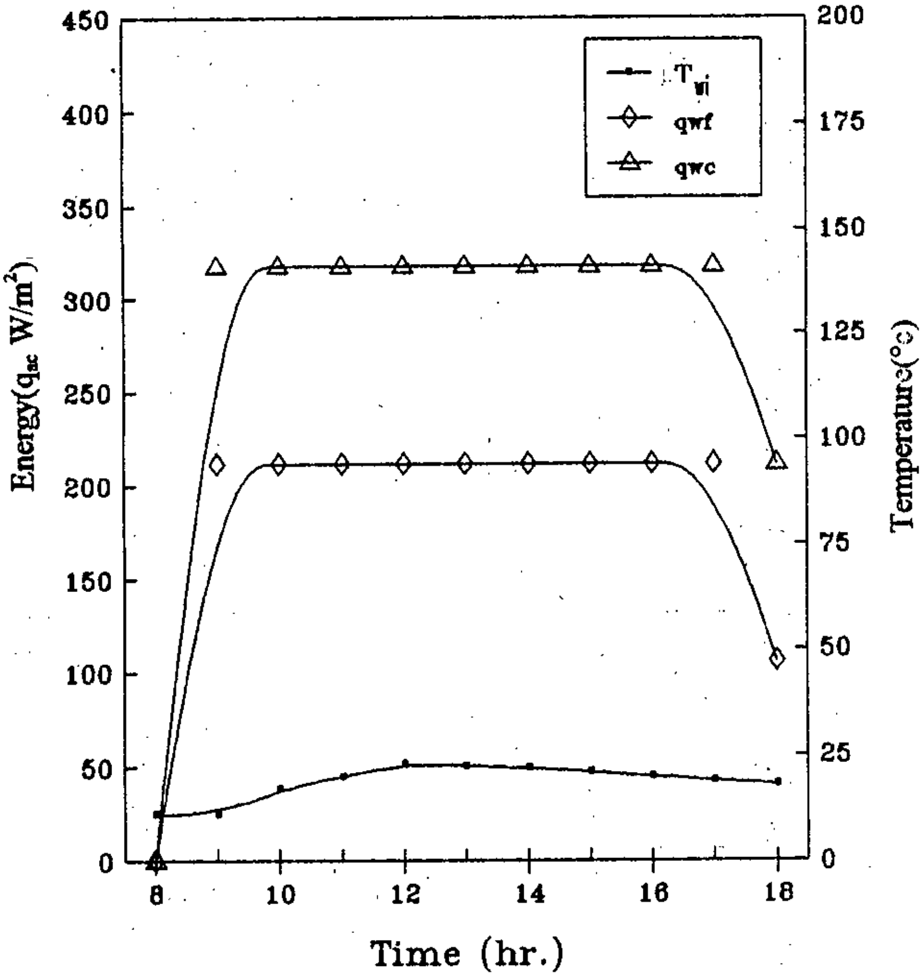


Fig. 4.40 The Heat Energy Absorbed and Initial Water Temperature on January 10, 1995.

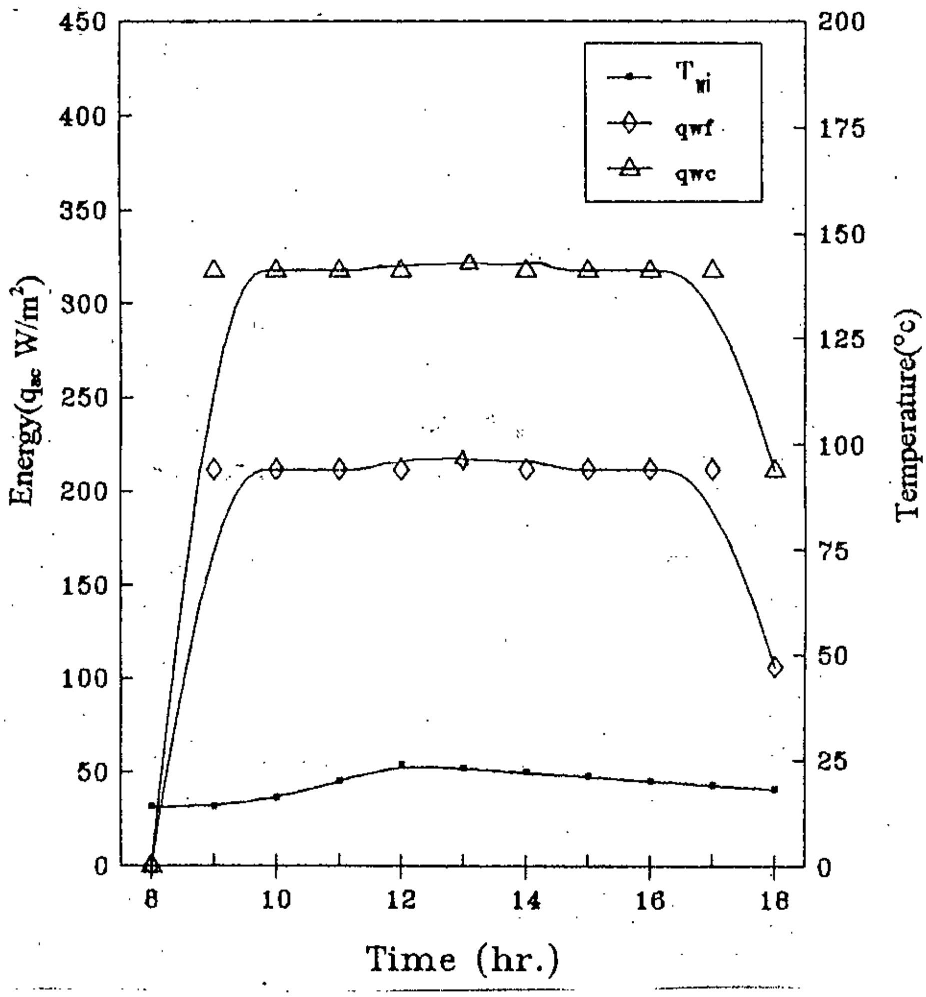


Fig. 4.41 The Heat Energy Absorbed and Initial Water Temperature on January 20, 1995.

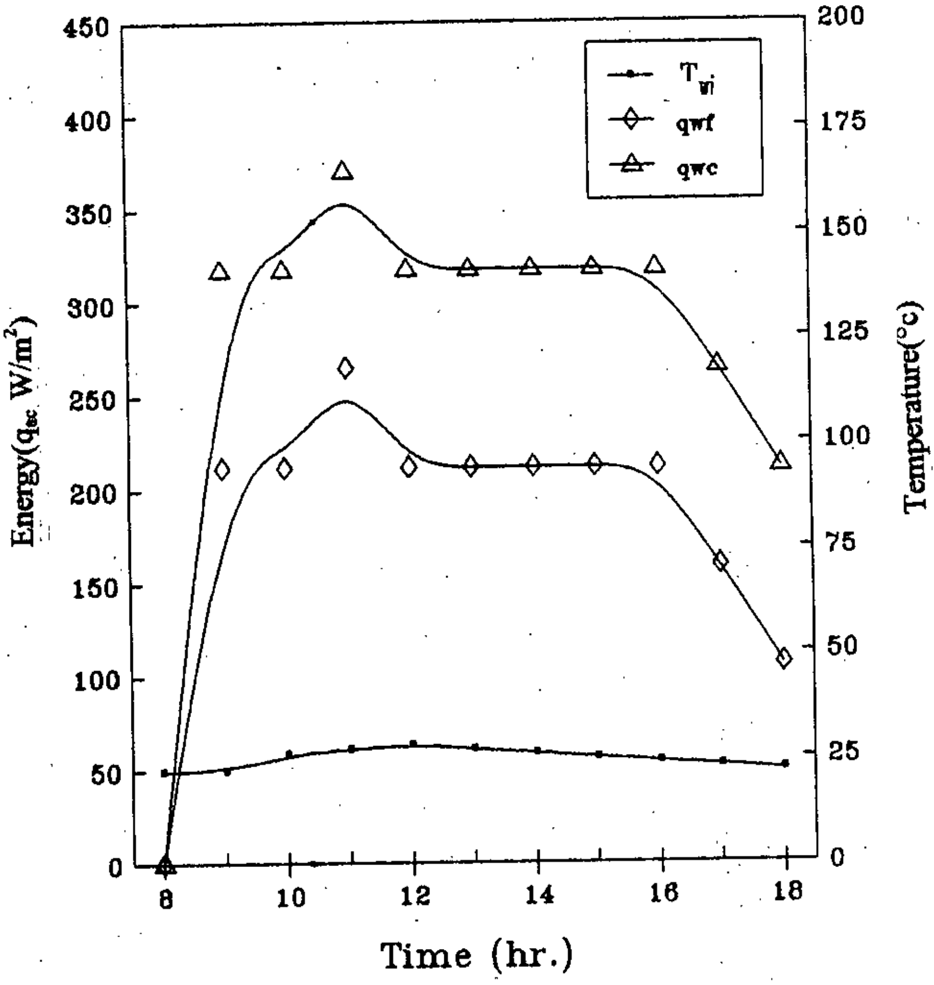


Fig. 4.42 The Heat Energy Absorbed and Initial Water Temperature on February 10, 1995.

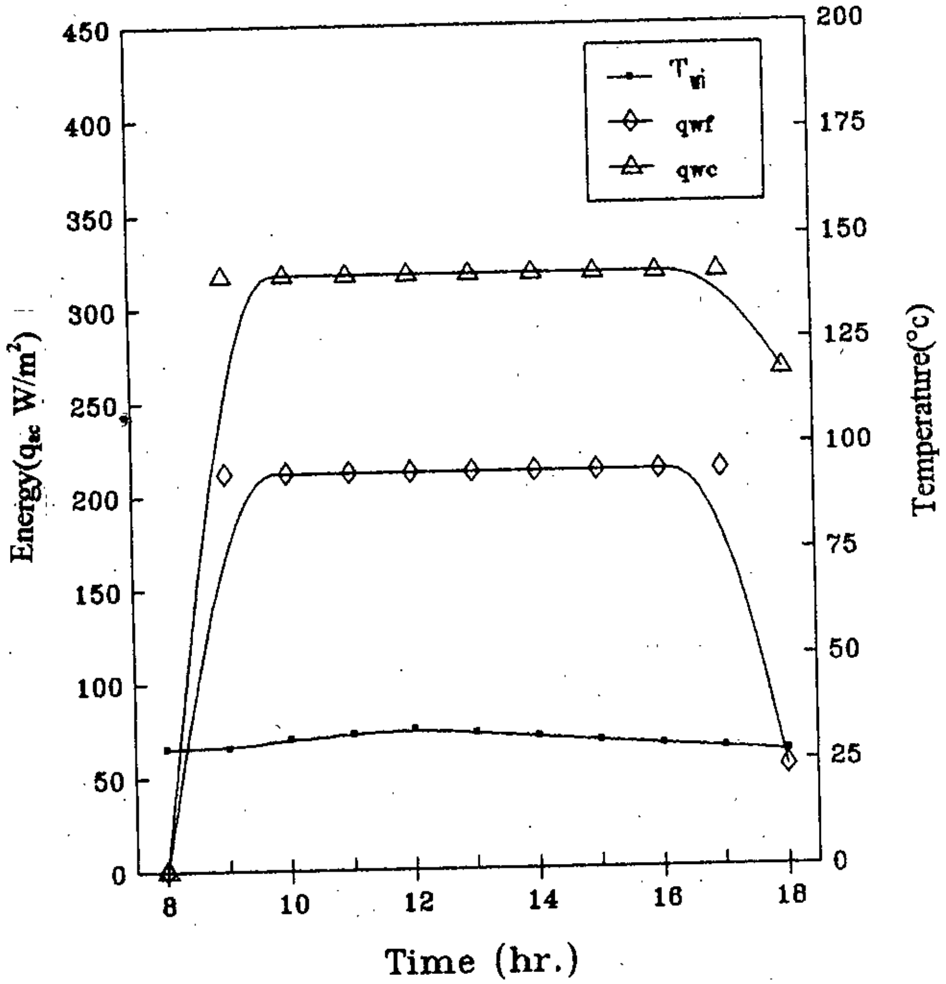


Fig. 4.43 The Heat Energy Absorbed and Initial Water Temperature on March 15, 1995.

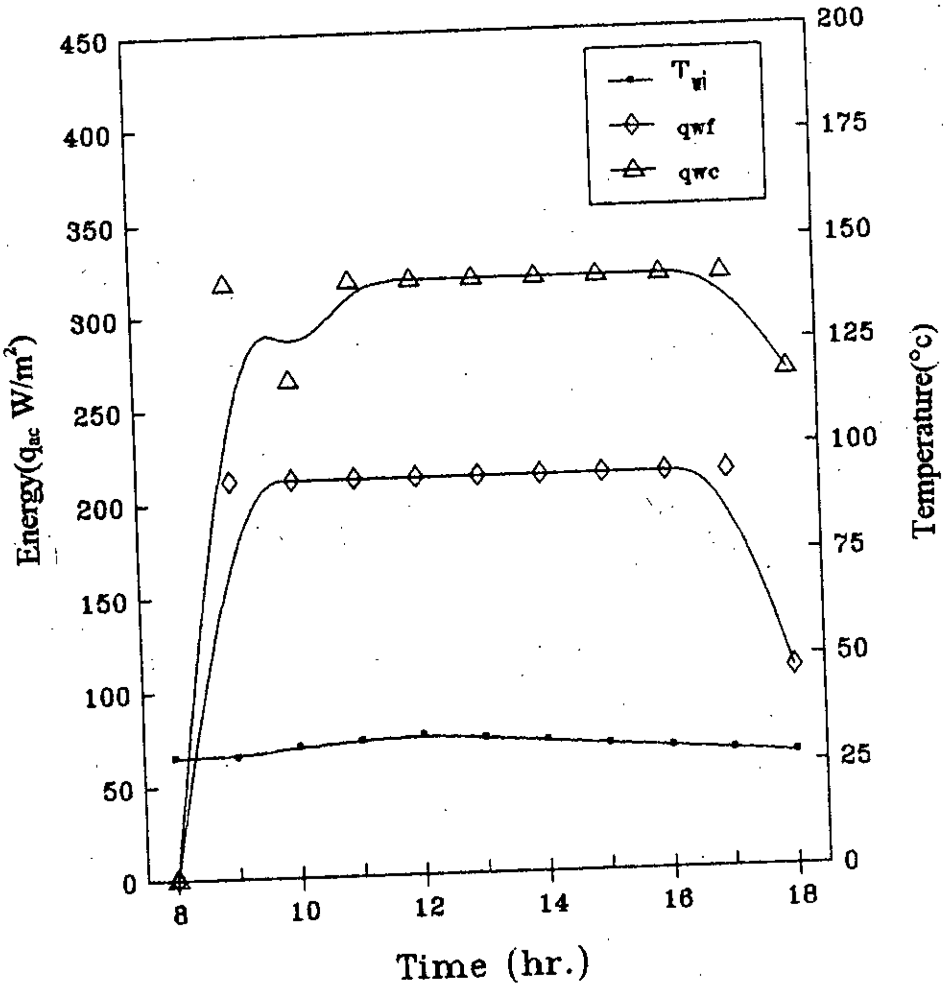


Fig. 4.44 The Heat Energy Absorbed and Initial Water Temperature on March 20, 1995.

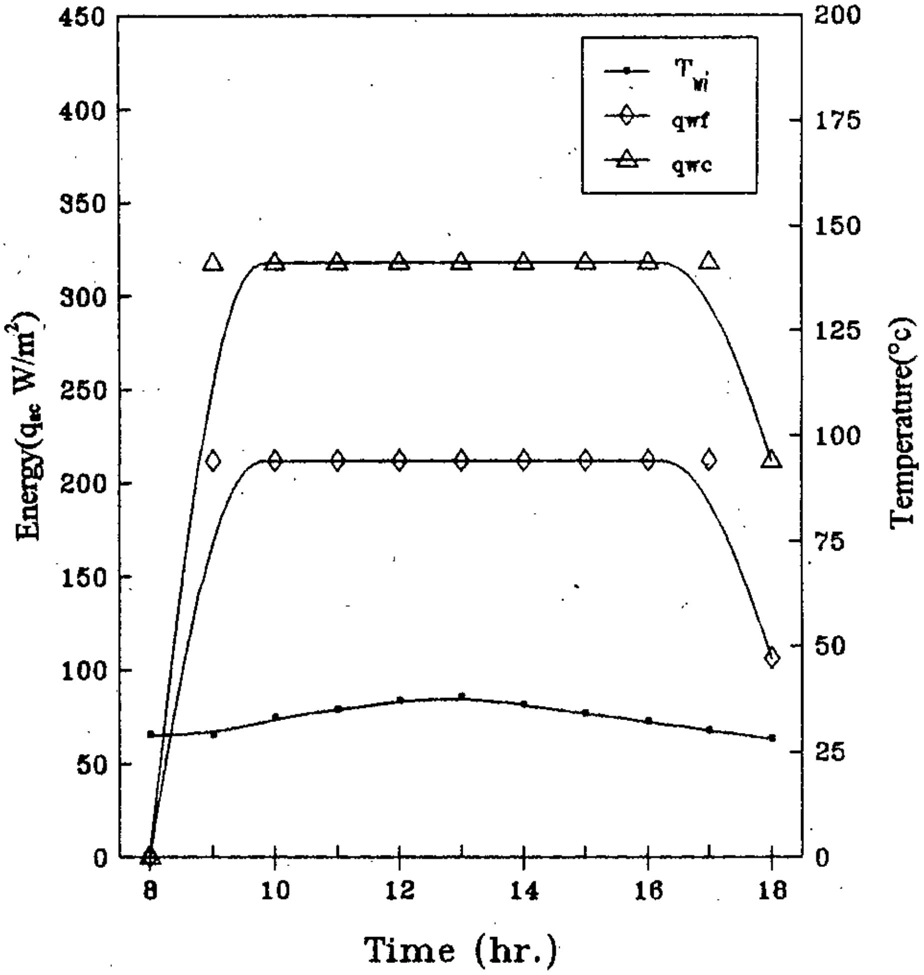


Fig. 4.45 The Heat Energy Absorbed and Initial Water Temperature on March 25, 1995.

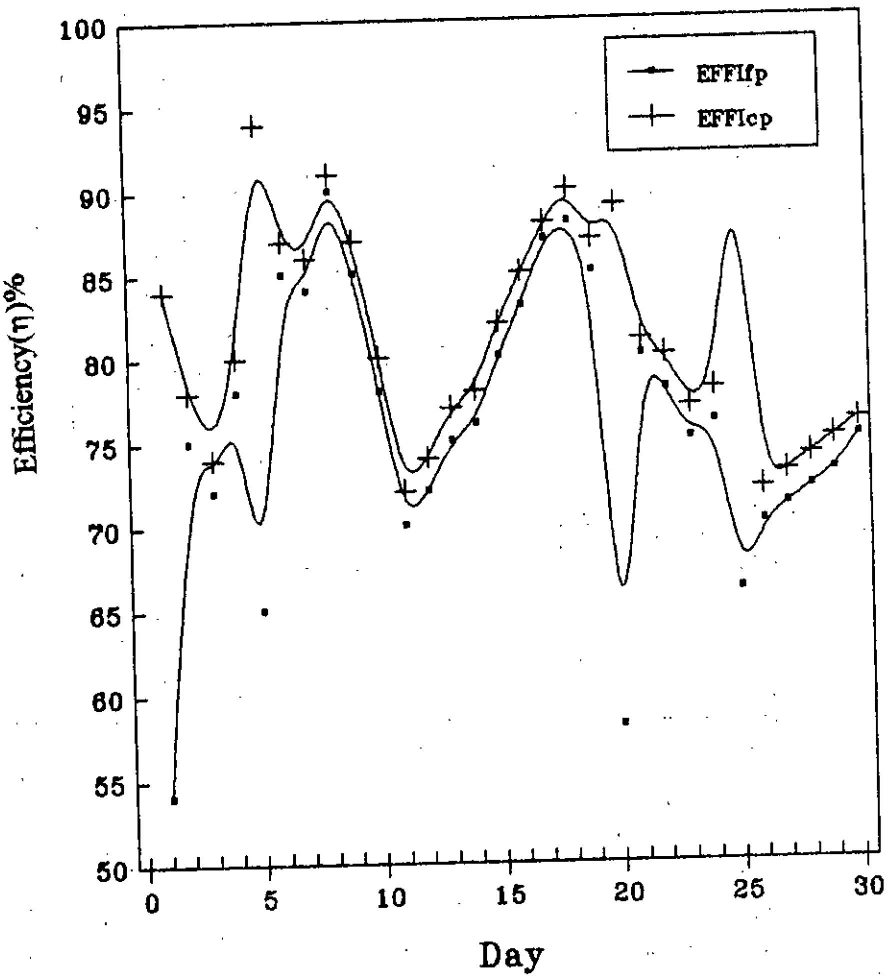


Fig. 4.46 The Average Efficiencies of CSWHF and CSWHC During the Month of November, 1994.

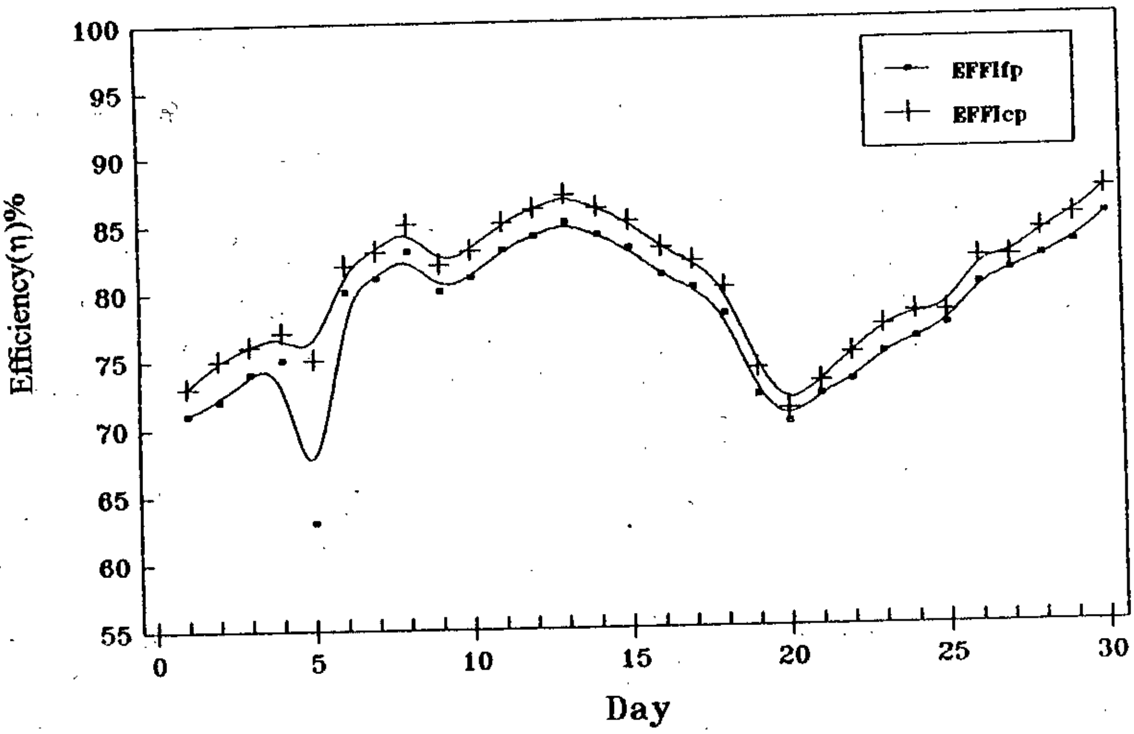


Fig. 4.47 The Average Efficiencies of CSWHF and CSWHC During the Month of December, 1994.

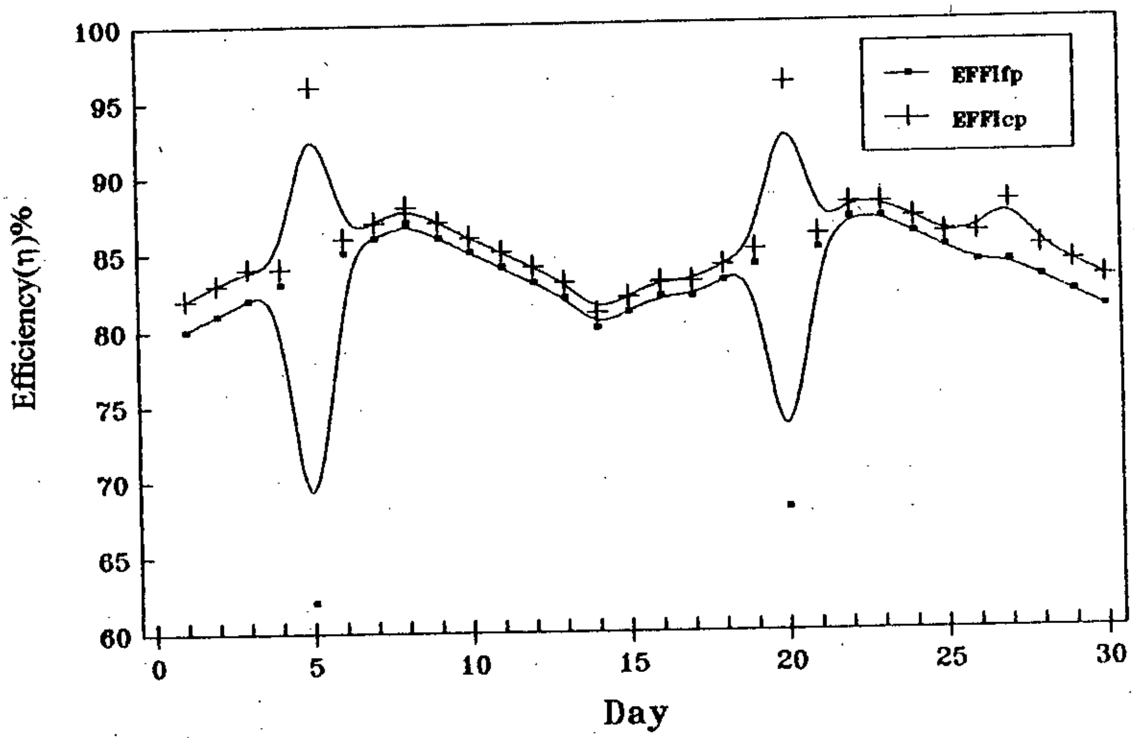


Fig. 4.48 The Average Efficiencies of CSWHF and CSWHC During the Month of January, 1995.

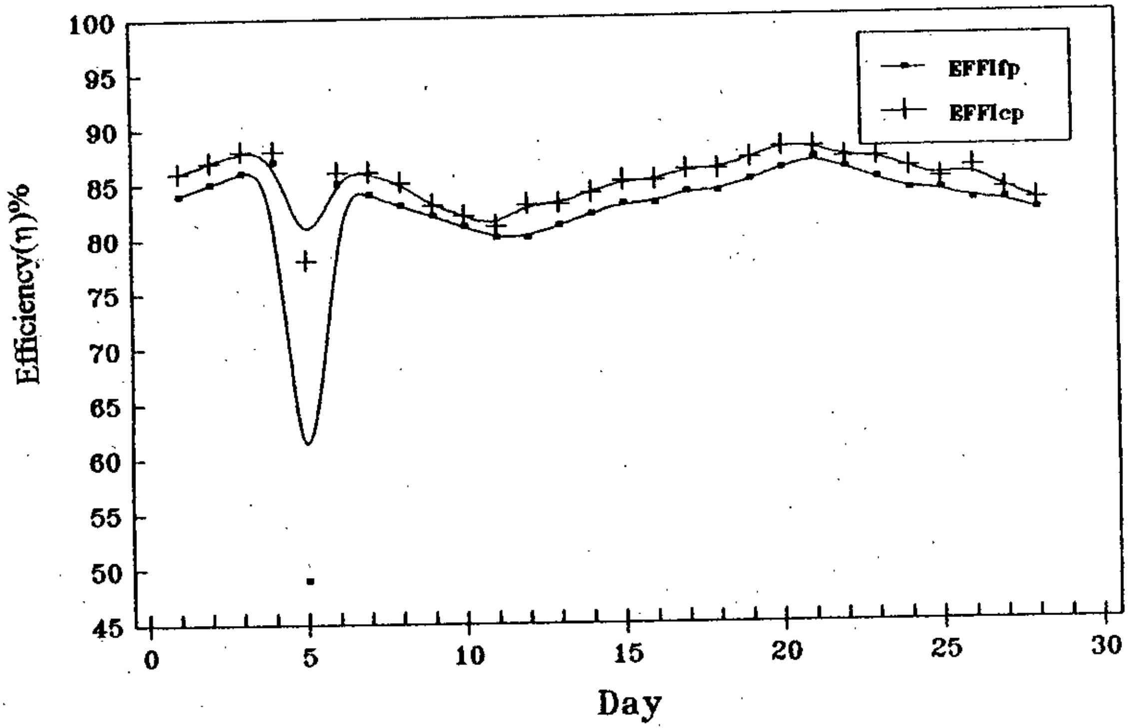


Fig. 4.49 The Average Efficiencies of CSWHF and CSWHC During the Month of February, 1995.

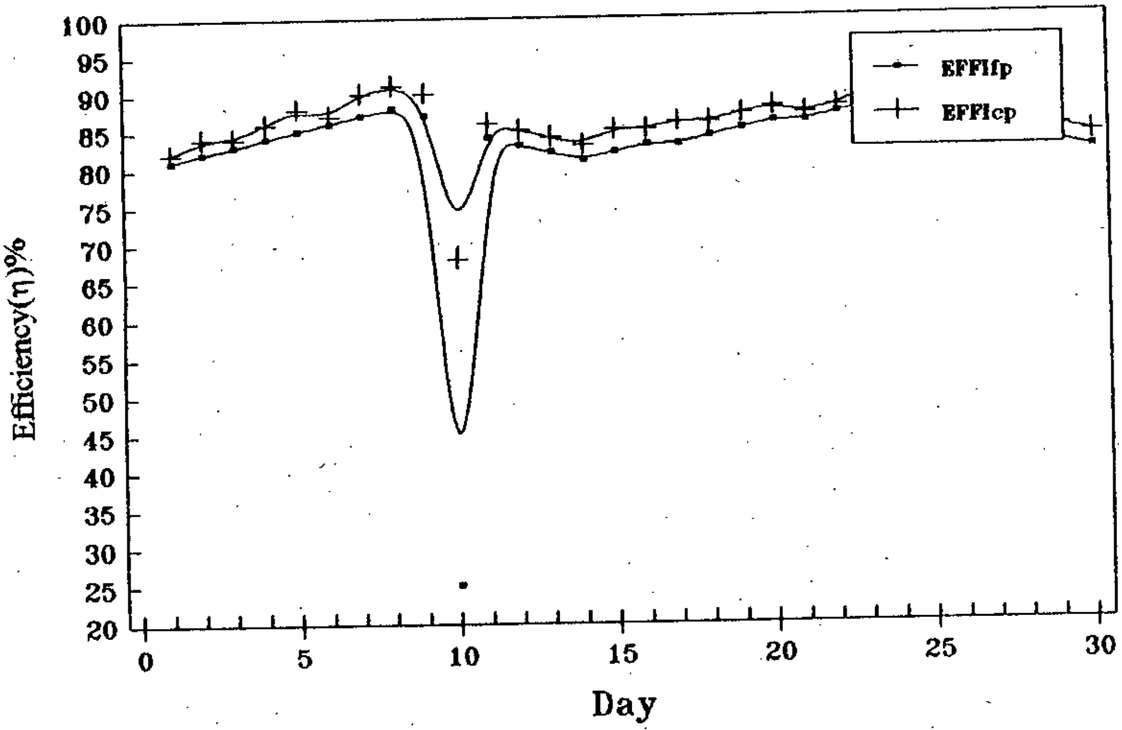


Fig. 4.50 The Average Efficiencies of CSWHF and CSWHC During the Month of March, 1995.

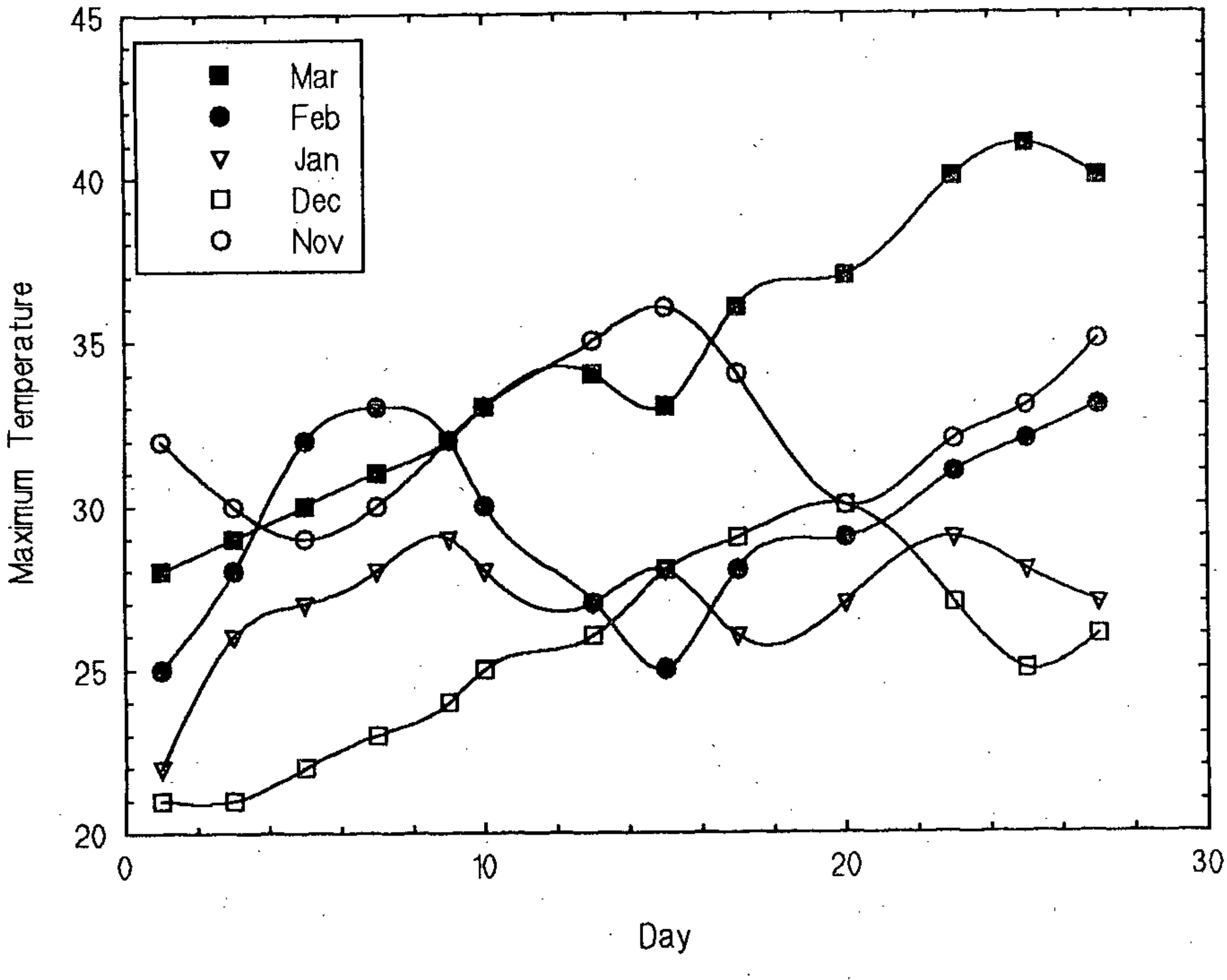


Fig. 4.51 Distribution of Daily Maximum Final Mean Water Temperature CSWHF in November, December 1994, January, February and March 1995.

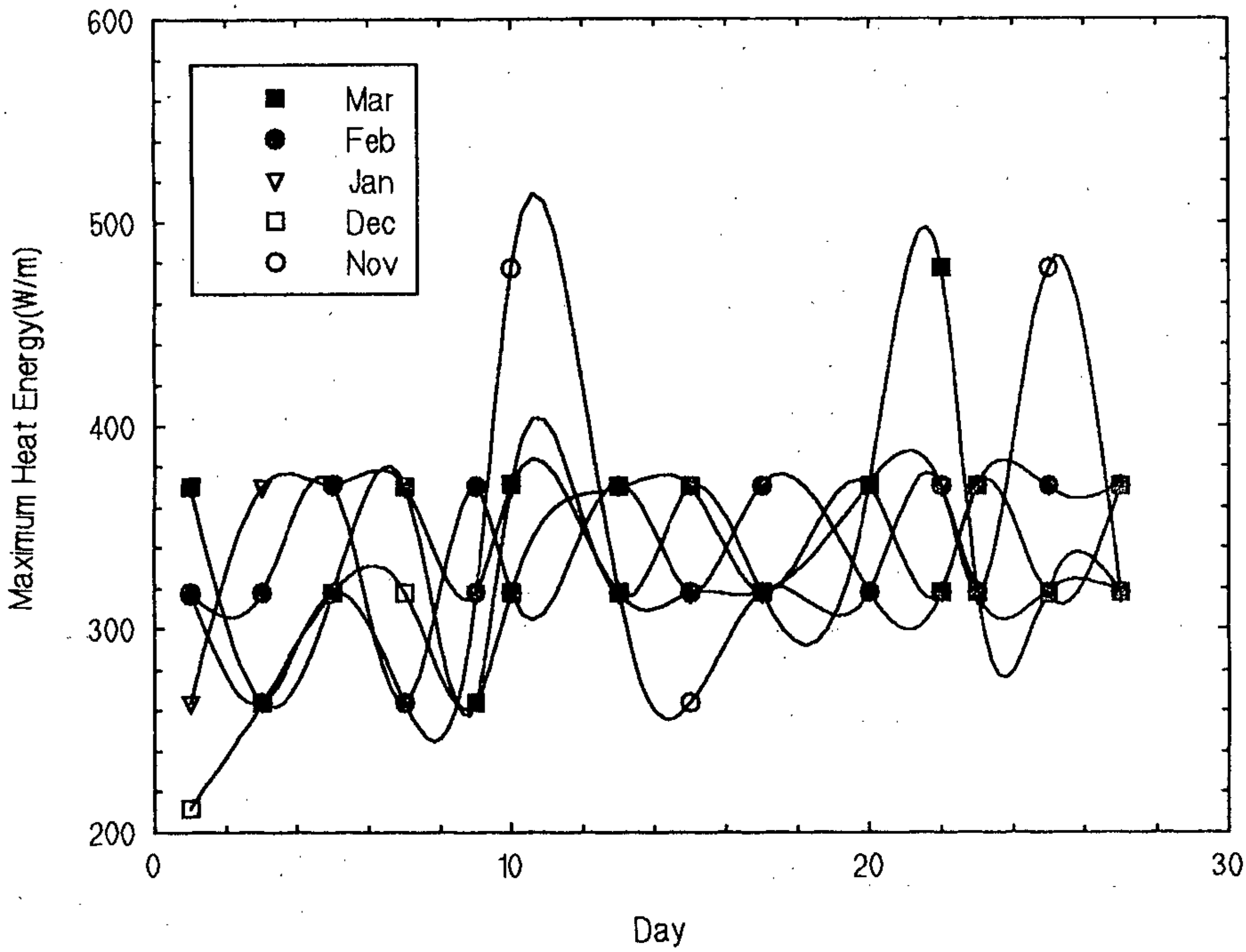


Fig. 4.52 Distribution of Maximum Heat Energy Obtained CSWHC in November, December 1994, January, February and March 1995.

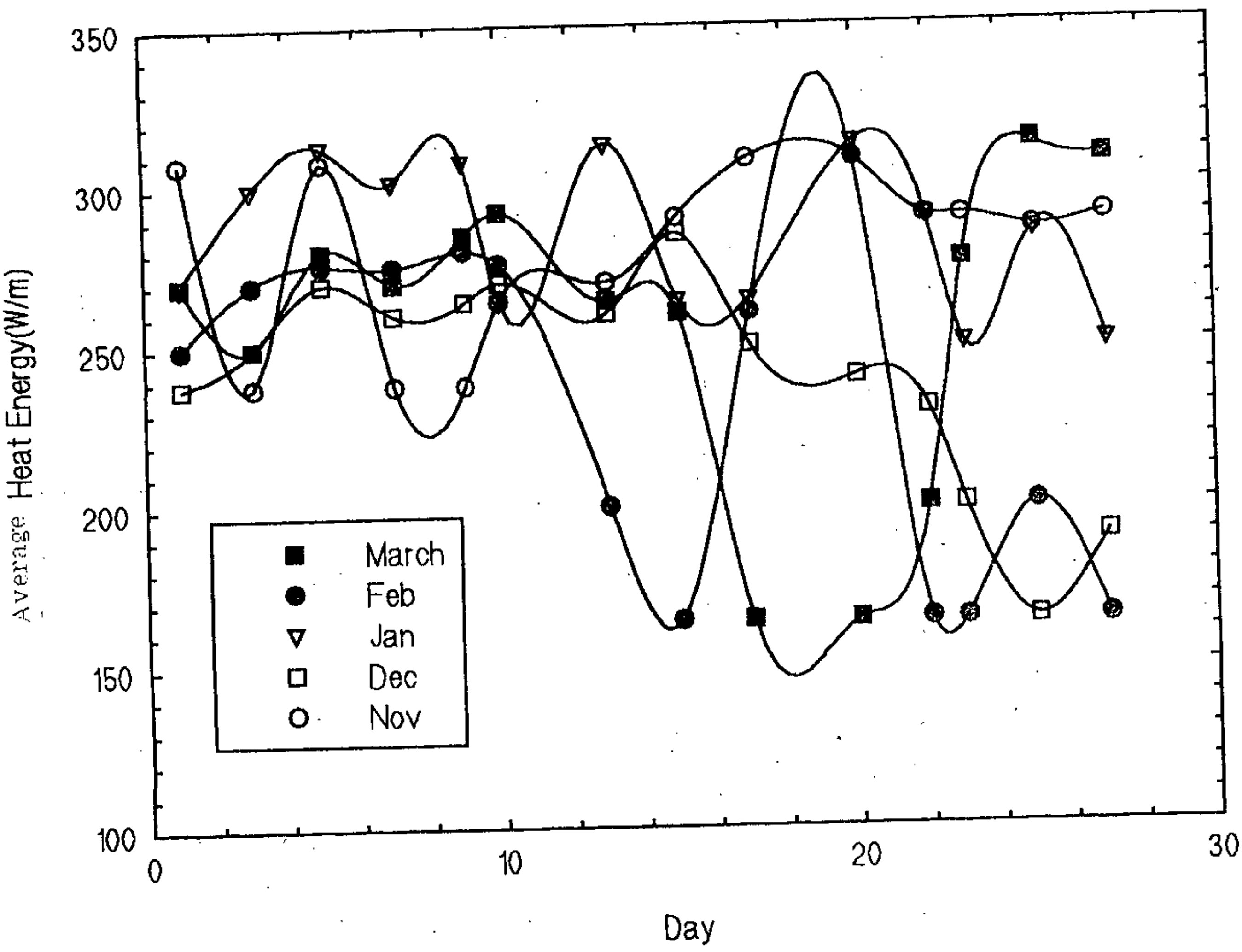


Fig. 4.53 Distribution of Average Heat Energy Obtained CSWHC in November, December 1994, January, February and March 1995.

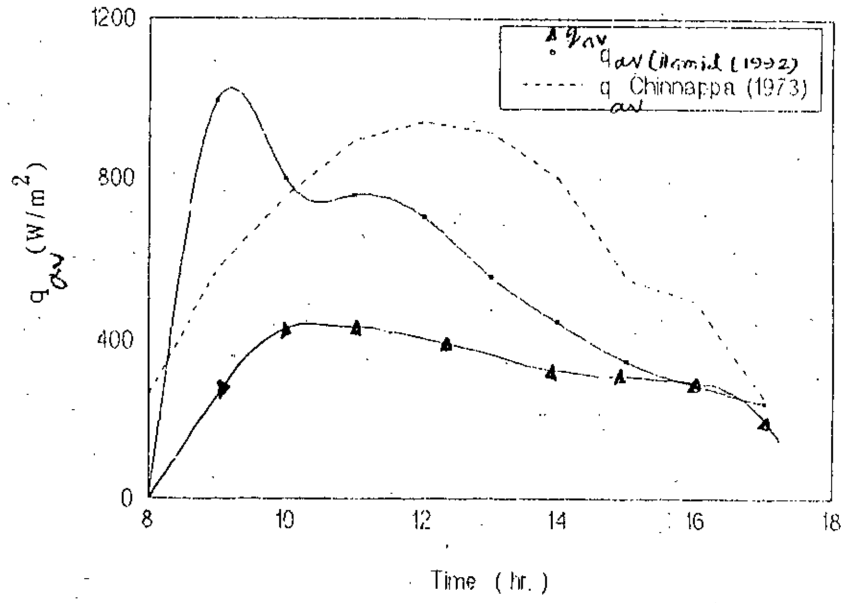


Fig. 4.54 Comparison of Results with Chinnappa [1973] and Hamid [1992] of Heat Energy Absorbed on February 11.

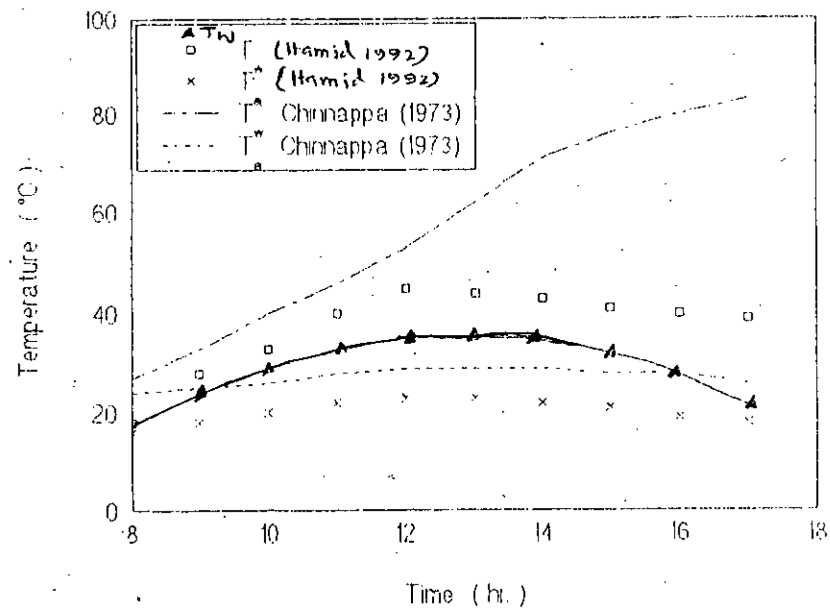


Fig. 4.55 Comparison of Results with Chinnappa [1973] and Hamid [1992] of Initial and Final Mean Water Temperature february 11.

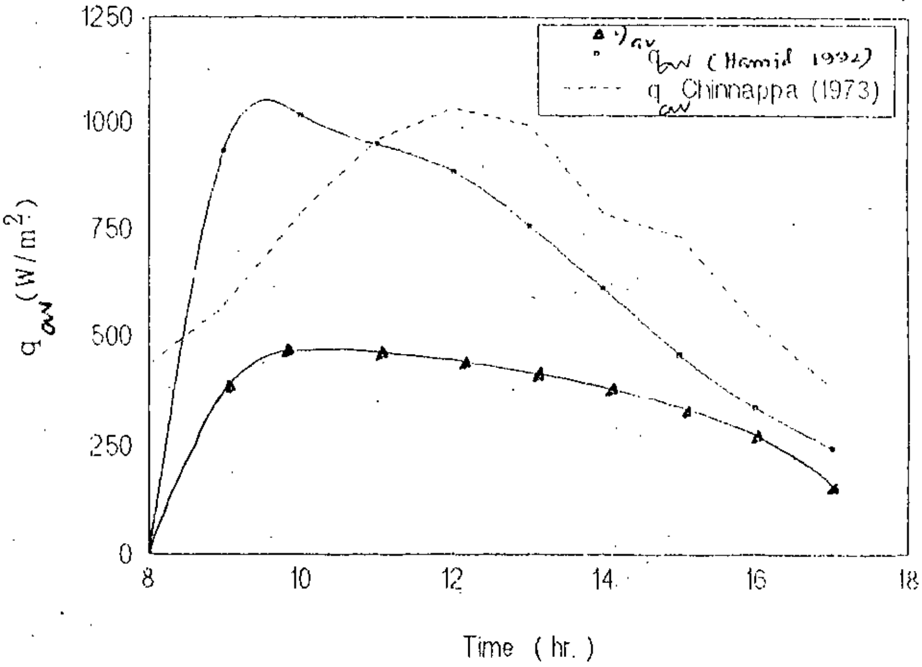


Fig. 4.56 Comparison of Results with Chinnappa [1973] and Hamid [1992] of Heat Energy Absorbed on January 11.

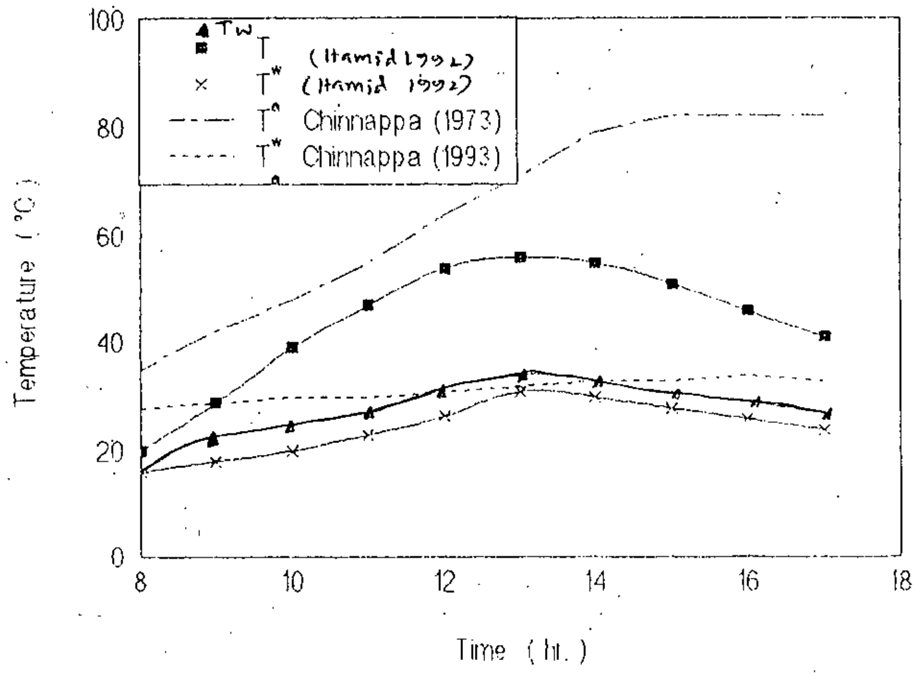


Fig. 4.57 Comparison of Results with Chinnappa [1973] and Hamid [1992] of Initial and Final Mean Water Temperature on February 19.

APPENDIX : B

B.1 Sample Calculations

The working formulae for efficiency of solar flat and corrugated plate collector:

$$\eta = \frac{\int \frac{Q}{A} dt}{\int I dt}$$

Where,

Q	=	$mC_p \Delta T$
m	=	mass flow rate = 114 kg/hr
C_p	=	4.18 kJ/kg°K
A	=	Collector area in m^2 [For corrugated plate it is projected area]
ΔT	=	Temperature difference in °K
I	=	Solar insolation in W/m^2
η	=	Efficiency

For short period of time the above equation may be expressed approximately Marschal et. al. [1978] as,

$$\eta = (Q/A)/I$$
$$= q/I$$
$$= Q/AI = \dot{m}C_p\Delta T/AI$$

$$\eta = mC_p\Delta T/AI$$

Now,

$$q = mCp\Delta T/A$$
$$= (114\ kg \times 4.18\ KJ/kg°K)/(1.25\ m^2 \times 3600\ sec) \times \Delta T\ °K$$
$$= 0.10589 \times \Delta T\ kW/m^2$$
$$q = 0.10589 \times \Delta T\ kW/m^2$$
$$= 105.89 \times \Delta T\ W/m^2$$

Note: Since the change in density of water with the change of temperature is negligible the mean value of the mass of water and the Cp (specific heat of water) value of water were assumed constant within the temperature range between 15°C to 65°C, performance was assumed steady state. Temperature drops through covers, Edge losses, and Heat losses due to convection were negligible.

For November 25, 1994

$$q = 105.89 \times \Delta T \ W/m^2$$

where ΔT = Rise in temperature of water in one hour.

Heat Energy accumulated for 10 hours in Flat Plate

q_{8-9} = 211.78 W/m^2

q_{9-10} = 211.78 W/m^2

q_{10-11} = 211.78 W/m^2

q_{11-12} = 211.78 W/m^2

q_{12-13} = 211.78 W/m^2

q_{13-14} = 211.78 W/m^2

q_{14-15} = 211.78 W/m^2

q_{15-16} = 211.78 W/m^2

q_{16-17} = 211.78 W/m^2

q_{17-18} = 211.78 W/m^2

q_{ac} for 10 hours = 2011.91 W/m^2

Now daily average hourly heat output,

$$q_{av} = (2011.91/10) \ W/m^2$$

$$= 201.191 \ W/m^2$$

From Helali [1985]

1 cal = 4.186 J

Now I = x $cal/cm^2.day$

$$x = [4.186 \ J \times (100 \times 100)] / [m^2.day]$$

$$= x \ (41860/m^2.day) \times (J/S) \times (h/3600)$$

$$= x \times 0.01163 \ kW/m^2.day$$

$$I = 0.01163 \ X/N \ kW/m^2$$

Where x = solar insulation in $cal/cm^2.day$

N = day length of bright sun shine in hr.

<u>For Example, For November 25, 1994.</u>

Here, $x = 282\ cal/cm^2\ day$

$N = 10.7$

$$I_{av} = 0.01163\ x/N\ kW/m^2$$
$$= 0.01163 \times (282/10.7)\ kW/m^2$$
$$= 0.3065102\ kW/m^2$$

Efficiency for Flat Plate,

$$\eta_f = q_{av}/I_{av} \times 100\%$$
$$= 0.201191/0.3065102 \times 100\%$$
$$= 65.64\%$$

<u>Heat Energy accumulated for 10 hours in Corrugated Plate</u>

$q_{8-9} = 317.67\ W/m^2$

$q_{9-10} = 317.67\ W/m^2$

$q_{10-11} = 370.615\ W/m^2$

$q_{11-12} = 264.725\ W/m^2$

$q_{12-13} = 264.725\ W/m^2$

$q_{13-14} = 264.725\ W/m^2$

$q_{14-15} = 264.725\ W/m^2$

$q_{15-16} = 317.67\ W/m^2$

$q_{16-17} = 317.67\ W/m^2$

$q_{17-18} = 158.833\ W/m^2$

q_{ac} for 10 hours $= 2859\ W/m^2$

Now daily average hourly heat output

$$q_{av} = 2859/10\ W/m^2$$
$$= 285.9\ W/m^2$$
$$= 0.2859\ kW/m^2$$

<u>Efficiency for corrugated plate (in case of projected area)</u>

$$\eta_c = q_{av}/I_{av} \times 100\%$$
$$= 0.2859/0.3065102 \times 100\%$$
$$= 93.27\%$$

Efficiency for corrugated plate (in case of total area)

Area of Flat Plate = AF = (137.16 cm x 91.44 cm) = 1.25 m^2

Total area of corrugated plate = A_c = (176 cm x 91.44 cm) = 1.6m^2

i.e. 1.28 times of Flat Plate area

$$q_{av} = 0.2859/1.28 \text{ kW/m}^2 = 0.2233593 \text{ kW/m}^2$$

$$\eta_c = q_{av}/I_{av} \times 100\% = (0.2233593/0.3065102) \times 100\% = 72.87\%$$

1 Langley = 1 cal/cm^2
= [1 x 4.186 J x (100 x 100)] / [m^2] S/S
= 4186 kW/m^2 x h/3600
= 0.01163 kWh/m^2

1 Langley/min = 0.01163 kWh/m^2.min
= 0.6978 kW/m^2

Y Langley/min = Y 0.6978 kW/m^2

From Chinnappa [February 19, 1969]

$$q = 0.625 \text{ Langley/min}$$
$$= 0.625 \times 0.6978 \text{ kW/m}^2$$
$$= 0.436 \text{ kW/m}^2$$

where,

Y = Heat Energy in Langley/min

I Langley = 1 cal/m^2.

For December 05, 1994.

$$q = 105.89 \times \Delta T \text{ W/m}^2$$

where, ΔT = Rise in temperature of water in one hour

Heat Energy accumulated for 10 hours in Flat Plate

q_{8-9} = 211.78 W/m^2

q_{9-10} = 211.78 W/m^2

q_{10-11} = 211.78 W/m^2

q_{11-12} = 211.78 W/m^2

q_{12-13} = 211.78 W/m^2

q_{13-14} = 211.78 W/m^2

q_{14-15} = 211.78 W/m^2

q_{15-16} = 211.78 W/m^2

q_{16-17} = 211.78 W/m^2

q_{17-18} = 105.89 W/m^2

q_{ac} for 10 hours = 2011.91 W/m^2

Now daily average hourly heat output

$$q_{av} = 2011/10 \text{ W/m}^2$$
$$= 201.191 \text{ W/m}^2$$
$$= 0.201191 \text{ kW/m}^2$$

For Example, For December 05, 1994.

Here, x = 287

N = 10.6

I_{av} = 0.01163 x/N kW/m^2

= 0.01163 x (287/10.6) kW/m^2

= 0.3148877 kW/m^2

Efficiency for Flat Plate,

η_f = (q_{av}/I_{av}) x 100%

= (0.201191/0.3148877) x 100%

= 63.89%

Heat Energy accumulated for 10 hours in Corrugated Plate

q_{8-9} = 264.725 W/m^2

q_{9-10} = 264.725 W/m^2

q_{10-11} = 264.725 W/m^2

q_{11-12} = 317.67 W/m^2

q_{12-13} = 264.725 W/m^2

q_{13-14} = 264.725 W/m^2

q_{14-15} = 264.725 W/m^2

q_{15-16} = 264.725 W/m^2

q_{16-17} = 264.725 W/m^2

q_{17-18} = 158.833 W/m^2

q_{ac} for 10 hours = 2378 W/m^2

Now daily average hourly heat output

q_{av} = 2378/10 W/m^2

= 237.8 W/m^2

= 0.2378 kW/m^2

Efficiency for Corrugated Plate (in case of projected area)

η_f = (q_{av}/I_{av}) x 100%

= (0.2378/0.3148877) x 100%

= 75.52%

Efficiency for Corrugated Plate (in case of total area)

Area of Flat Plate = A_f

= (137.16 cm x 91.44 cm) = 1.25 m^2

Total area of corrugated plate A_c

= (176 cm x 91.44 cm) = 1.6 m^2

i.e. 1.28 times of Flat Plate area

q_{av} = (0.2378/1.28) kW/m^2 = 0.1857812 kW/m^2

η_c = (q_{av}/I_{av}) x 100% = (0.1857812/0.3148877) x 100% = 58.99%

Data

Time	T_{wi}	Twf	Twc	Twf - T_{wi}	Twc - T_{wi}	qwf	qwc
8	16	16	16	0	0	0	0
9	16	18	19	2	3	211.78	317.67
10	19	21	22	2	3	211.78	317.67
11	21.5	23.5	25	2	3.5	211.78	370.615
12	24	26	26.5	2	2.5	211.78	264.725
13	23.5	25.5	26	2	2.5	211.78	264.725
14	23	25	25.5	2	2.5	211.78	264.725
15	22.5	24.5	25	2	2.5	211.78	264.725
16	22	24	25	2	3	211.78	317.67
17	21.5	23.5	24.5	2	3	211.78	317.67
18	21	22	22.5	1	1.5	105.89	158.835

25-11-94

Data

Time	T_{wi}	Twf	Twc	Twf - T_{wi}	Twc - T_{wi}	qwf	qwc
8	15	15	15	0	0	0	0
9	15	17	17.5	2	2.5	211.78	264.725
10	17	19	19.5	2	2.5	211.78	264.725
11	18.5	20.5	21	2	2.5	211.78	264.725
12	20	22	23	2	3	211.78	317.67
13	19.5	21.5	22	2	2.5	211.78	264.725
14	19	21	21.5	2	2.5	211.78	264.725
15	18.5	20.5	21	2	2.5	211.78	264.725
16	18	20	20.5	2	2.5	211.78	264.725
17	17	19	20	2	3	211.78	317.67
18	16	17	17.5	1	1.5	105.89	158.835

05-12-94