Effect of Absorber Plate Geometry on the Performance of Collector-cum-Storage Type Solar Water Heater

by

Nishith Kumar Das

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(Nishith Kumar Das)

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NOMENCLATURE

A : projected area of the collector surface, m^2

CSWHCR : collector-cum-storage type solar water heater with rectangular corrugated absorber plate

CSWHCT : collector-cum-storage type solar water heater with trapezoidal corrugated absorber plate

CSWHF : collector-cum-storage type solar water heater with flat absorber plate

CSWHC: collector-cum-storage type solar water heater with corrugated absorber plate

C_p : specific heat at constant pressure, kJ/kg K

I : solar insolation, W/m^2

m : mass flow rate, kg/hr

q : energy absorbed, W/m^2

T : temperature, K

ΔT : rise in temperature of water, K

η : efficiency

SUBSCRIPTS

air : ambient air

w : water

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ABSTRACT

Three built-in-storage type solar water heaters of equal volume are tested under identical conditions for performance evaluation. One of these water heaters is flat absorber plate and the other two are rectangular corrugated absorber plate and trapezoidal corrugated absorber plate. The test is carried out during the month of March, April, July and August 2001 at Dhaka. The rectangular corrugated absorber plate collector heats water up to 69^0C and 72^0C in the month of March and April whereas flat absorber plate collector heats up to 63.5^0C and 66^0C respectively. The maximum water temperatures are found to be 61^0C and 66^0C for trapezoidal corrugated absorber plate and 57^0C and 61.5^0C for flat absorber plate collector for the month the July and August respectively. The average efficiency is found to be 76% in the month of March and 79% in the month of April for rectangular corrugated absorber plate collector, whereas that of flat absorber plate is 64% and 66% in the month of March and April respectively. The average efficiency is 73% and 62% for trapezoidal corrugated absorber plate collector and flat absorber plate collector, respectively.

Chapter 1

INTRODUCTION

1.1 GENERAL

After the oil crisis of the 1970s the renewable energy has enjoyed a genuine global revival. Solar energy is one of the most promising sources of renewable energy. Total energy consumption rate all over the world is increasing day by day because it is directly related to the people and the degree of industrialisation. As the industrialisation of the world progresses, the non-renewable energy reserve is depleting rapidly.

If any nation can increase their GDP then the life style of that nation can be changed. For this reason energy is an indispensable element of the socioeconomic development of a nation. The availability of the sources of energy seems preconditions to sustain development process, skills and techniques for utilizing the energy is also equally important to attain sustainable development (Marsh1994).

Nuclear energy came on the scene after the Second World War. The first large nuclear power station was commissioned during the middle of the last century, and already, nuclear energy is providing a small but significant amount of the energy requirements of many countries (Sukhatme1998). In an industrialised country like the USA, most of the energy requirements are met from fossil fuel, hydroelectric power and nuclear power. Some European countries had successfully innovated techniques matching the potential sources available to them; generation of hydroelectric power plant with water from the mountains or even electricity out of windmills in the coast of the North Sea might be worth mentioning. Apparently availability of both energy and matching technology are interlinked for sustainable development and quality of life.

Non-renewable sources of energy consumption are increasing with respect to time and eventually these sources will be exhausted in future. According to various sources, world's production of fossil fuels and other exhaustible energy bases will last only for a limited period. From environmental point of view, the use of conventional energy sources is destructing the environment day by day. So it is essential to develop methods of diversification of energy sources, reduction of energy consumption and increasing the efficiency in the utilisation of energy.

Solar energy is a very large, inexhaustible source of energy. Approximately $1.8X10^{11}$MW energy received by the earth from the sun in a day, which is many thousand times larger than the present consumption rate on the earth of all commercial energy sources. Ignoring all areas of seas, the amount of solar energy received by the rest of the land area of the earth is $2.0275X10^{13}$kW, assuming eight hours of sunshine a day (Rai 1984).

Solar energy is available in our country and it can not pollute the environment. It is available in adequate quantities in almost all parts of the world. However, there are many problems associated with its use. The main problem is that it is a dilute form of energy. Its radiation flux is low from the technological point of view. Consequently, large collecting areas are required in many applications and these results in excessive costs. Another problem associated with the use of solar energy is that its availability varies widely with time. The variation in availability occurs daily because of the day-night cycle and also seasonally because of the earth's orbit around the sun.

In our country, year round practical data on solar radiation intercepted and converted into useful energy by various means are not available yet. So, there is ample scope of research work for scientist, engineer and interested person for further research and development work.

1.2 OBJECTIVES OF THE PRESENT STUDY

1. a) To record water temperature for a sunny day

   b) To record water temperature for a cloudy day

2. To record the temperature distribution along the depth of the collectors
3. To determine the daily average energy absorbed by the collectors
4. To determine the efficiency of solar water heaters

Chapter 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

In prehistoric time, Iraq using the sun used polished golden vessels to ignite fire. Around 1455 B.C., in Egypt, 'Sounding States' were found, the sound being caused by escaping air that had been heated by the rising sun falling in them. In China, the Han-dynasty (202 B.C.) used concave mirrors to light torches for sacrifices.

In 1855, Gunter proposed the use of utilisation of solar energy. Probably, the first major solar energy was used for a water distillation plant in Chile, built in 1872, covering an area of 4800 m^2 producing 2300 litres of distilled water a day. Shuman *et al.* (1912-13) built the world's largest solar water pump of 37 to 40 kW to pump water from the Nile for irrigation.

Many researchers have done extensive work on flat plate collectors. Hottle, H. C. C. and Woertz, B. B. (1942,1958) studied the performance of flat plate solar heat collectors.

In 1953, Whiller investigated solar energy collection and its utilisation for house heating.

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 made a lot of contributions towards the analysis of the thermal performance (Hottel & Wortz 1942, Hetyxob 1957 and Wiley 1974). Whiller (1965), Simon (1976) and others also presented some indoor test procedures.

Bliss, R. W. (1959) derived all variables influencing the efficiency of a flat plate solar heat collector as a heat exchanger could be combined into a single 'efficiency factor'. These efficiency factors are more or less design constants of the particular collector design, and are only slightly influenced by operating conditions. Consequently, they are extremely convenient for use in accurate design and performance calculations. The full mathematical derivations are presented for several of these efficiency factors for various types of collectors, together with graphical data and examples of their use.

DeSa, V. G. (1964) has done an experiment at Dhaka to utilise solar energy for water heating and for refrigeration. He presented how much solar energy is available at Dhaka. He also presented experimental and theoretical analyse by using two types of flat-plate solar collectors. He used 6-square foot sinusoidal tube-plate collector and 18-square foot corrugated-sheet, flat-plate collector.

The materials used for collectors in decreasing order of cost and thermal conductivity are copper, aluminum and steel. Whiller *et al.* (1964) found that steel pipes are as good as copper pipes. If the temperature difference between the collector and the ambient air exceeds 6.5^0C, one layer of glass cover is justified.

First, built-in-storage type solar water heater is proposed by Tanishita, I. (1964), is considered to be an improvement over conventional collectors because of its reduced overall size, cost, loss of heat etc.. After that the researcher are doing their work all over the world and trying to improve the performance of built-in-storage type solar water heater.

Gupta and Garg (1968) ran a computer model for predicting the thermal performance of domestic solar water heaters, employing thermosyphon circulation between the collector and the insulated storage tank. Absorber plate efficiency factor as computed by the computer in terms of its geometry and material specifications along with its thermal capacity was incorporated in the model. The radiation intensity and ambient air temperature have been harmonically analysed and twelve harmonics have been found adequate as input for the model. Ideal condition of no drain-off during the day was assumed. Proving sets for clear and cloudy weather, comparing the predicted results with the observed values were also shown.

Garg, H. P. (1971) reported the design details of a solar water heater suitable for large, intermittent demands for hot water by hospitals and hotels. It employs a flat-plate collector consisting of a wire-tied aluminium fin of 28 gauge with galvanised iron pipes of 19mm diameter spaced at 10cm centres. The unit is adjusted to give maximum efficiency per unit cost under Indian conditions. The system is fully automatic and heats 600l. of water up to 55^0C in winter months at Roorke.

Chinnappa *et. al.,* (1973) studied pressurised built-in-storage type solar water heater and found that 30-50 gallons of water could be supplied a day at 120^0F (48.89^0C) and the efficiency was 46 percent.

Garg, H. P. (1974) performed an improved solar water heater capacity 90 litres made up of rectangular tank which performs the dual function of absorbing heat and storing the heated water in Joodhpur. He found that the efficiency factor was reaching as high as 70 percent. The year-round performance tests show that this heater can supply water 50^0C to 60^0C in winter and 60^0C to 75^0C in summer (at 4:00 p.m.).

Chauhan and Kadambi (1975) carried out the experiment in four different modes: water circulation with a small pump, natural convection condition, water draw-offs taking place when the water is around 50-60^0C and water flowing continuously past the absorber plate with different flow rates. They found the day-long efficiency of 50%-53% in the first two modes and rise in temperature of 57-50^0C. The average collection efficiency of 64.8% with water heats up from 38.5^0C to 58^0C in the third mode. In the fourth mode the collection efficiency found 71.8%.

Wang Shing-An (1978) proposed an experimental study of corrugated steel sheet solar water heater. He concluded that the flat plate solar collectors are simple solar utilisation equipment, which transfers solar radiant energy to the fluid. They had 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 collector and have 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.

Eggers *et al.* (1979) found single layer of glass required when temperature between air and absorber plate exceeded 6.5^0C, two layers of glass covers required when it exceeded 30^0C and three layers for temperature exceeding 75^0C. Glass wool was most widely used in collectors as insulation materials because of its low thermal conductivity and moderate cost. Plastic foam may be used and can add structural strength when molded integrally between the collector and the collector case. Glass fibre reinforced plastics are used as vases instead of steel sheets, because they are strong, lighter, waterproof, weather resistant and non-corrosive. 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.

Garg, H. P. and Rani, U. (1982) investigated theoretical and experimental studies on a built-in-storage solar water heater, whose absorber plate performed dual function of absorbing the solar energy and storing the heated water. They found its night cooling effect. During the cooling hours, they used insulation cover on the top and insulated baffle plate inside the water tank.

Sokolov *et. al.* (1983) reported that the performance of the rectangular and triangular one with baffle plates was same.

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.

Goetzberger and Rommel (1987) studied solar water heater where water flowing through the copper pipe and absorber plate brazed with the pipe still a costly affair type. The cost of a system is 30% due to the collector itself while 70% is contributed by associated components like extra storage tank, piping, gate-valves, stand, Heat exchanger, electronic control besides installation charges.

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 solar water heater become narrower producing enhanced natural convection and thus resulting in better performance during heating period.

Ecevit *et al.* (1990) carried out a comparative evaluation of the performances of three built-in-storage type SWHs of equal volume. They found the triangular SWH without baffle plate was the most efficient (46%). The rectangular and triangular one with baffle plate heaters was 43% and 40% efficient respectively.

Hamid, M. A. *et al.* (1995) used built-in –storage type solar water heater (BSWH) having flat absorber plate at Dhaka during the month of January, February and March 1992. BSWH can heat 115 litres of water to a temperature of 50^0C absorbing 0.743 kW/m^2 in February and to 61^0C absorbing 0.979 kW/m^2 in March. From February to March energy absorption increased by 32 percent but the water temperature increased by 22 percent. He found the monthly average heat energy absorbed by BSWH was 0.240 kW/m^2 with efficiency of 59 percent in February and 0.270 kW/m^2 with 54 percent efficiency in March. On very clear bright sunny days, the maximum efficiency of 70 percent can be obtained with a mean water temperature of 56^0 C in February and 58 percent efficiency with a mean water temperature of 63^0 C in March.

Rönnelid *et al.* (1996) carried out a test and compared compound parabolic concentrator collector with flat plate collectors.

Akhanda, M. A. R. *et al.* (1997) studied an experimental investigation of the effect of corrugated absorber plate on the performance of collector-cum-storage solar water heater at Dhaka during the months of November, December 1994 and January, February, and March 1995. This investigation was carried out to compare performances between two collector-cum-storage type solar heaters one having flat absorber plate (CSWHF) and the other having corrugated absorber plate (CSWHC). Both the collectors were 114 litres in capacity. It was starting from 8 AM to 6 PM the collector-cum-storage flat plate type solar water heater can heat 114 litres of water to a temperature of 32^0 C absorbing 0.211 kW/m^2 in November, 25^0 C absorbing 0.106 kW/m^2 in December, 26^0 C absorbing 0.212 kW/m^2 in January, 32^0 C absorbing 0.318 kW/m^2 in February and to 41^0 C absorbing 0.371 kW/m^2 in March. The collector-cum-storage corrugated type solar water heater can heat 114 litres of water to a temperature of 32.5^0 C absorbing 0.318 kW/m^2 in November, 26^0 C absorbing 0.212 kW/m^2 in December, 27^0 C absorbing 0.318 kW/m^2 in January, 33^0 C absorbing 0.424 kW/m^2 in February and to 42^0 C absorbing 0.477 kW/m^2 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.

Amer, E. H. *et al.*(1997, 1998a, 1998b, 1999) reported extensive research work on solar water heaters by using transient method, dynamic method and dynamic method with variable weather conditions.

Garg, H. P. and Adhikari, R. S. (1998) developed a computer simulation model for predicting the transient performance of a conventional photovoltaic/thermal (PV/T) air heating collector with single and double glazing configurations. It has been observed that the hybrid PV/T systems are interesting with respect to system efficiencies; however, their adaptability in future must be weighed in terms of cost effectiveness of these systems.

Tripanagnos, Y. *et al.* (2000) studied flat-plate collector with glass cover and without glass cover with colour black, blue, red and brown. He found the glass cover with black colour absorber plate was the most efficient.

Akhanda, M. A. R. *et al.* (2001) carried out an experimental investigation to compare the performances between two collector-cum-storage type solar water heaters having flat absorber plate (CSWHF) and the other having vee corrugated absorber plate (CSWHC). Both collectors of 114 litres of capacity, 1.25 m^2 of collector projected surface area and 9.2 cm in average depth studied at Dhaka during the months of November 1994 to March 1995. The CSWHC heated water to a maximum temperature of 29, 28.2, 28, 31 and 42^0 C in absorbing energy of 0.318, 0.282, 0.312, 0.310 and 0.311 kW/m^2 and the CSWHF heated water to a maximum temperature of 28, 27, 26.8, 30 and 41^0 C in absorbing energy of 0.212, 0.21, 0.212, 0.213 and 0.211 kW/m^2 in the months of November, December, January, February and March respectively. The average efficiency of CSWHC was found to be more than that of CSWHF by 10% in November, 17% in December, 23% in January, 13% in February and 22% in March.

2.2 SCOPE OF PRESENT WORK

Experimental investigation of the performance characteristics of the three collector-cum-storage type solar water heater having rectangular corrugated absorber plate, trapezoidal corrugated absorber plate and flat absorber plate provide the present work. The test was carried out in the month of March, April, July and August 2001 at Dhaka. The results of the experimental study were compared with available information in the literature.

Available technologies were applying for the experimental investigation. This is not new but its a kind of different work in a sense of corrugated sheet is used to absorber plate of the collector. Corrugated sheet has good heat transfer characteristics and can reduce the overall cost.

Lot of research work have been carried out all over the world on flat plate collectors but limited research work on the corrugated absorber plate collector solar water heater has been done. So, the experimental data are quite inadequate for analysing the performance characteristics of these collectors.

In future, solar energy is expected to play a vital role in the energy sector. For this reason the present study on corrugated absorber plate solar water heater and flat absorber plate solar water heater will be fruitful in future applications.

Chapter 3

THEORETICAL ASPECTS

3.1 SOLAR ENERGY COLLECTIONS

Continuous radiation of heat generated by 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:

a) Natural collections of solar energy such as wind, waves etc., and

b) Technological Collections of solar energy such as photovoltaic, thermal conversions.

3.1.1 NATURAL COLLECTIONS OF SOLAR ENERGY

Waves, winds, biological conservation are some examples of natural collections of solar energy. About 71% of the world's surface is covered with oceans, which provide tremendous storehouse of solar energy. The ocean holds the energy as sensible energy of water as well as wave energy. Utilisation of wind power has been widespread since prehistoric days. The energy content of the wind increases as the third power of the wind velocity and hence wind power installations is economical where unidirectional winds of sufficient speed is available. In biological conversion the solar energy is present in the form of vegetables, plants, animals, organic fuel, fossil fuel etc.

3.1.2 ARTIFICIAL COLLECTIONS OF SOLAR ENERGY

There are two methods of artificial collections. These methods are

a) Photovoltaic conversion method and

b) Thermal conversion method.

In photovoltaic conversion method, the solar energy is converted directly into electricity by means of photocells with efficiency ranging between 15 and 20 percent. The technology is well developed but its large-scale application is absent due to high cost of photocells.

In thermal conversion method, the solar radiation is collected as heat energy employing different techniques of collector technology like solar water heater, solar cooker, solar ponds, stills, etc. Thermal conversion technology is discussed in details under the heading of solar collectors.

3.2 USEFUL SOURCES OF ENERGY

People all over the world need energy and the energy consumption rate is increasing day-by-day for their existence and better living. At the primitive stage man required energy in the form of food (Sukhatme1998). Generally people are trying to improve their technology and life style. In the 1870s, after the invention of internal combustion engine; fossil fuels i.e., oil and natural gas began to be used extensively as a non-renewable source of energy. World's fossil fuel reserves are limited in quantity and have adverse effect on environment causing air pollution. The world reserve of natural gas and coal will last limited period of time. Therefore, as these non-renewable sources are consumed the mankind must turn its attention to longer-term, permanent type of energy sources. The two most significant such sources are nuclear energy and solar energy.

The first nuclear power station went into operation in USA and subsequently the growth in installed capacity was spectacular (Sukhatme1998). It requires advanced technology and costly means for its safety and reliable utilisation and many have undesirable side effects. The disposal of radioactive waste is another problem. So the nuclear power station installed capacity growth rate is projected to be less than two percent in the nineties. Though the reserve of nuclear fuel is limited, so it is clear that a difficult situation will arise after a certain period of time if the present growth rate continues to use uranium as a nuclear fuel (Sukhatme1998).

So, solar energy shows the promise of becoming a dependable energy source, as it does not require any highly specialised technique for its wide spread use. In addition, it appears to be pollution free.

Modern scientific research in the utilization of solar energy commenced in 1855 when G. Gunter, an Australian invented a solar boiler using mirrors. In 1876 an American inventor, John Ericsson who invented several types of hot air engines, visualised that at some time in the near future, a chain of solar power stations across North Africa, Middle East, India, Australia and Central America would be set up (Duffie & Beckman 1991). In the later half of the 19th century and during the first half of last century, progress in the field of energy research was fairly slow. This was mainly due to availability of cheap fossil fuels.

Solar energy research was revived in 1940 when Godfray Cobot left a large sum of money for research projects at the Massachusetts Institute of Technology. During the recent energy problem, research in the utilisation of solar energy has gathered considerable momentum, especially in industrialised countries such as USA, CIS, France, Australia, and Canada. The near future will certainly show some major break through in solar energy technology.

Solar energy received by the earth surface is varied from few hundred hours per year as in the Northern countries and the lower part of South America, to four thousands hours per year as in the case in most of the Arabian Peninsula and the Sahara desert. To estimate 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 $20X10^6$ km^2 with average solar insolation of $583.30W/m^2/day$ (Hamid1993). Assuming eight hours of sunshine in a day, total amount of energy produced in deserts with a recovery rate of only 5 percent is about 60 times of the estimated world energy demand in the year 2000 (Sukhatme1998). 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. Now-a-days, as energy can be stored by mechanical or electrical storage devices, this old argument is no more valid.

3.3 SOLAR COLLECTORS

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

a) Flat-plate collectors

b) Concentrating or Focusing collectors and

c) Intermittently turned concentrating collectors

3.3.1 FLAT-PLATE COLLECTORS

Flat-plate collectors operate without concentration of solar radiation. It is simple, technically feasible and economically viable for obtaining temperature below 100^0C. 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 radiation and convection heat loss from the absorber plate to the atmosphere one or two sheets of glass or polythene are placed over the absorber. This type of collectors may further be subdivided into three classes. These are

a) The plain sheet collectors

b) The plain sheet and tube type collectors

   i) Tubes bonded above absorber plate collectors

   ii) Tubes in-line with absorber plate collectors and

c) 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 (Whiller1964). In plain sheet and corrugated sheet collectors, absorbed solar energy is transferred to fluid as sensible heat through direct contact and hence, from the viewpoint of heat transfer, the advantage is evident.

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

a) Collector plate and storage tank
b) Surface covering
c) Fluid
d) Insulation and
e) Casing.

3.3.2 CONCENTRATING OR FOCUSING COLLECTORS

Concentrating type collectors are 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. The absorber may be convex, flat or concave and may be covered or uncovered. French solar furnace at Odeillo, Trombe has achieved temperature over 3000^0C (Trombe1973). 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.

3.3.3 INTERMITTENTLY TURNED 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 focusing devices.

3.4 POSSIBILITY OF SOLAR THERMAL ENERGY IN BANGLADESH

Bangladesh is one of most over populated country all over the world. It's total area 147570 km^2 and population of about 130 million with approximately 876 persons per square kilometer. But its position is one of the lowest in terms of commercial fuel consumption.

All over the world industrialisation is increasing day by day. So, the demand of energy consumption is going up this factor continuously aggravate the energy scene creating serious problem in the energy sector and the future economic development of the nation. In that case, it is necessary to develop and establish new primary energy source, Bangladesh will face a great problem because we have no huge amount of energy sources in our country. Solar energy can play a vital role to explore alternative energy sources.

Statistical review of world energy (Rapp 1991) estimated that the major percentage of energy consumed by the developed world. Obviously, the consumption of energy in Bangladesh is very low. World Bank declared 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 utilisation of available energy resources in the country.

In Bangladesh about two million tons of crude oil and petroleum products are imported 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 irrigation pumps. Diesel is also used in engines for rice husking machines, power tillers and country boats. Above all, most of the mechanized river crafts 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 day by day and the world is to face a massive fuel crisis in the near future (Sukhatme1998). The current projected demand in energy supply may not be sufficient to support the desired level of economic growth of the developing countries as well as for the developed countries in the years ahead. This becomes evident in Niebaus and Williams' illustration (Wohlmeyer1987) that fossil fuels are declining rapidly and the excessive dependency on non-fossil energy sources may occur. Decline of fossil fuels cause its 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 capability to purchase fuels for meeting their future crisis. Sudden increase in oil price in the 1970's resulted in a perceptible fall of economic growth in developed countries (Wohlmeyer1987). 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 economic growth. Apart from economic stress, use of diesel generally pollute the environment by emitting carbon dioxide, carbon monoxide etc. which creating green house effect, acid rains and so forth. For this point of view diesel substitution is necessary.

Bangladesh, located between $20^0 26'$ and $26^0 20'$ north latitude and $80^0 01'$ and $92^0 24'$ east longitude, is endowed with an abundance of sunshine during most of the year and blessed with sufficient amount of non-depletable resources of solar energy. The average incident rate of solar energy in Bangladesh was about 3000 times its consumption rate (Hossain1980).

The monthly average total solar radiation in Dhaka is 0.376 kW/m^2 and in Bangladesh 0.365 kW/m^2. The maximum monthly average radiation in Bangladesh is found to be 0.373 in April in Dhaka and 0.292 in January in Jessore (Helali1985).

The yearly total diffused radiation in Dhaka is considerable. It is about 72 percent of the total radiation (Helali1985). 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 countryman will have to increasingly depend upon renewable resources of energy. Apart from its free availability 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 source of energy, and all forms of energy in 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 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.

Chapter 4

EXPERIMENTAL CONDITIONS AND TEST PROCEDURES

4.1 GENERAL

Figures 4.1(a) shows the schematic diagram of the experimental apparatus and measuring devices. Figures illustrate three collector-cum-storage type solar water heaters in which one absorber plate is flat and another two is corrugated absorber plate and measuring equipment (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, and 0.725cm. The larger pipe diameter of the probe is 1.905 cm and smaller pipe diameter is 4mm. These thermocouples are connected to the Digital Milivoltmeter through the selector switch. The Digital Milivoltmeter is used to measure water temperature in terms of e.m.f. generated in the thermocouples. Finally these e.m.f.s are converted into temperature with the help of K type New Reference Tables.

4.2 FABRICATION OF A COLLECTOR-CUM-STORAGE TYPE CORRUGATED SOLAR WATER HEATER AND FLAT ABSORBER PLATE SOLAR COLLECTOR

Figures 4.1(a) to 4.5 illustrate, in details, the collector-cum-storage type solar water heater using corrugated plate as absorber and CSWHF. The complete description of the corrugated type solar water heater and CSWHF fabrication are given below:

4.2.1 Corrugated Absorber Plate Solar Collector and Flat Absorber Plate Solar Collector

The solar collector and the storage tank were built in one unit and worked together. External dimensions of the collectors are 155.5cm X 109.5cm X 31cm and a capacity 125 litres each. 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 short wave solar radiation. The wooden frame made by 'Gorjon Wood', supports the plate and to avoid leakage gaskets are used and the plates are tightened with nuts and bolts as illustrated in fig. 4.3(a). All the collectors placed on the mild steel angle frame (3.81cm X 3.81 cm X 0.375 cm) and have the provision of setting the collectors at 17.5 to 45 degree angle of inclination. A probe containing five 35 SWG Chromel-Alumel thermocouples are installed in each SWH for measuring water temperature at different depths inside the collectors as shown in fig. 4.3(b) and 4.4. Two G.I. pipes of diameter 19.05mm and length 45.72cm were fitted one for coldwater inlet at the front and the other one for hot water outlet at the back-side of the collector per unit.

The performance of the solar water heaters mainly depends on the collector design. So, it is necessary to take more care for the design of the collector. If solar collector absorbs the solar energy properly and mitigate losses then the efficiency of the solar water heater high up.

4.2.2 Absorber Plate

Absorber plate as shown in fig. 4.2 absorbs the incoming solar radiation and heats up 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^0C 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 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 cheaper 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 whereas cost of copper is high. So corrugated sheet is used in the absorber plate. 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. 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. A 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 radiator. These 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, that paint can serve well.

4.2.3 Glass Cover Plate

Transparent cover plate, as shown in fig. 4.3 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 will be better if it is also opaque to the longer heat wave lengths that are being reradiated by the absorber plate. The functions of glass cover are to trap heat. This is always better to use low iron content glass to reduce the absorption of solar radiation. One sheet of 0.32cm glass transmits about 82-90 percent of the visible light striking it. Locally made glass has high iron content and this leads to significant absorptions of solar radiation. For this reason 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 in flat plate collectors. With this glass up to 92 percent of the solar radiation may be transmitted. Generally, the use of local window glass is cheaper and with its high absorption of solar radiation. Here 4mm thickness window glass is used. To reduce heat losses from the collector by radiation and convection to a minimum value, a glass cover with optimum air gap of 25.4 mm is used as per work of Marsh, (1994).

The question may arise that why plastic sheet was not used although it is a cheap material. The following table 4.1 gives the answer.

Table 4.1: 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	0.08

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

Plastics are affected by continuous exposure to solar radiation. Effects such as 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 radiations possible as well as to reduce heat losses from the collector by re-radiation and convection to a minimum value, a glass cover of 155cmX 109cmX4mm with optimum air gap is used. The glass rests on a wooden frame, made of 'Gorjon' of 155cmX109cm and is secured by wooden batten of 2.54cmX156cm, screwed with the wooden box, as shown in fig. 4.4(b).

4.2.4 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.

Glass-wool is used due to its low thermal conductivity of 0.041W/mK and of moderate cost, was used as insulation having thickness of 10cm at the bottom surface and 25.4mm at sides.

4.2.5 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 wood cutting worms does not easily attack 'Pine' wood. The lower portion (Fig. 4.5) contains space for insulating material. The box is so designed that collector assembly can easily be detached. The external dimensions of the box are 155.5cmX109.5cmX31cm.

4.2.6 Steel Stand and Structure

The supporting steel structure for the heaters consists of a frame made of angle iron bar. The corrugated collector-cum-storage type solar water heaters and flat collector-cum-storage type solar water heater are held rigidly and it has the provision of setting the collector at any desired inclination between 17.5 and 45 ^{0} manually, as shown in the fig. 4.2.

4.3 TEST PROCEDURES AND MEASUREMENTS

Calibration of thermocouples was carried out in a hot water bath for temperatures up to 100^{0}C and in a muffle furnace up to a temperature of 200^{0}C. The readings were compared with a precision thermometer. The indicated e.m.f. was compared with the tabulated values for Chromer-Alumel thermocouples of British Standard No. 4938, part 4:1973 and 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 were used to obtain temperature distribution. These temperatures and the initial water temperature were recorded every hour from 8 AM to 5 PM during the experimental period. The results obtained to a maximum error of $\pm 0.2^0$C at a maximum operating temperature of 60^0C.

4.4 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 by calculator. The results and discussion are described in Chapter-5. The working formulae and sample calculations are provided in Appendix-A.

Chapter 5

PERFORMANCE ANALYSIS OF THE COLLECTORS

The test was done over one hour interval. Fresh water was introduced in to the collectors at 8 AM and data were collected up to 5 PM. Inlet water temperature and water temperature at different section were measured and final mean temperature of water in the collector was taken for calculations. Solar insolation was measured by the pyranometer.

The collector was placed south facing at an angle of inclination 23.5^0, the latitude of Dhaka , so that a perpendicular beam of sun rays falls on the absorber plate.

Chapter 6

RESULTS AND DISCUSSIONS

Test was carried out for studying performance characteristics of three collector-cum-storage type solar water heaters, one having flat absorber plate and other two having corrugated absorber plate. The experiment had been conducted in two phases, first phase was conducted from March to April, 2001 at Dhaka in between rectangular corrugated absorber plate and flat absorber plate. And second phase experiment was conducted during July and August, 2001 in between trapezoidal corrugated absorber plate and flat absorber plate at Dhaka. All the collectors were filled with fresh water at atmospheric temperature at every morning and readings were taken on hourly basis until 5 PM. Results are presented graphically from figures 5.1 to 5.36.

Fig. 5.1 to 5.23 show the mean water temperatures on the basis of calculation. It is observed from these figures that as the ambient temperature increases the mean water temperature also increases and reaches maximum value at around noon. In the afternoon both water and ambient temperature decreases at almost the same rate. The mean water temperature increases at a faster rate from 8 AM to 1 PM because the heat energy absorbed by water during this period is faster than that absorbed by the collector after 1PM. From 8 AM to 5 PM the average ambient temperature varies from 20^0C to 34^0C in March, 20^0C to 36^0C in April, 22^0C to 34^0C in July and 21^0C to 35^0C in August. Comparatively April is hot and clear than any other months. During the experimental period rectangular absorber plate collector-cum-storage type solar water heater can heat 125 litres of water up to a mean temperature of 69^0C in the month of March and 72^0C in the month of April at 13:00. And flat absorber plate collector-cum-storage type solar water heater can heat 66^0C and 63.5^0C for the month of March and April, respectively at the same period. The trapezoidal absorber plate collector-cum-storage type solar water heater is heat up the water from 61^0C to 66^0C in the month of July and August whereas flat absorber plate can heat up to 57^0C and 61.5^0C respectively. But in a cloudy day rectangular plate collector gain in temperature 12^0C higher than ambient air temperature and flat plate collector can heat 9.2^0C higher in the month of April.

Temperature distribution of water along the depth of collectors are shown in figures 5.24 to 5.28.the water temperature of the collectors decrease with the increase of the depth of water inside the collector. First probe shows the highest temperature and the bottom probe record the lowest temperature. We calculated the mean temperature of the collector. Upper portion of the water is in close contact with absorber plate so the temperature is higher.

Figure 5.29 shows the daily average heat energy absorbed by the rectangular collector-cum-storage type solar water heater in the month of March and April 2001. Solar energy absorbed by the collector is increased up to 1 PM then the energy collection rate is decreased. The figure indicates that the daily average energy absorbed by the rectangular plate collector varies from 359.4 W/m^2 to 411.35 W/m^2 in March and 373.2 W/m^2 to 417.6 W/m^2 in the month of April.

Comparison of daily average heat energy absorbed by the CSWHCR and CSWHF in the month of March 2001 is shown in figure 5.30. From this figure it is clear that the average energy absorbed by CSWHCR is higher than CSWHF. These values vary from 359.4 W/m^2 to 411.35 W/m^2 for CSWHCR and 264 W/m^2 to 298.7 W/m^2 for CSWHF.

Fig. 5.31 and 5.32 represent comparison of the daily average energy absorbed by the CSWHCT and CSWHF for the month of July and August. For the CSWHCT varies the values from 188.63 W/m^2 to 285.25 W/m^2 in July and 185.6 W/m^2 to 249.15 W/m^2 in August and by the CSWHF varies the values 153.17 W/m^2 to 255.5 W/m^2 in July and 148.81 W/m^2 to 211.2 W/m^2 in August.

The daily average efficiency of the CSWHCR in the months of March and April 2001is depicted in figure 5.33. During the month of March efficiency variation is higher than in the month of April. Efficiency varies from 63% to 83% in the month of March whereas in the month of April it varies from 76% to 85%.

For performance comparison, the efficiencies of the present built-in-storage type solar water heater and that of Murad (1995) for sinusoidal absorber plate are considered only in the month of March shown in figure 5.34. The figure indicates that the monthly average efficiencies of SWHs are 64, 76, and 73% for flat, rectangular, and sinusoidal corrugated absorber plates, respectively. Therefore, the efficiency of CSWHC is more than that of flat plate collector.

Figure 5.35 and 5.36 indicate the performance comparison between CSWHCT and CSWHF during the month of July and August. It is clear from the figures that the average efficiency of CSWHCT varies from 63.3% to 81.5% and 62.9% to 75.5% in the month of July and August respectively. On the other hand for CSWHF these values varies from 51.4% to 73% in the month of July and 49.2% to 64% in the month of August.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

From the investigations the following conclusions can be drawn:

i. The water temperature of the CSWHCR is 5.5^{0}C and 6^{0}C higher than the CSWHF in the month of March and April, respectively. And maximum water temperature for CSWHCT is 4^{0}C and 4.5^{0}C higher than CSWHF for the month of July and August, respectively.

ii. The average maximum temperature of CSWHCR and CSWHCT at a cloudy day is found to be 2.8^{0}C and 2.7^{0}C higher than that of the flat absorber plate, respectively.

iii. Maximum water temperature of the solar water heaters reach at 13:00. Maximum water temperatures are found to be 69 ^{0}C and 72 ^{0}C for rectangular absorber plate and 66 ^{0}C and 63.5 ^{0}C for flat absorber plate for the months of March and April and 61 ^{0}C and 66 ^{0}C for the trapezoidal absorber plate and 57 ^{0}C and 61.5 ^{0}C for flat absorber plate during July and August respectively. The average temperature for corrugated absorber plate is always higher than flat absorber plate.

iv. The daily average heat energy absorbed by the rectangular corrugated absorber plate varies from 359.4 to 411.35 W/m^2 in March and 373.2 to 417.6 W/m^2 in April. And by the trapezoidal corrugated absorber plate varies from 188.63 W/m^2 to 285.25 W/m^2 in July and 185.6 W/m^2 to 249.15 W/m^2 in August. Lastly, the flat absorber plate collect 264 W/m^2 to 298.7 W/m^2 in March, 153.17 W/m^2 to 255.5 W/m^2 in July and 148.81 W/m^2 to 211.2 W/m^2 in August.

v. On a sunny day the maximum temperature and efficiency is higher than a cloudy day for corrugated and flat absorber plate.

vi. Average energy absorbed by the CSWHCR is 23 percent higher than the CSWHF and the CSWHCT is 18 percent higher than the CSWHF. On the other hand, the daily average efficiency of the CSWHCR is found to be about 12% higher than that of CSWHF and the efficiency of CSWHCT is 11% larger than that of flat absorber plate collector. The efficiency of corrugated type collector is more than that of flat plate collector.

7.2 RECOMMENDATIONS

The following recommendations are put forward on the basis of the experience gained out of this research and concerning solar collectors are consider worth recording here for subsequent investigations.

i. The year round performance characteristics of the flat plate and corrugated absorber plate type solar water heaters should be studied simultaneously.

ii. It should be necessary to study the effect of per hour tilt angle on the performance of the collectors.

iii. Transparent material effects on the performance characteristics of the flat plate and corrugated absorber plate type solar water heaters.

iv. The performance characteristics of the flat plate and corrugated absorber plate type solar water heaters for various depths of the collectors.

v. The performance characteristics of the flat plate and corrugated absorber plate type solar water heaters for various sizes of the collectors.

vi. Comparison of performances between the experimental and theoretical values should be studies.

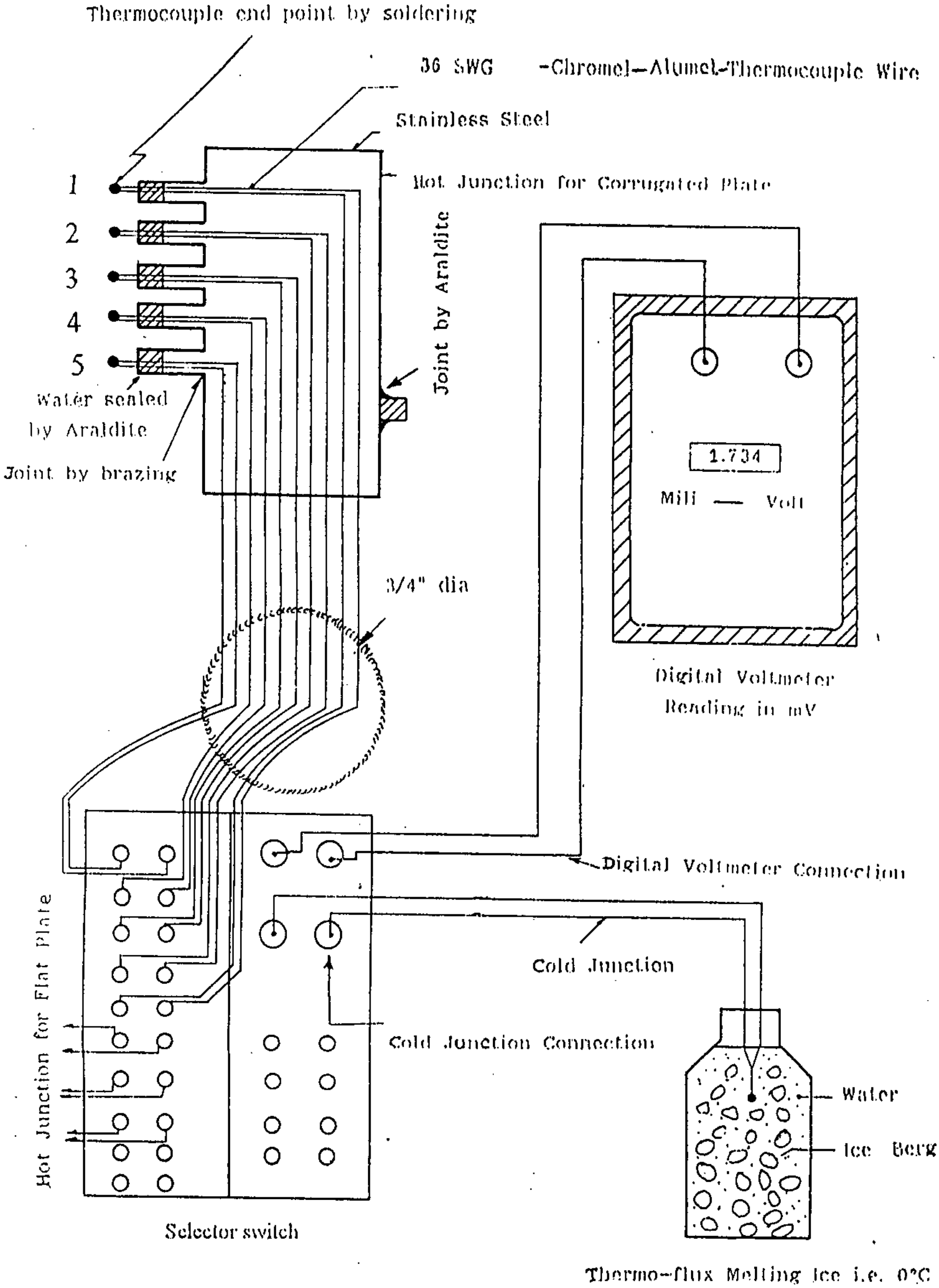

Fig. 4.1 (a) Details of Temperature Measurements Instrument.

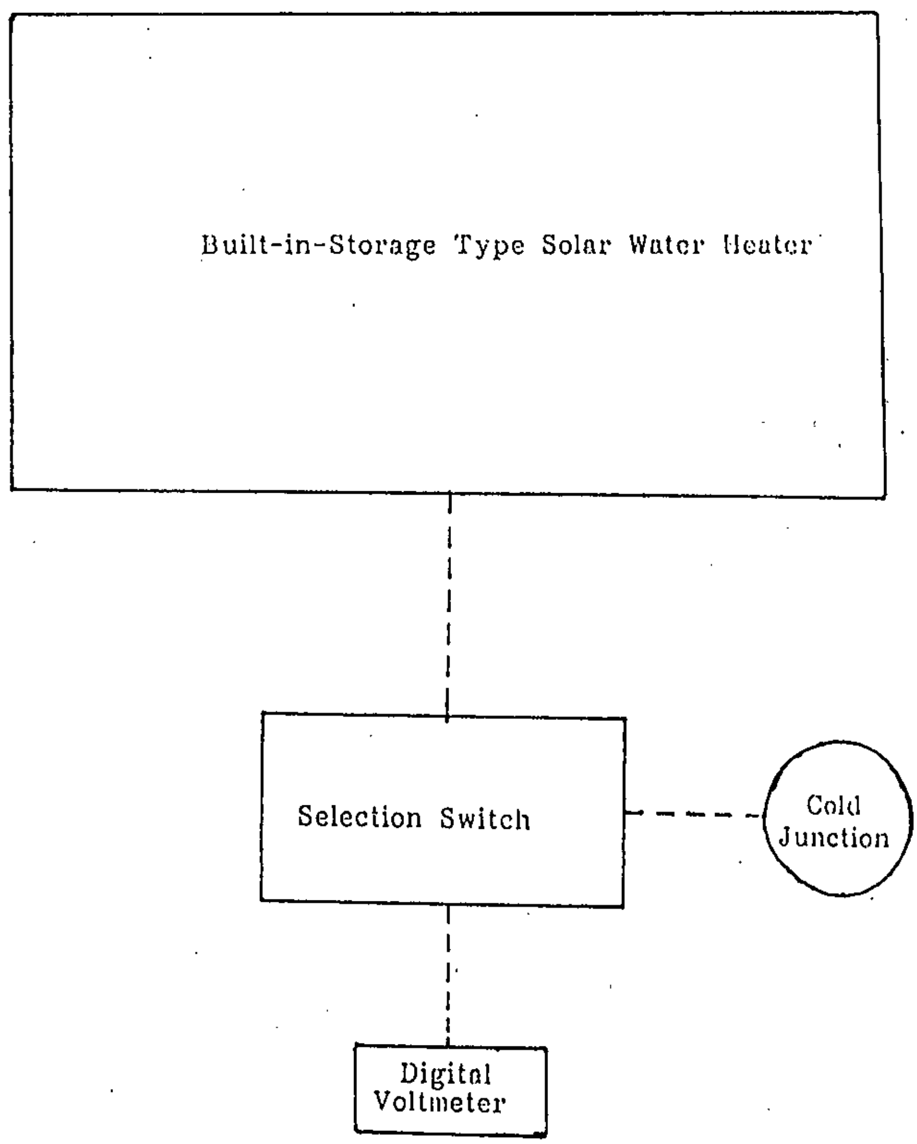

Fig. 4.1 (b) The Schematic Diagram of Experimental Set-up.

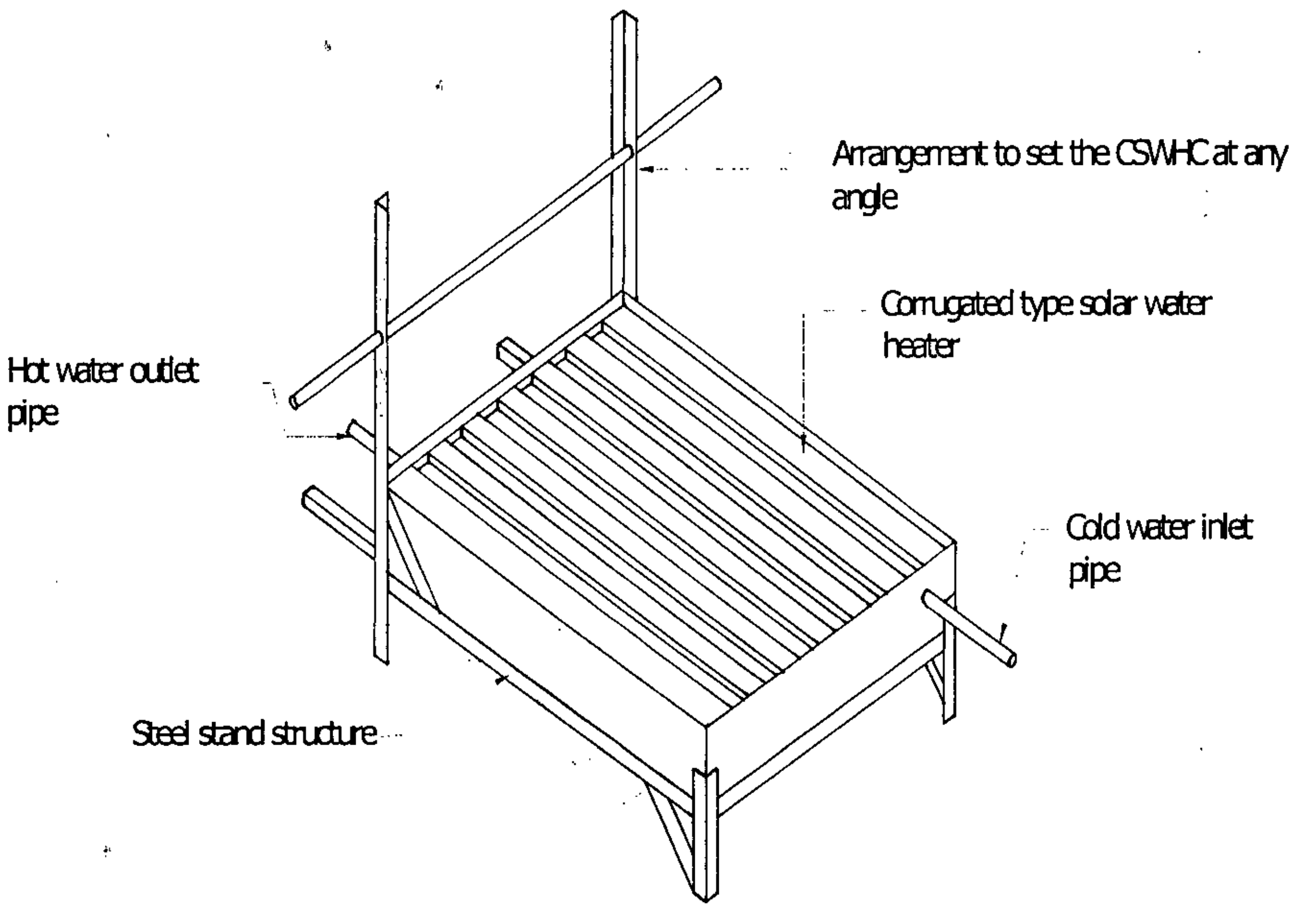

Fig. 4.2 (a) The Schematic Diagram of CSWHCR and Steel Stand Structure

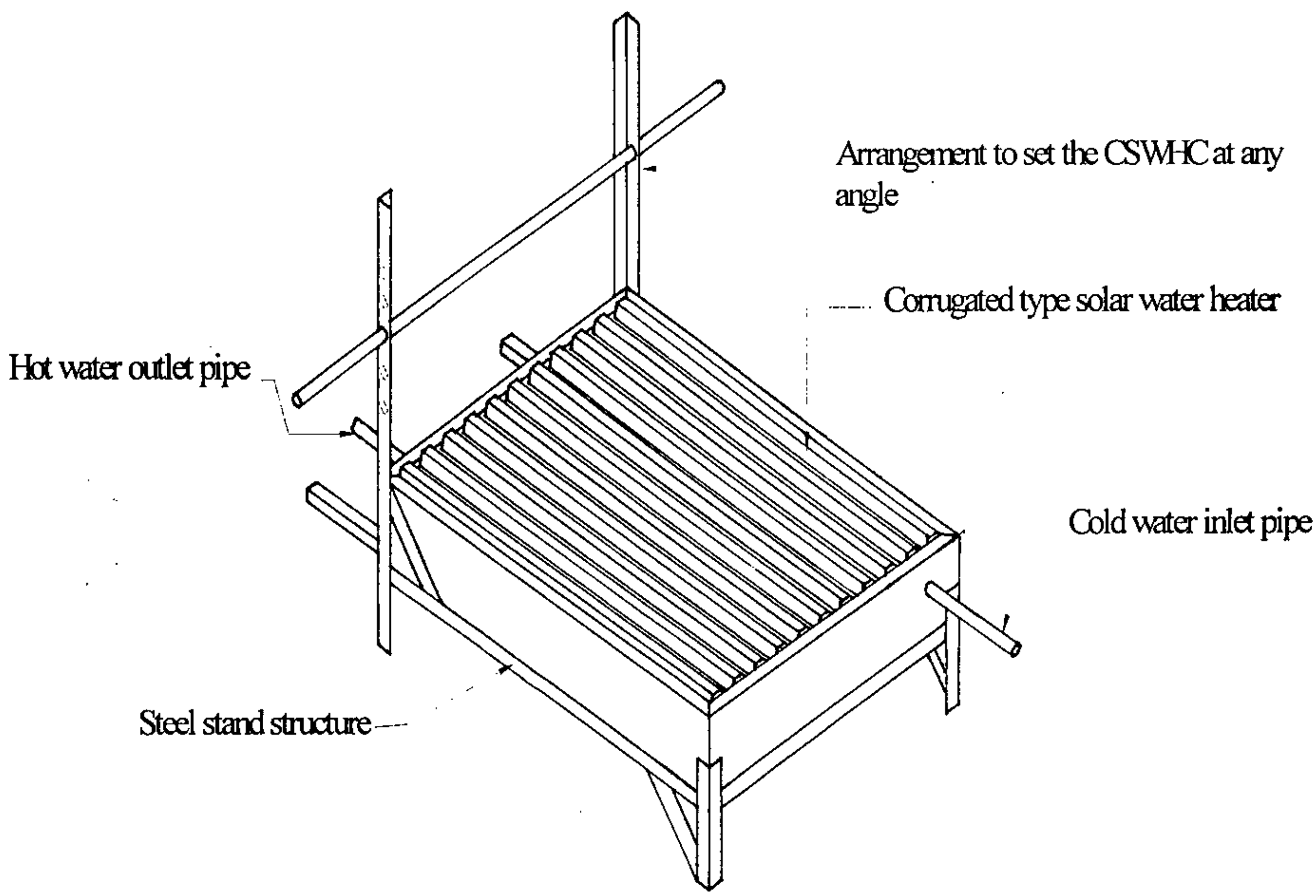

Fig. 4.2 (b) The Schematic Diagram of CSWHCT and Steel Stand Structure

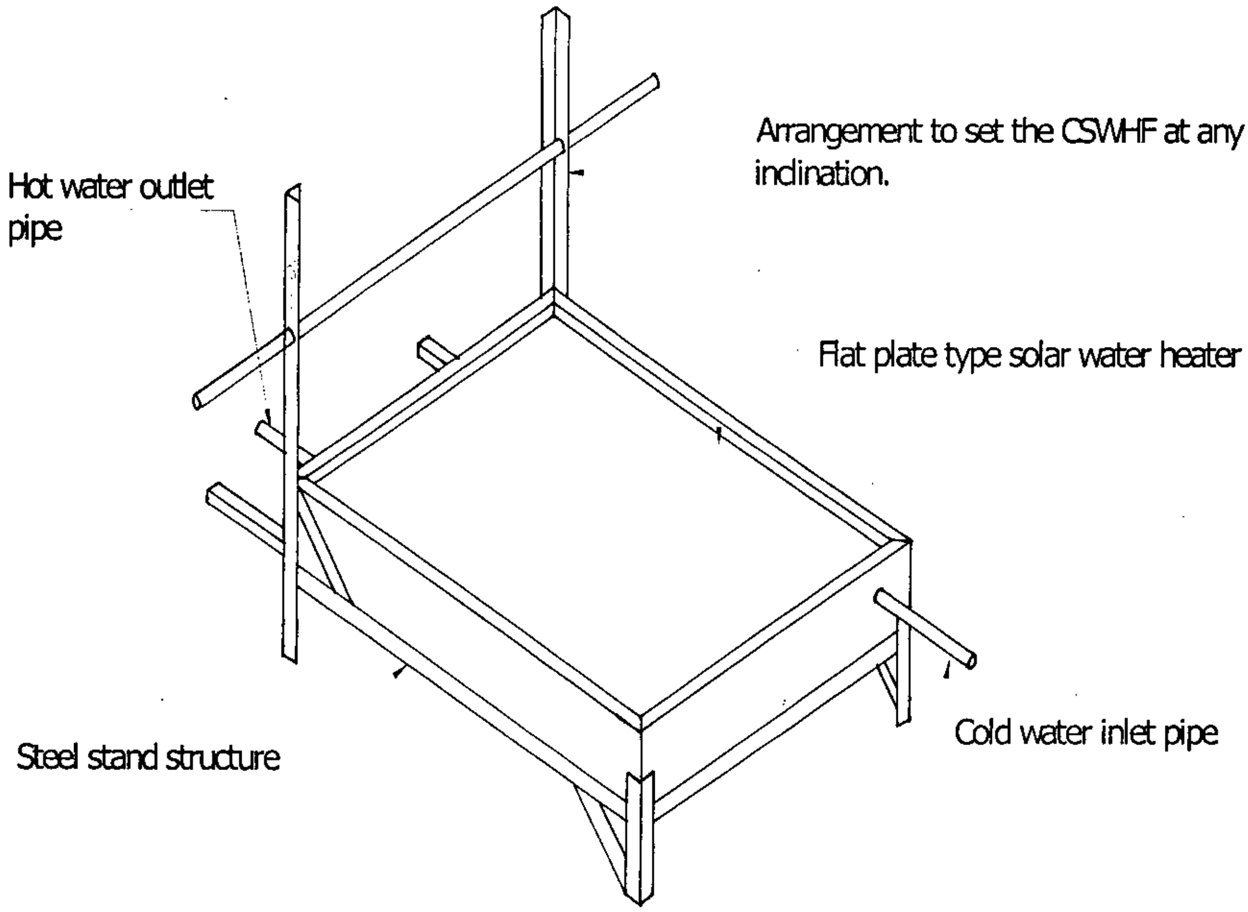

Fig. 4.2 (c) The Schematic Diagram of CSWHF and Steel Stand Structure

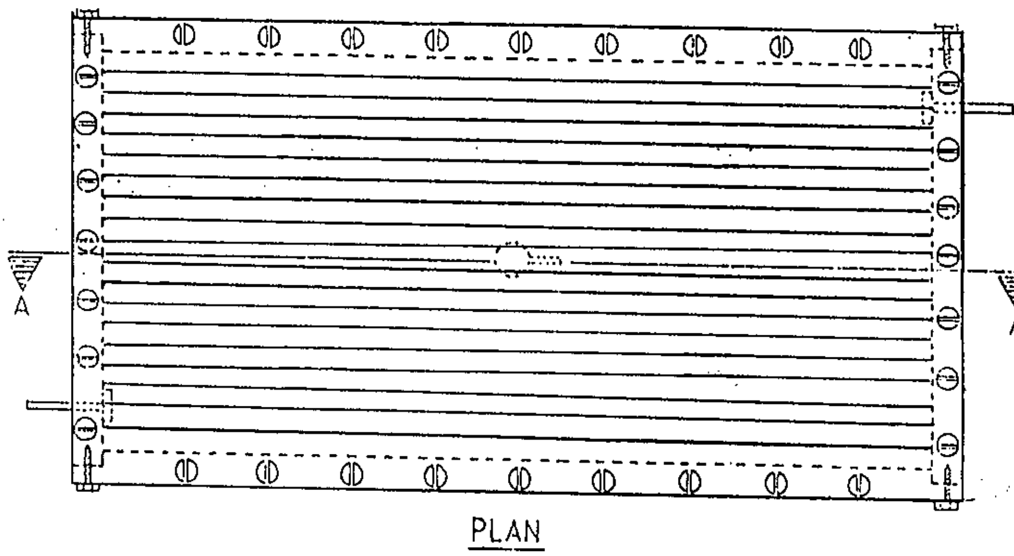

Fig. 4.3 (a) The Plan View of CSWHCR

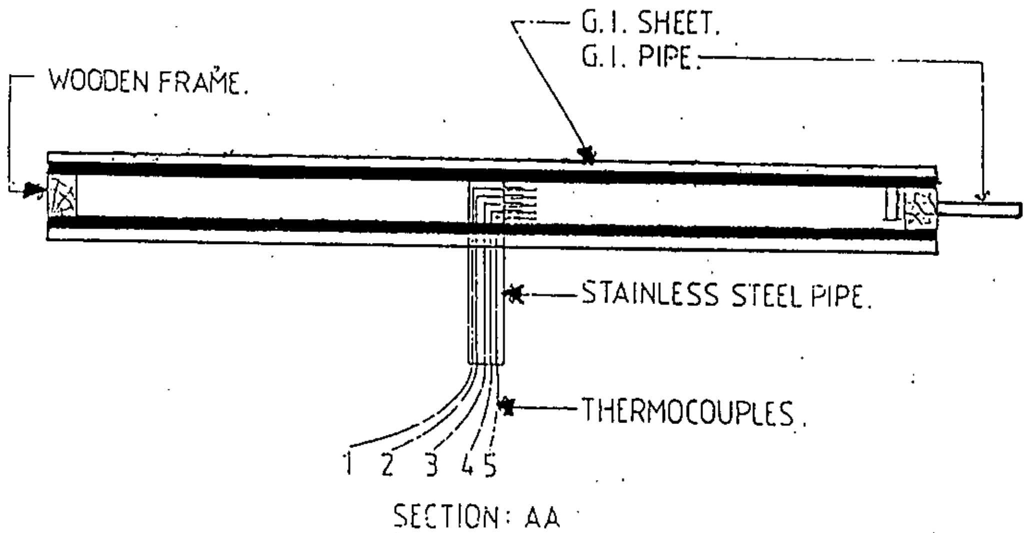

Fig. 4.3 (b) X-Sectional View of CSWHCR Illustrating the Set-up of Thermocouples.

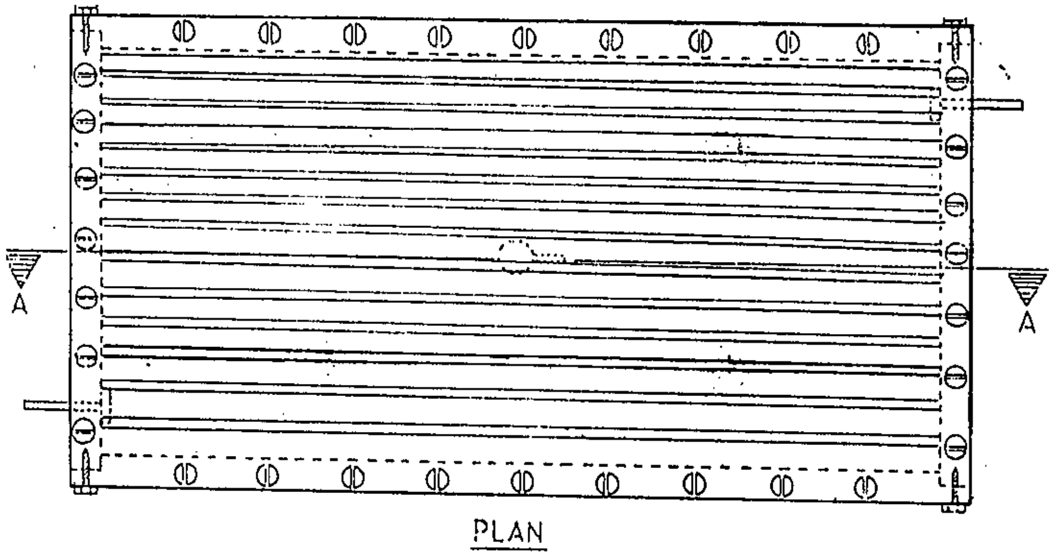

Fig. 4.3 (c) The Plan View of CSWHCT

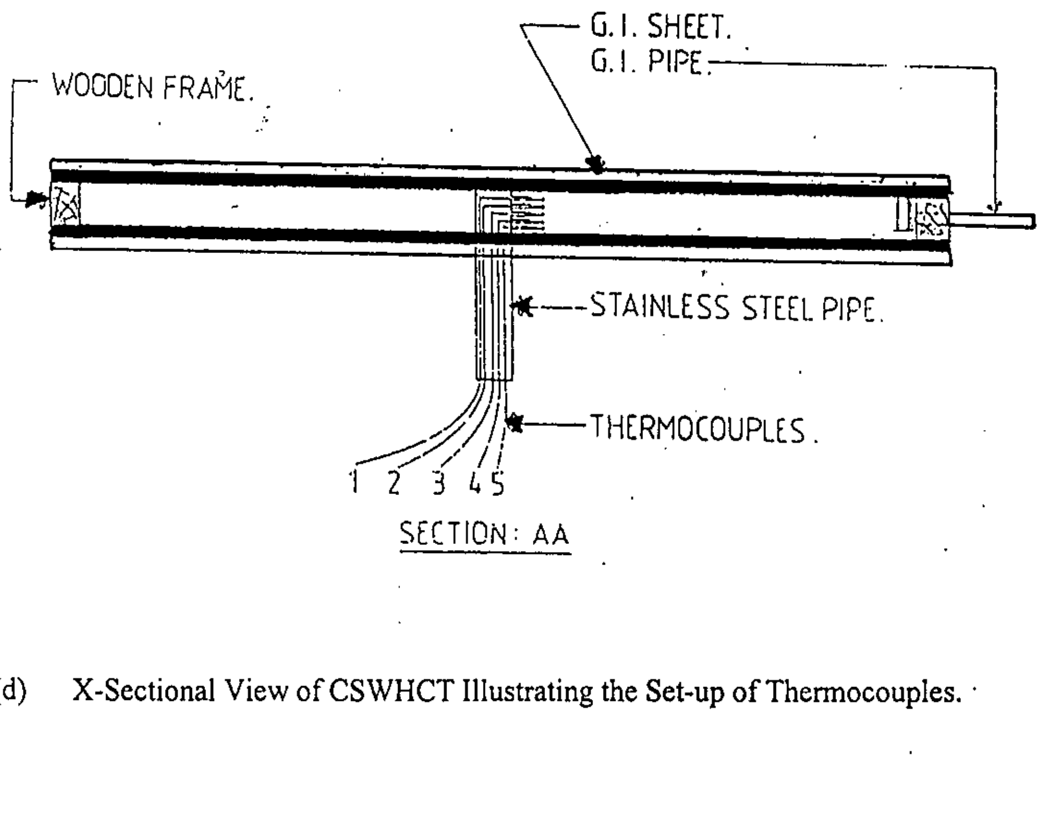

Fig. 4.3 (d) X-Sectional View of CSWHCT Illustrating the Set-up of Thermocouples.

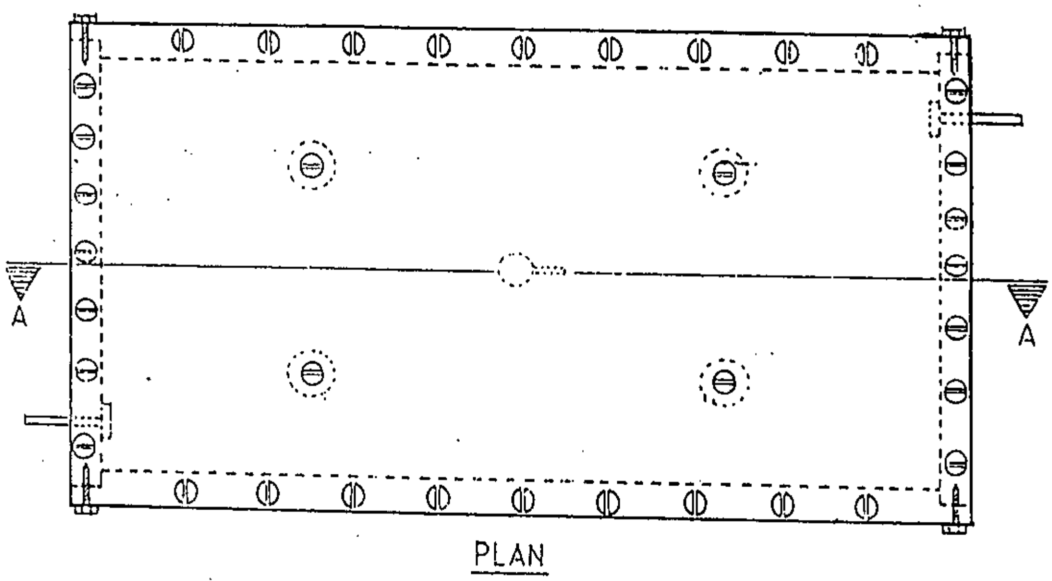

Fig. 4.3 (e) The Plan View of CSWHF

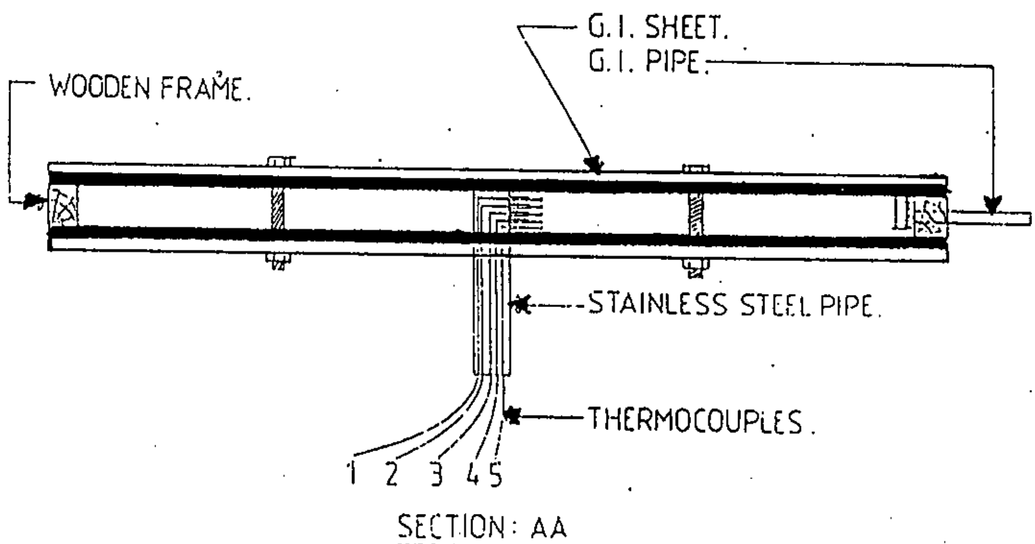

Fig. 4.3 (f) X-Sectional View of CSWHF Illustrating the Set-up of Thermocouples.

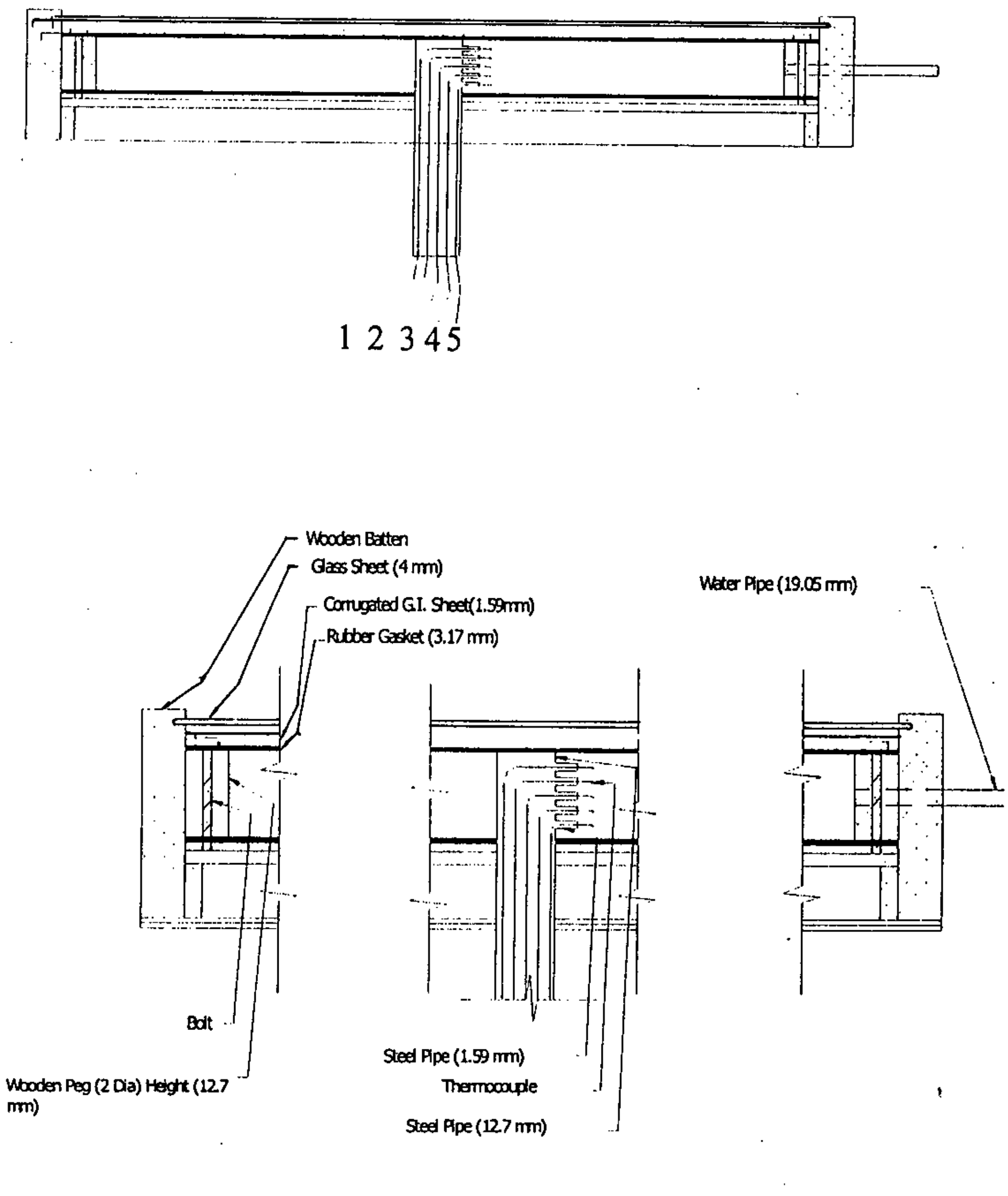

Fig. 4.4 (a) Cross sectional View of CSWHCR Illustrating the Interior Set-up

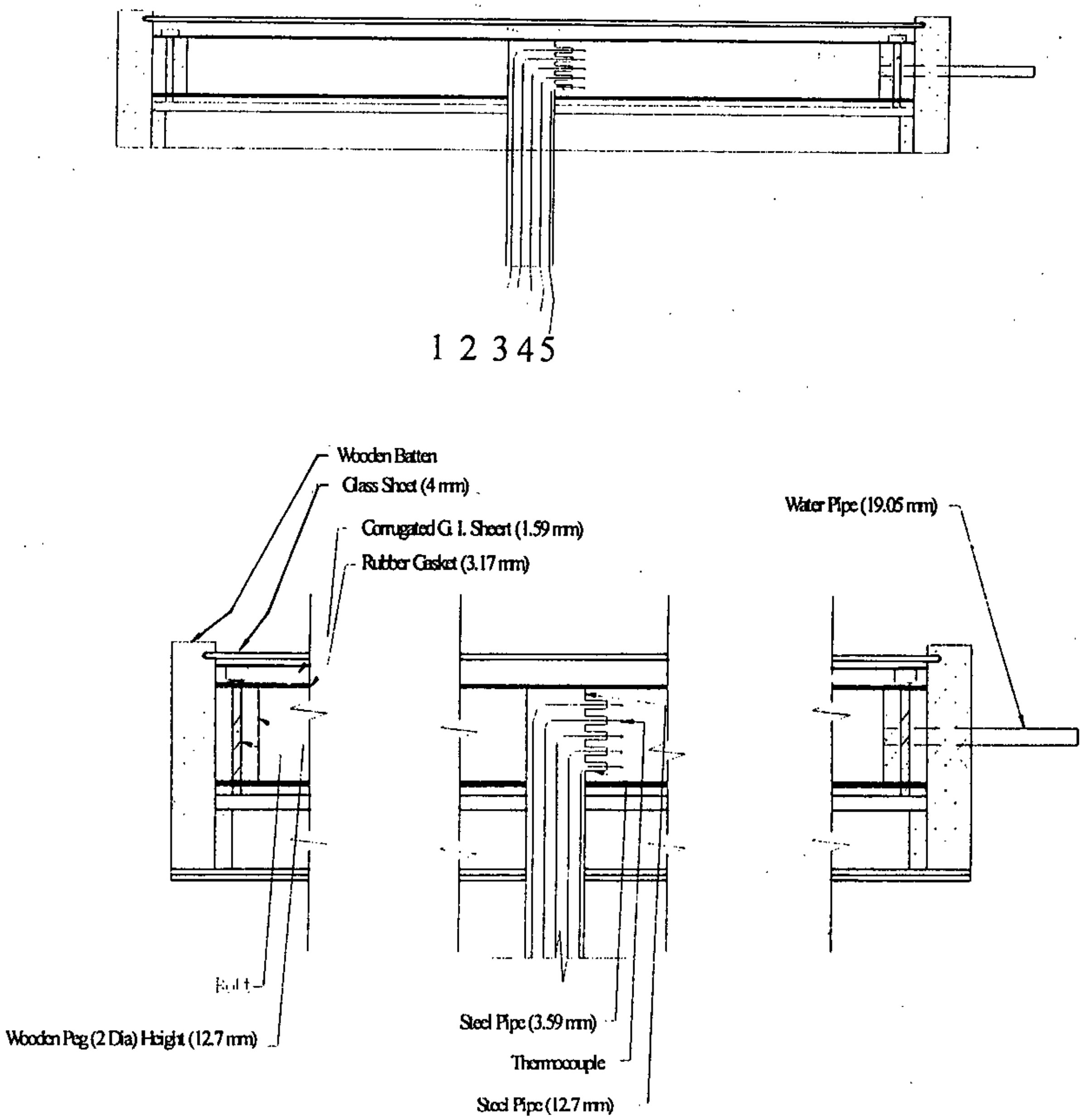

Fig. 4.4 (b) Cross sectional View of CSWHCT Illustrating the Interior Set-up

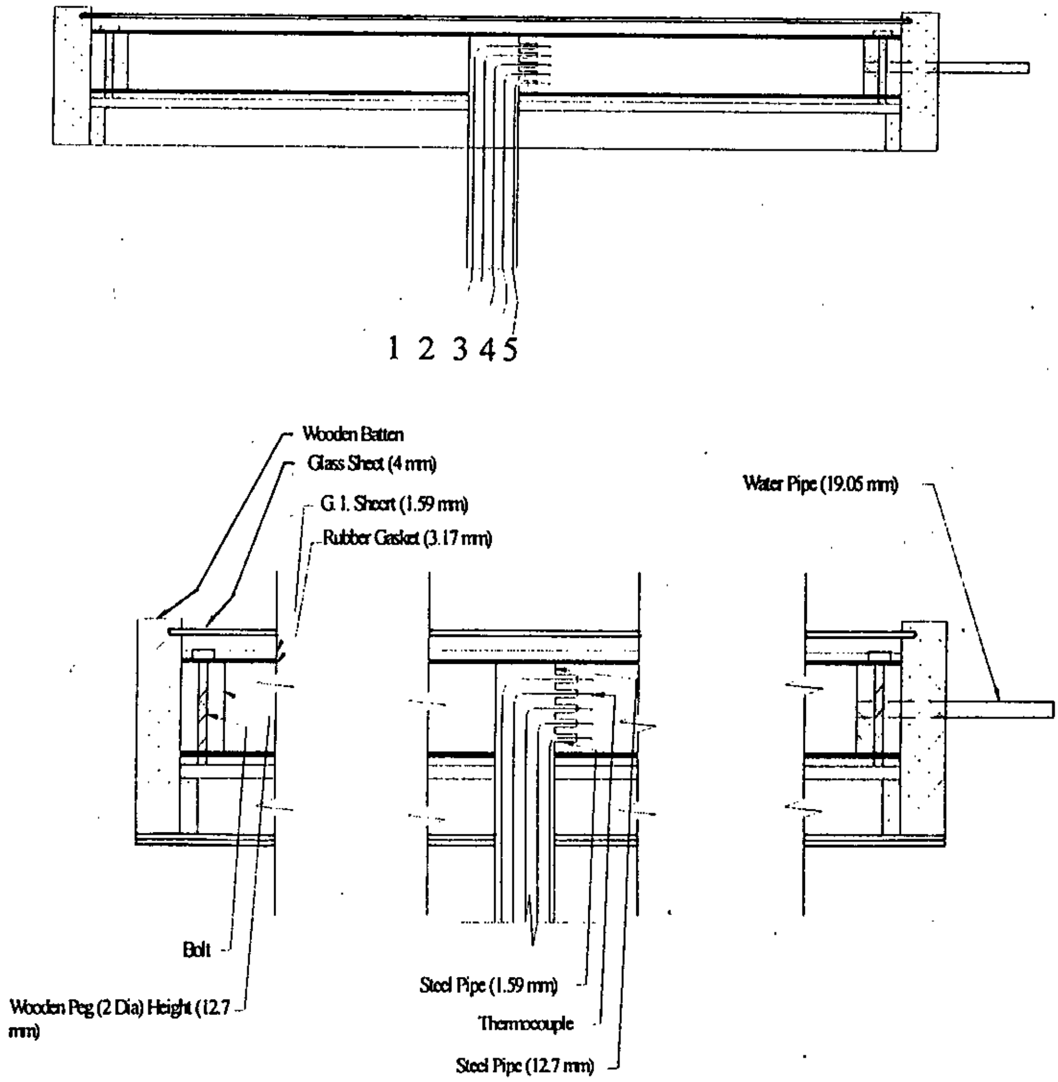

Fig. 4.4 (c) Cross sectional View of CSWHF Illustrating the Interior Set-up

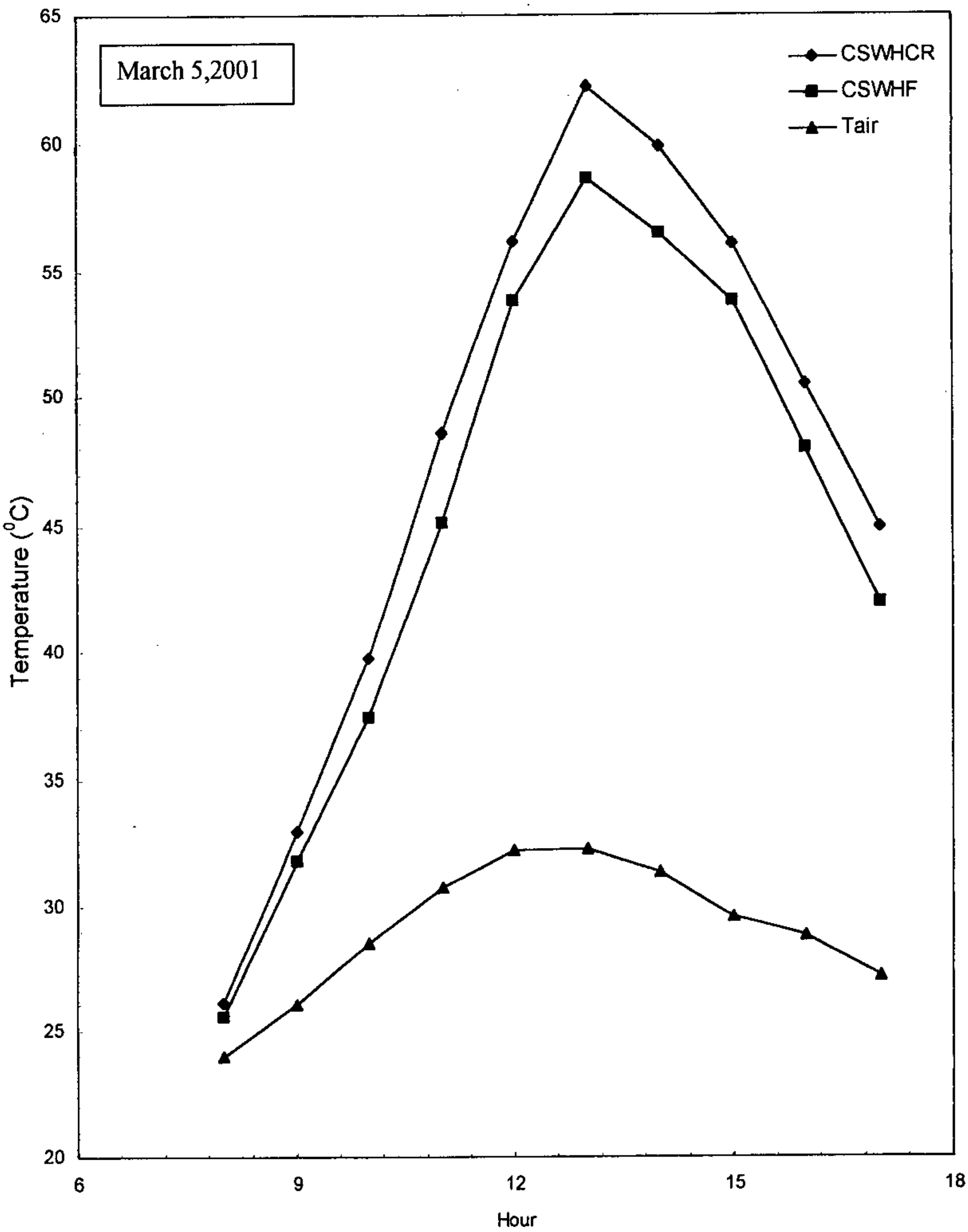

Fig. 5.1 Daily Temperature Distribution

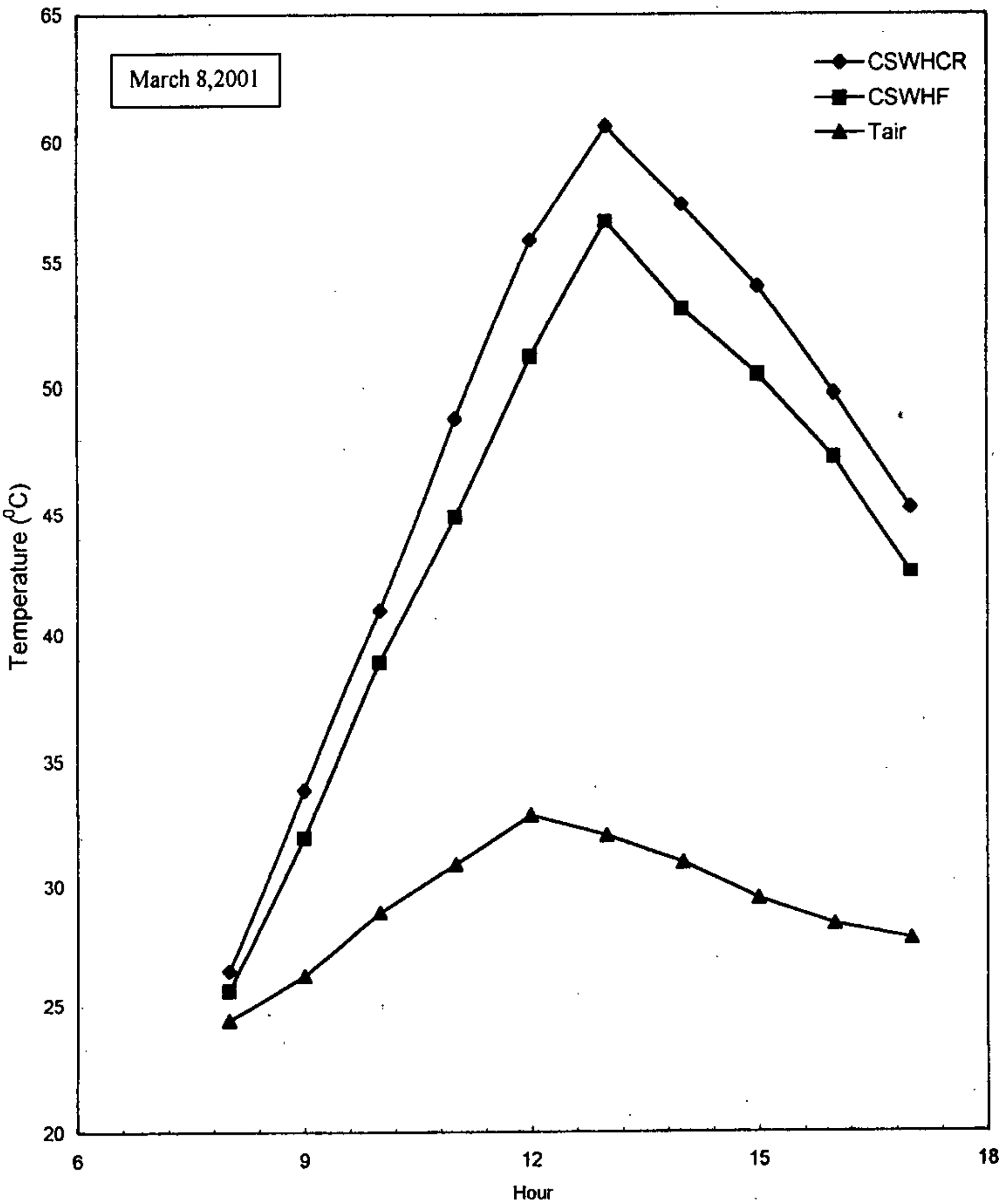

Fig. 5.2 Daily Temperature Distribution

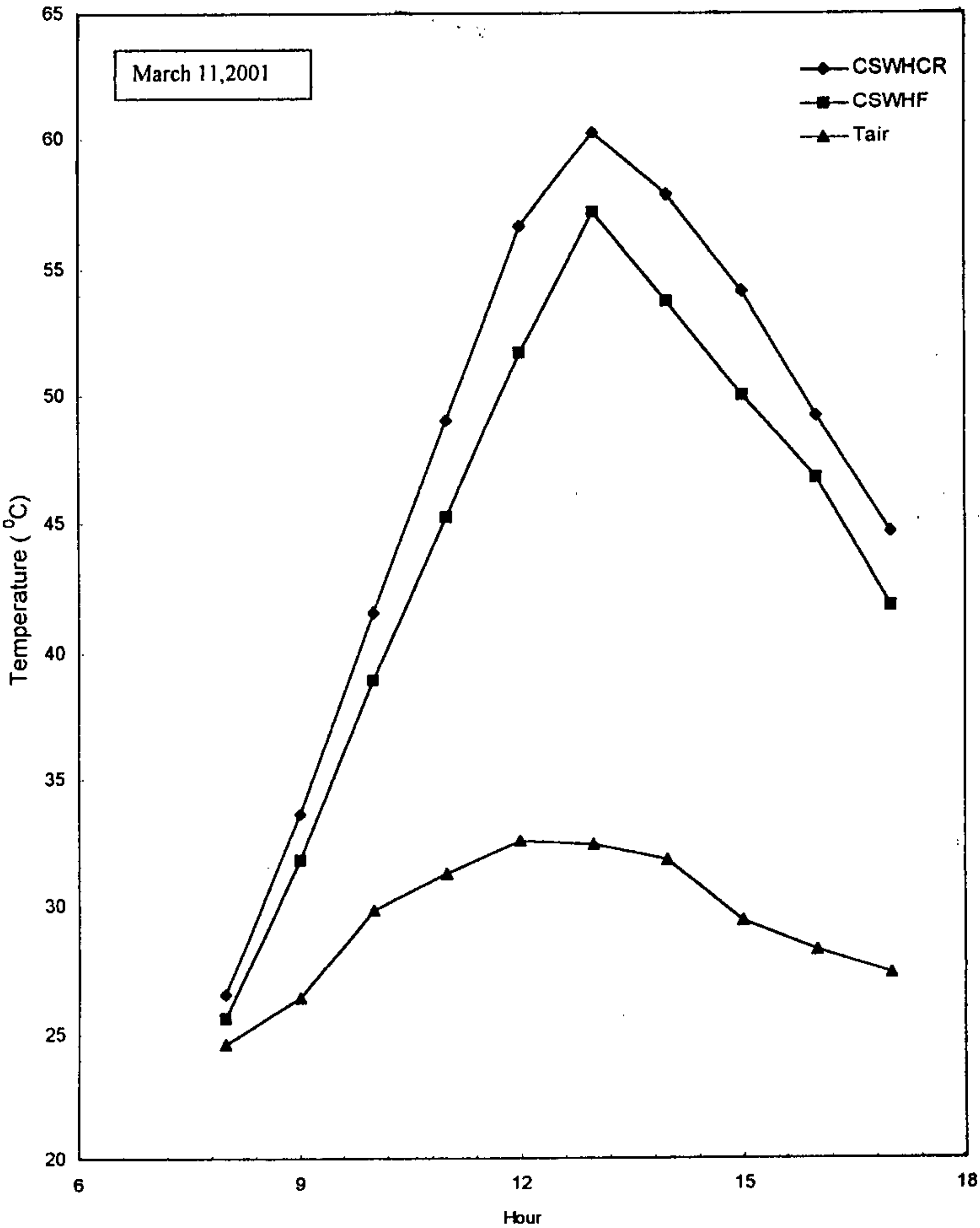

Fig. 5.3 Daily Temperature Distribution

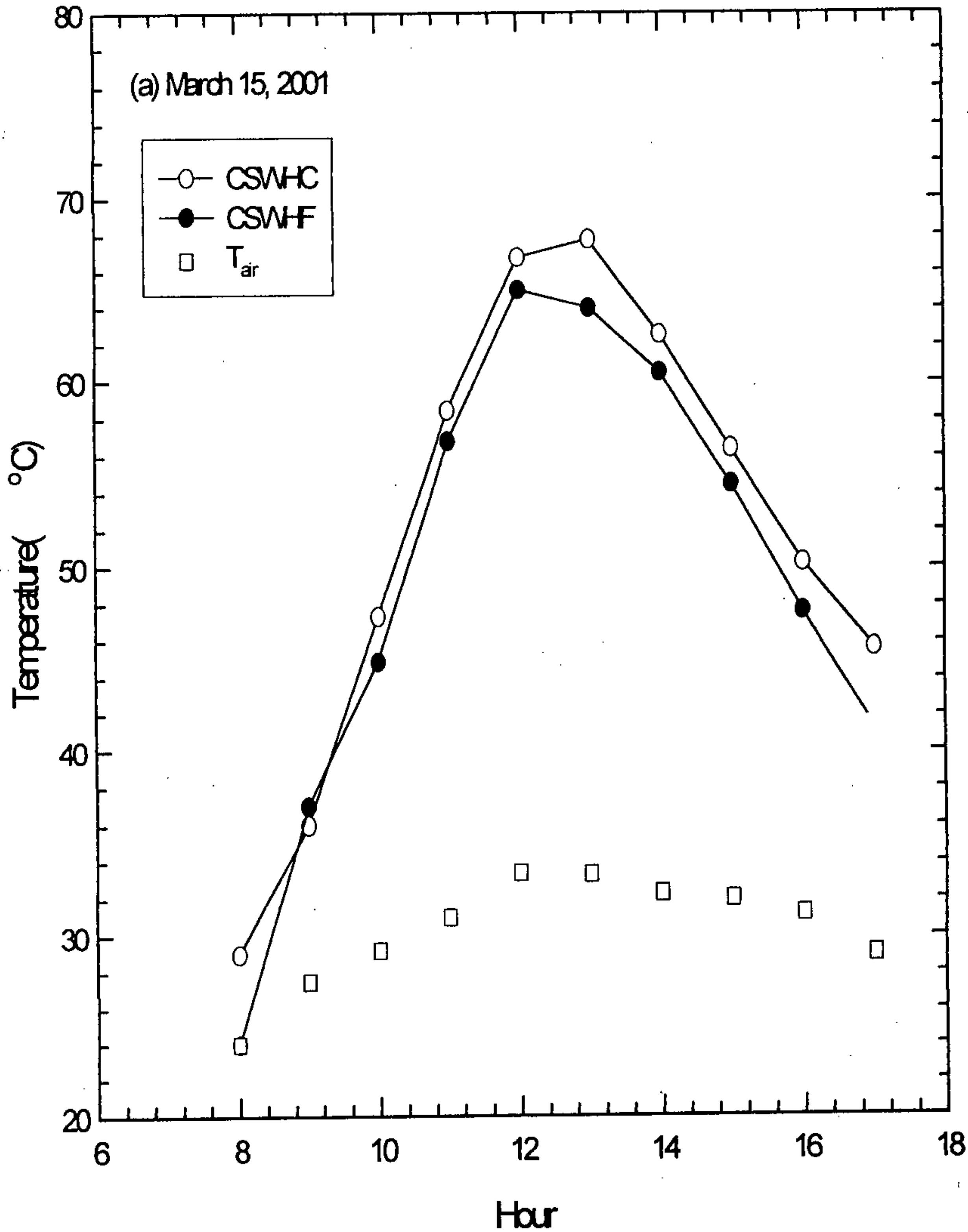

Fig.5.4 Daily Temperature Distribution

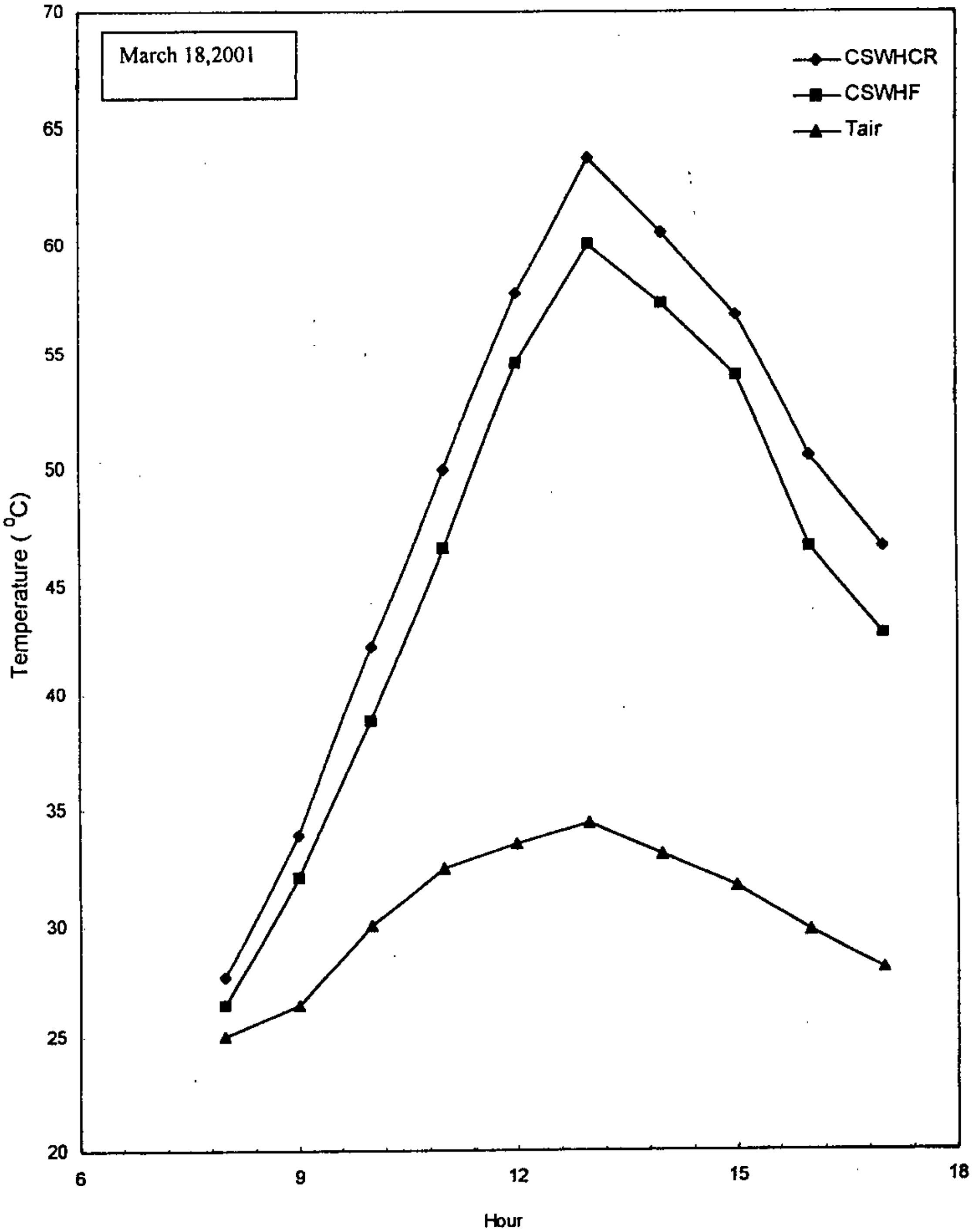

Fig. 5.5 Daily Temperature Distribution

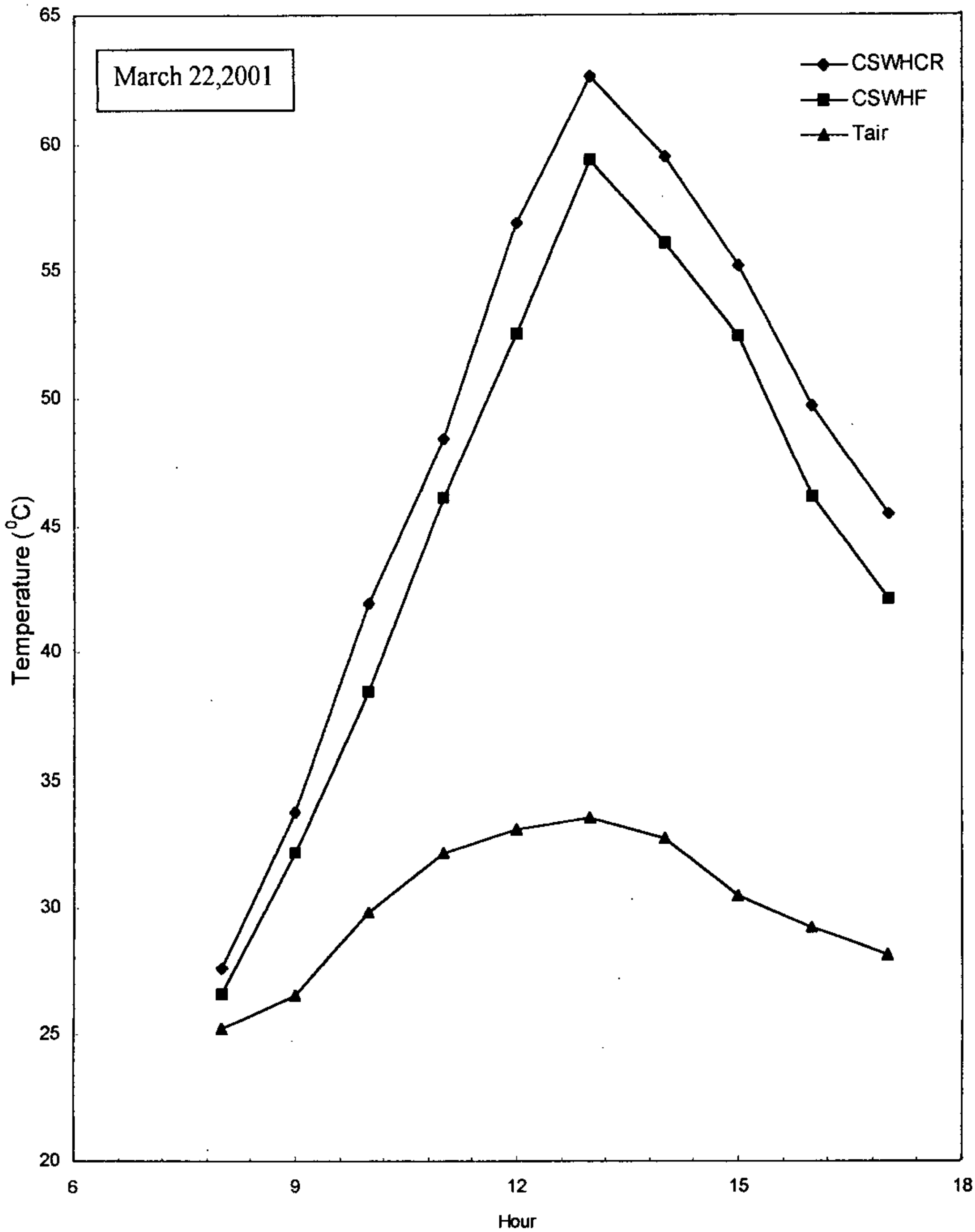

Fig. 5.6 Daily Temperature Distribution

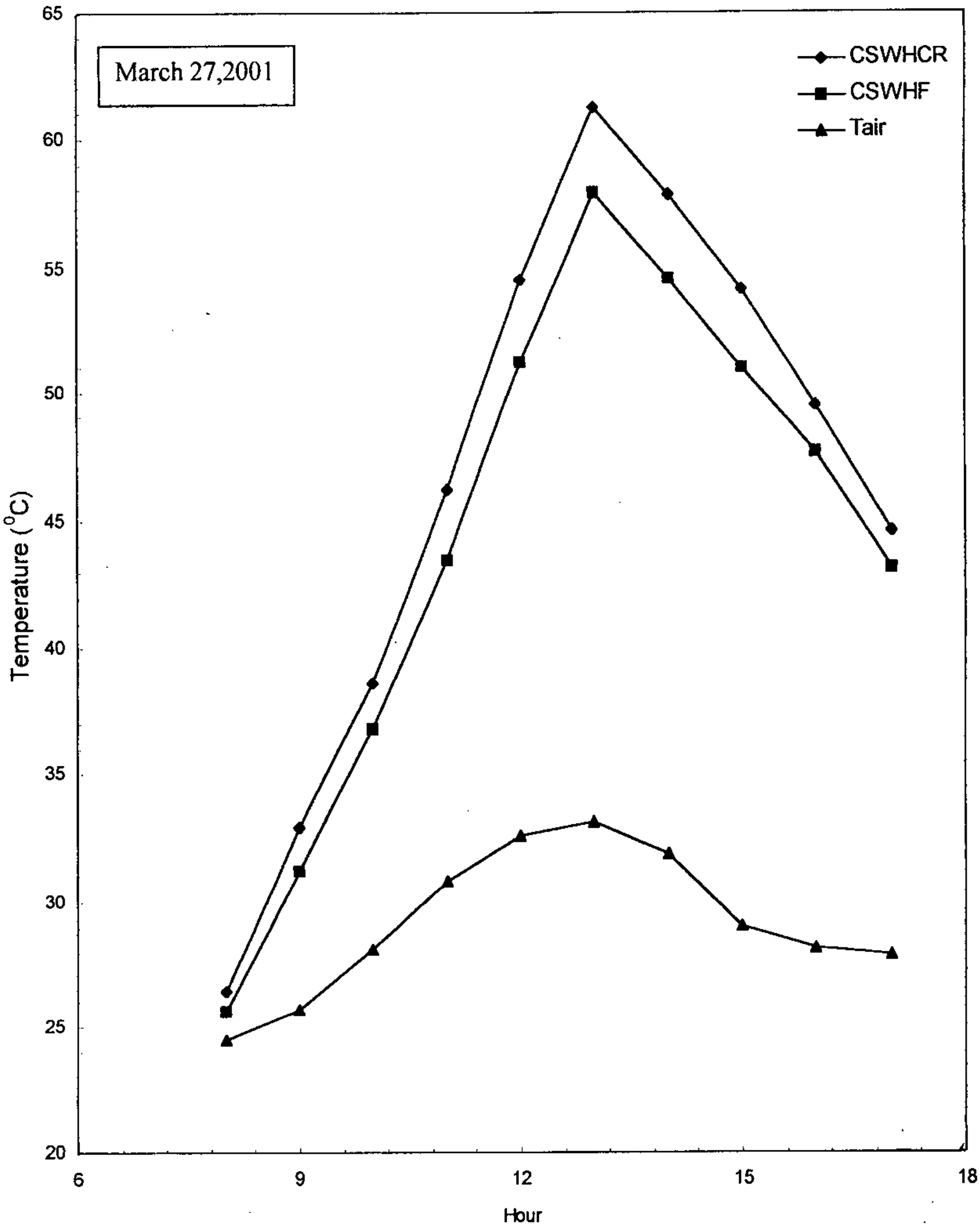

Fig. 5.7 Daily Temperature Distribution

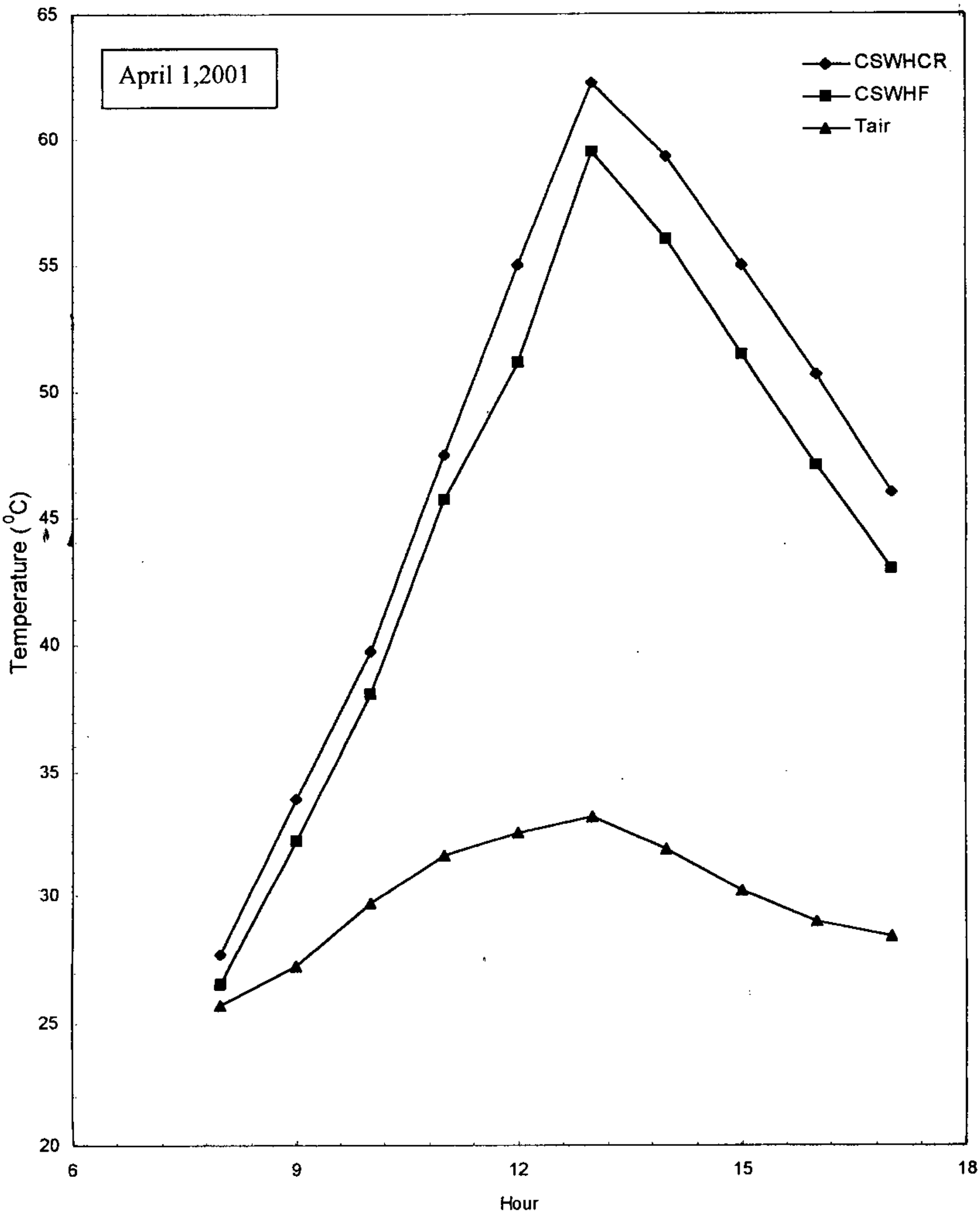

Fig. 5.8 Daily Temperature Distribution

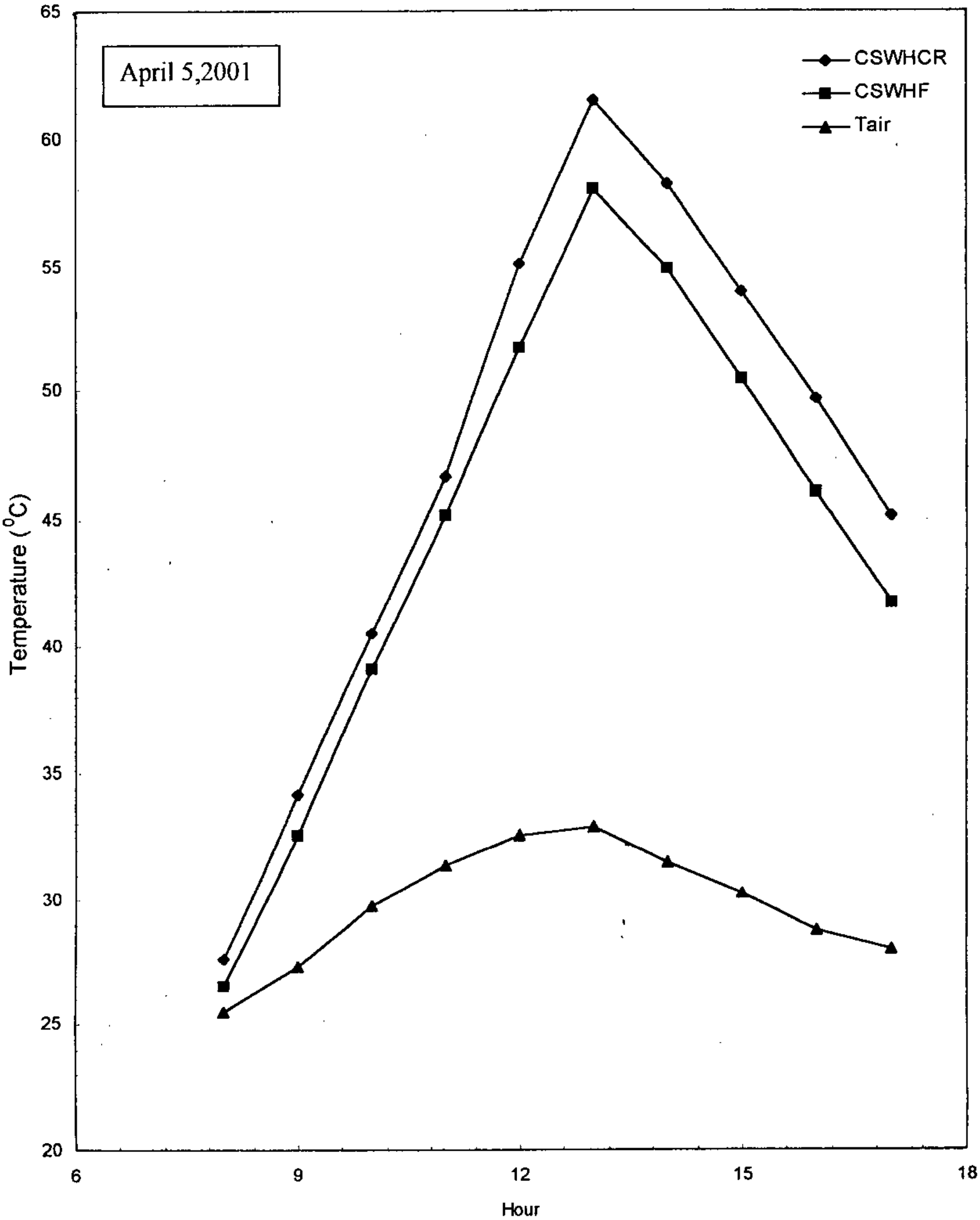

Fig. 5.9 Daily Temperature Distribution

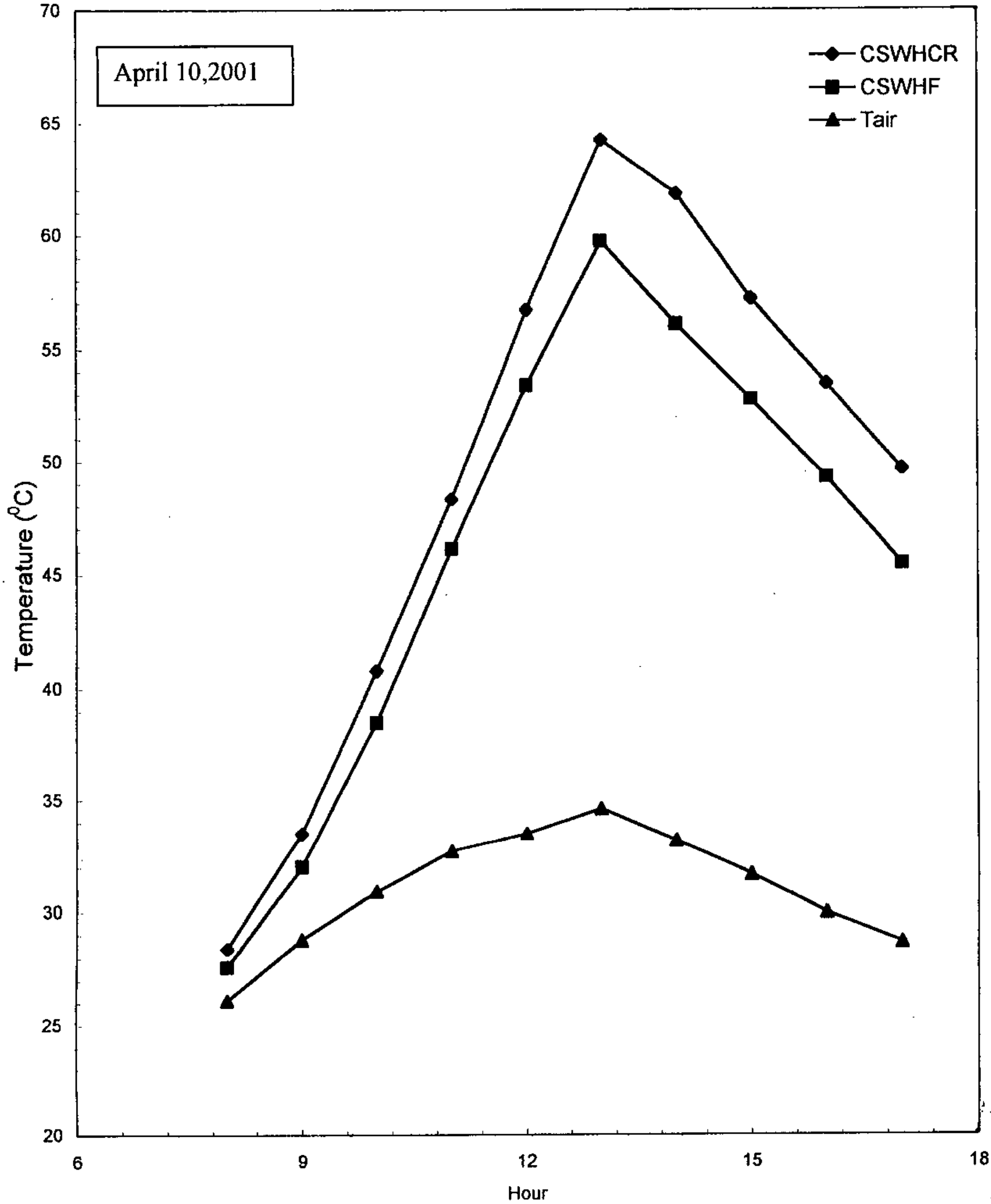

Fig. 5.10 Daily Temperature Distribution

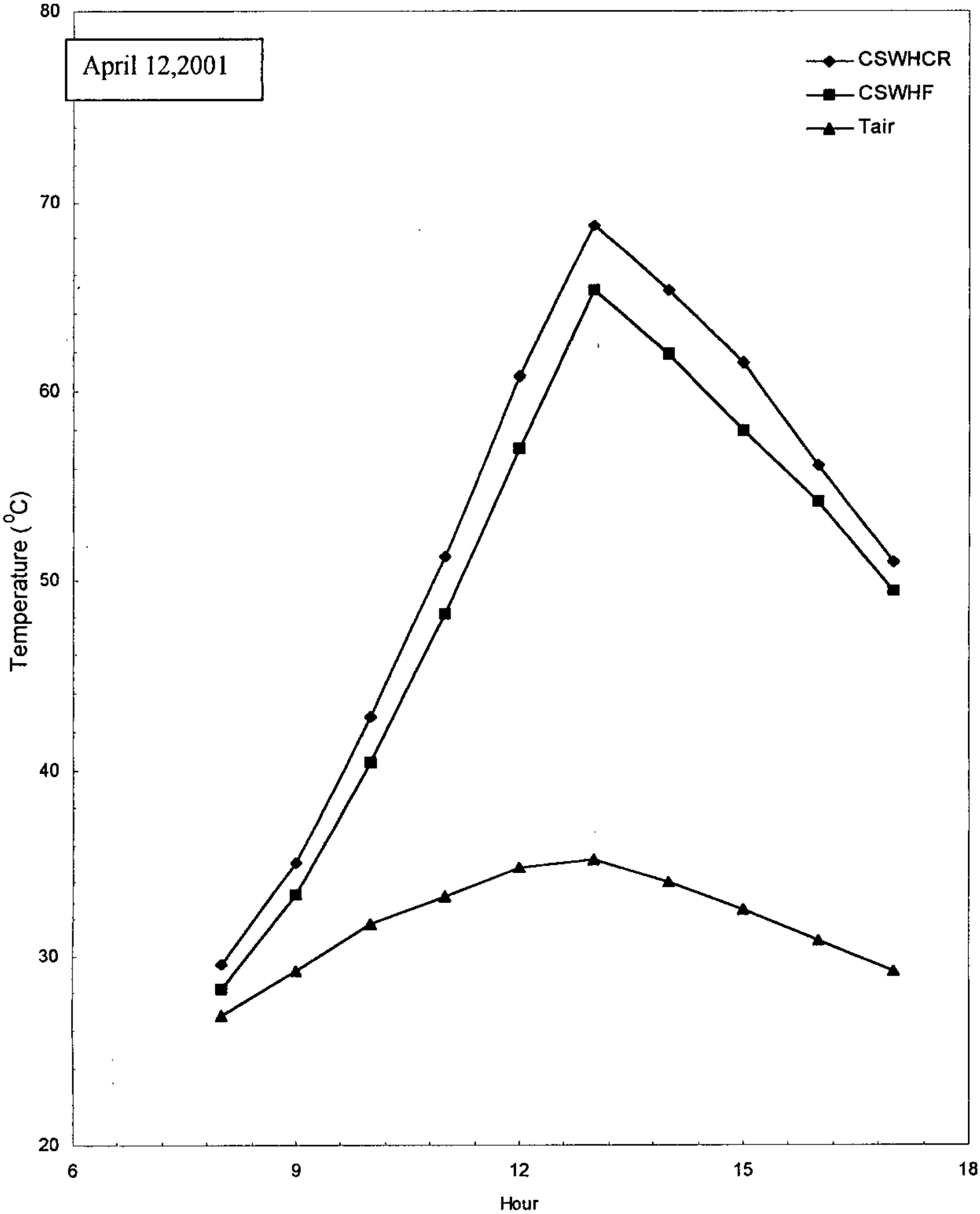

Fig. 5.11 Daily Temperature Distribution

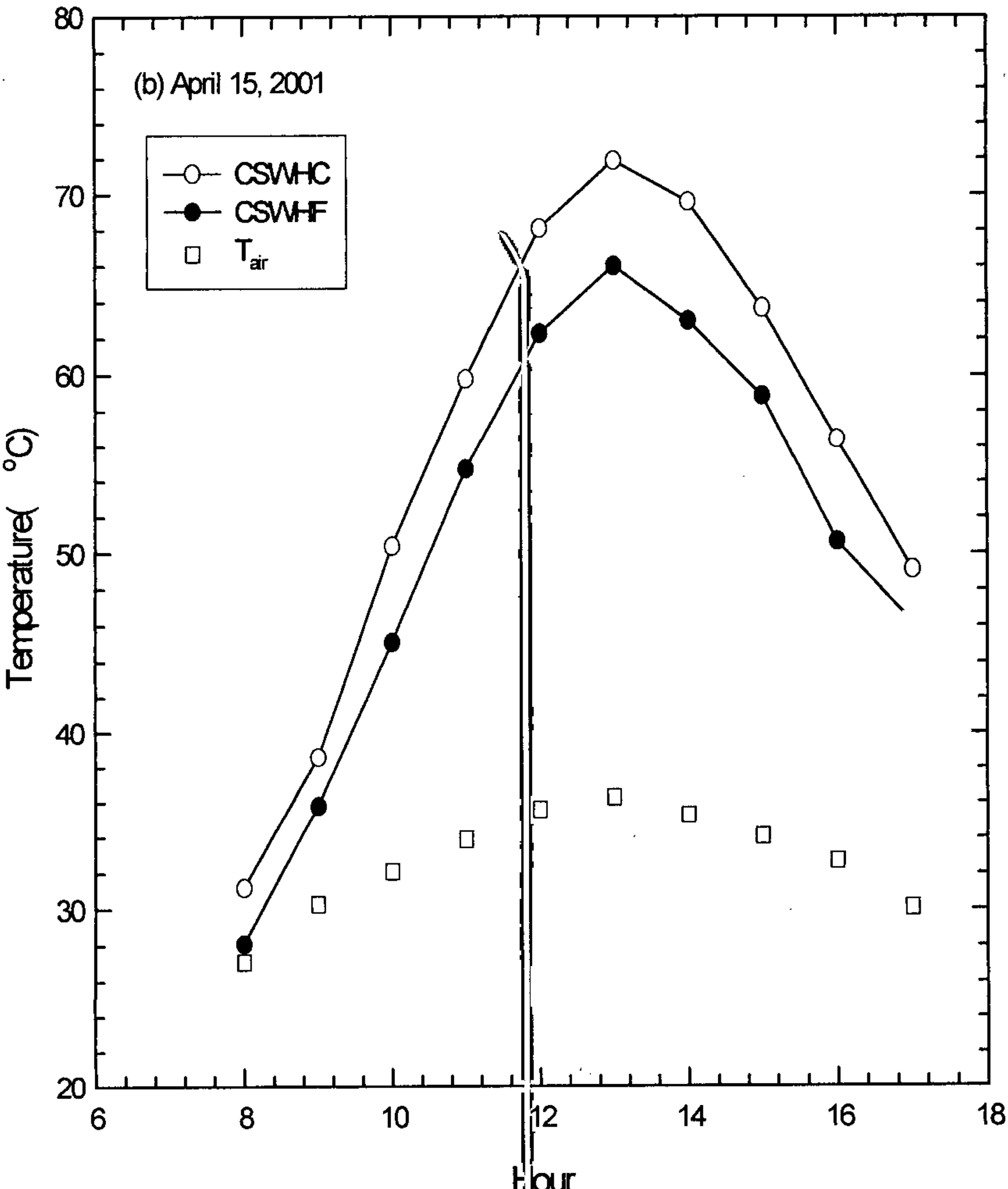

Fig. 5.12 Daily Temperature Distribution

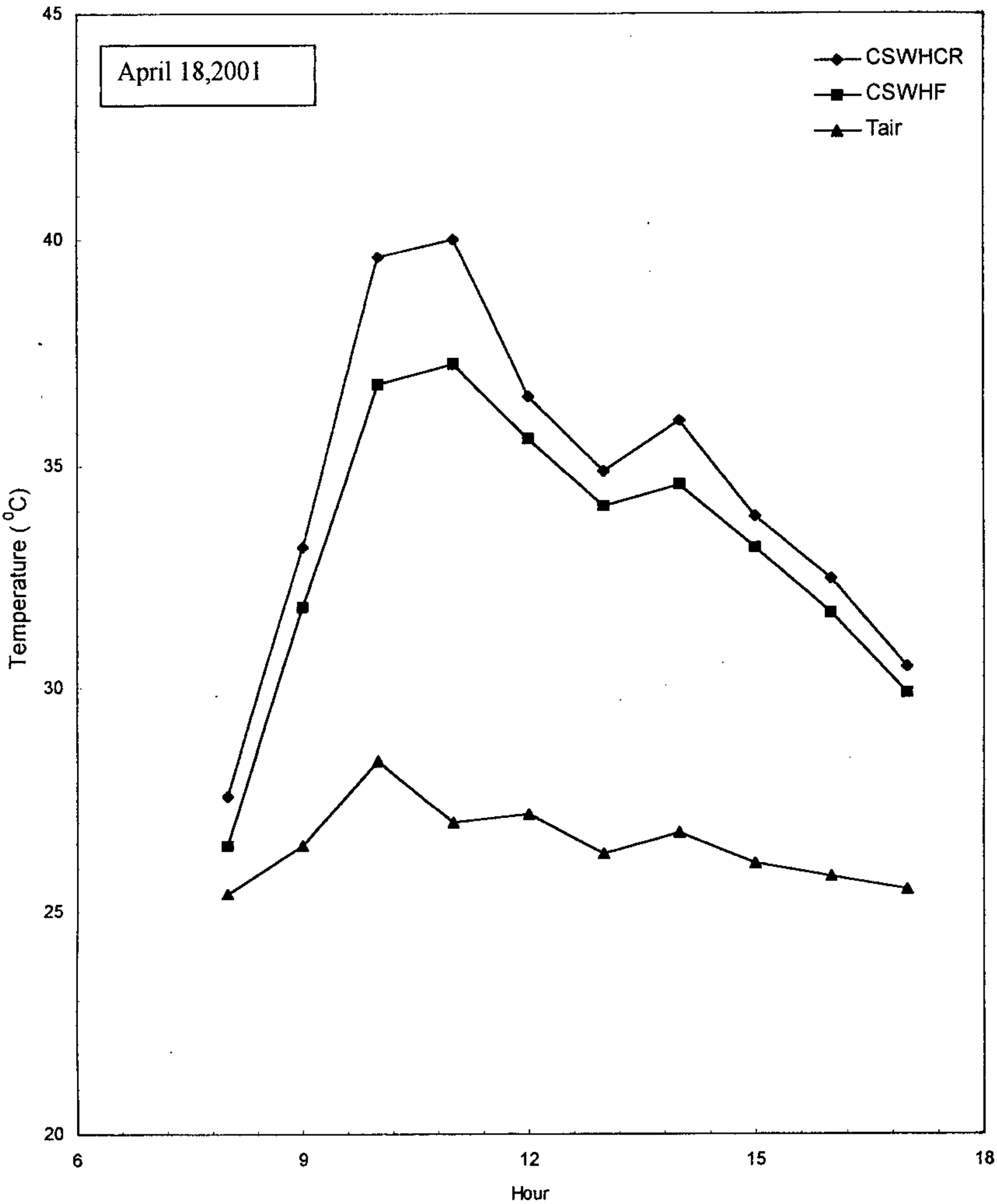

Fig. 5.13 Daily Temperature Distribution

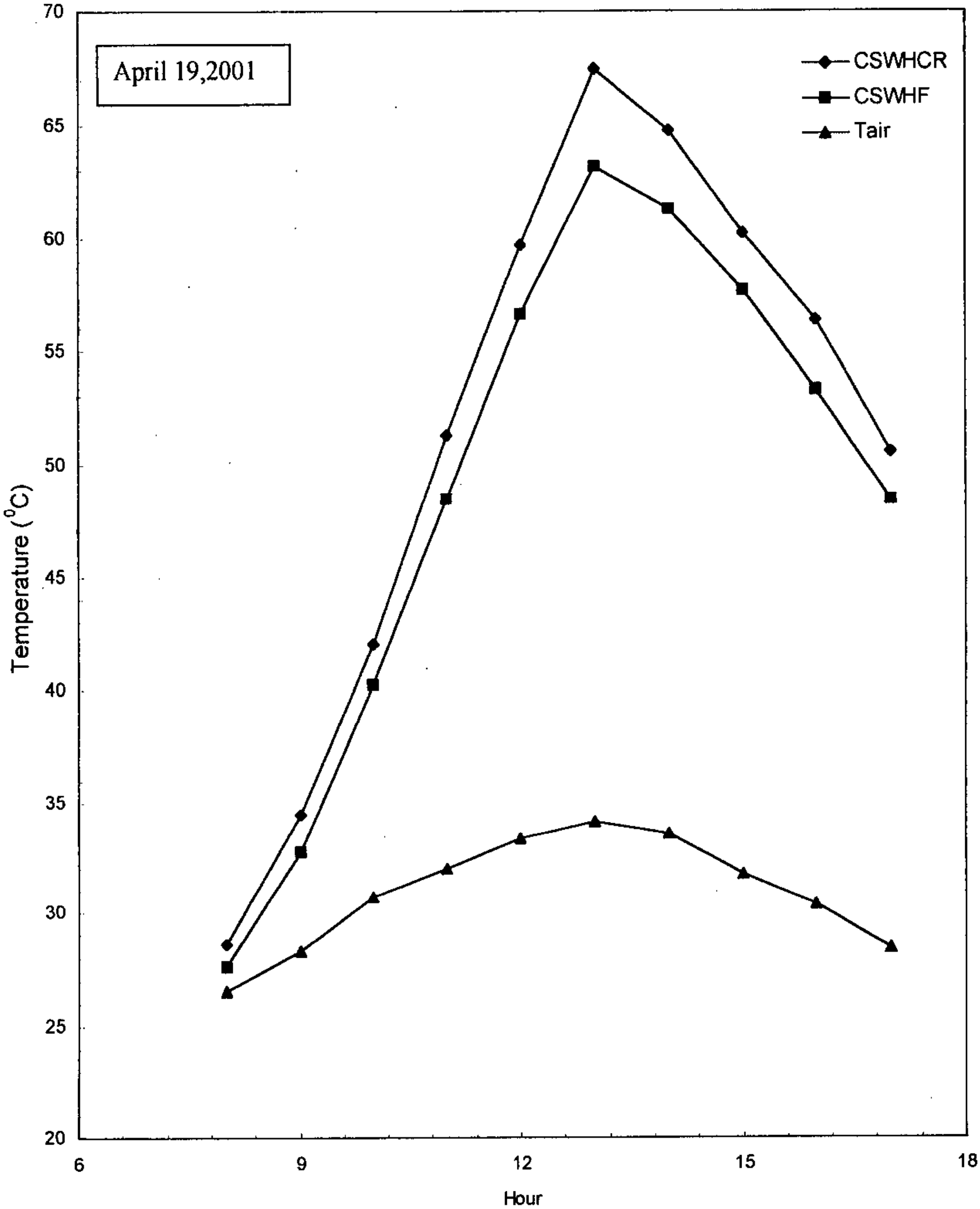

Fig. 5.14 Daily Temperature Distribution

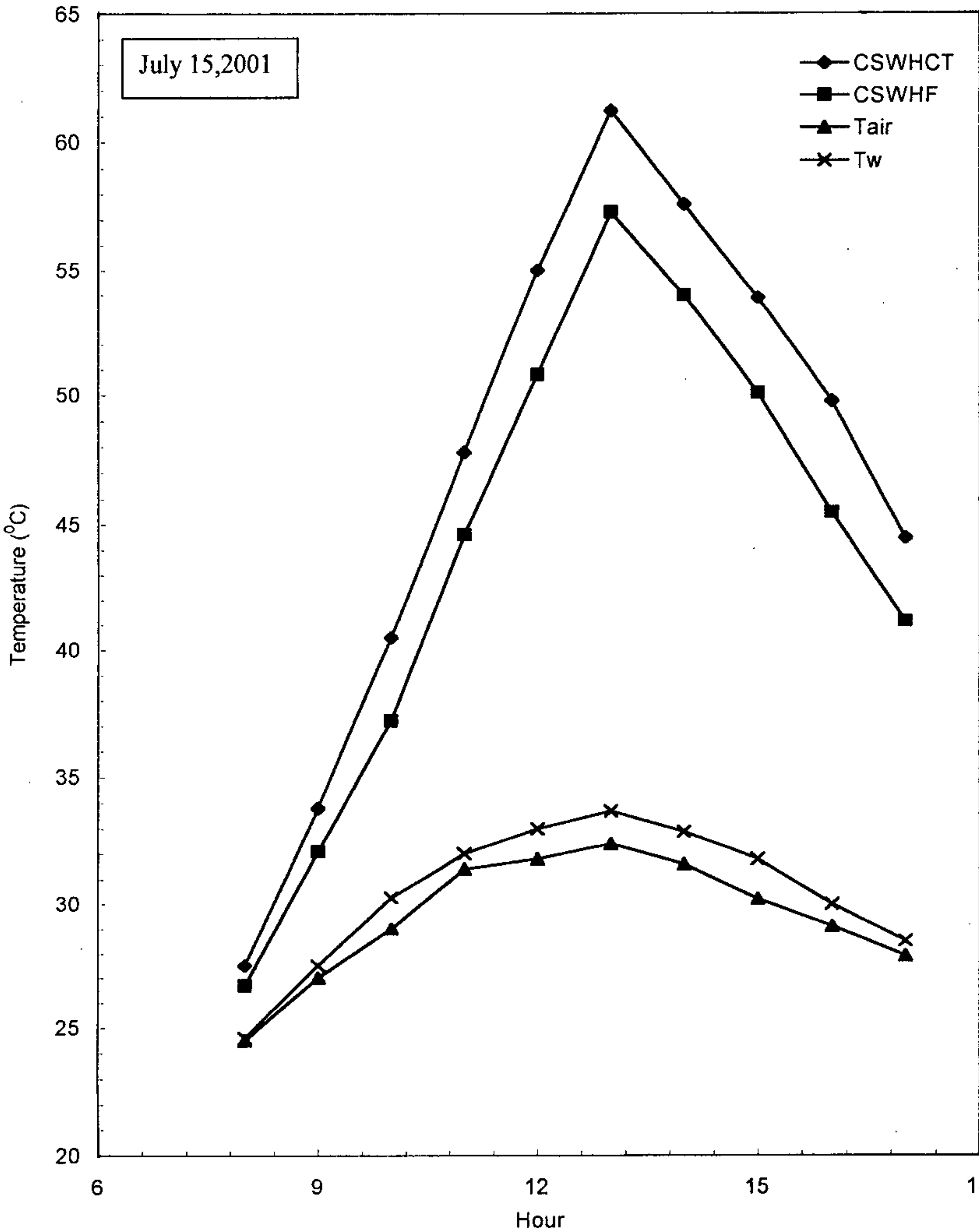

Fig. 5.15 Daily Temperature Distribution

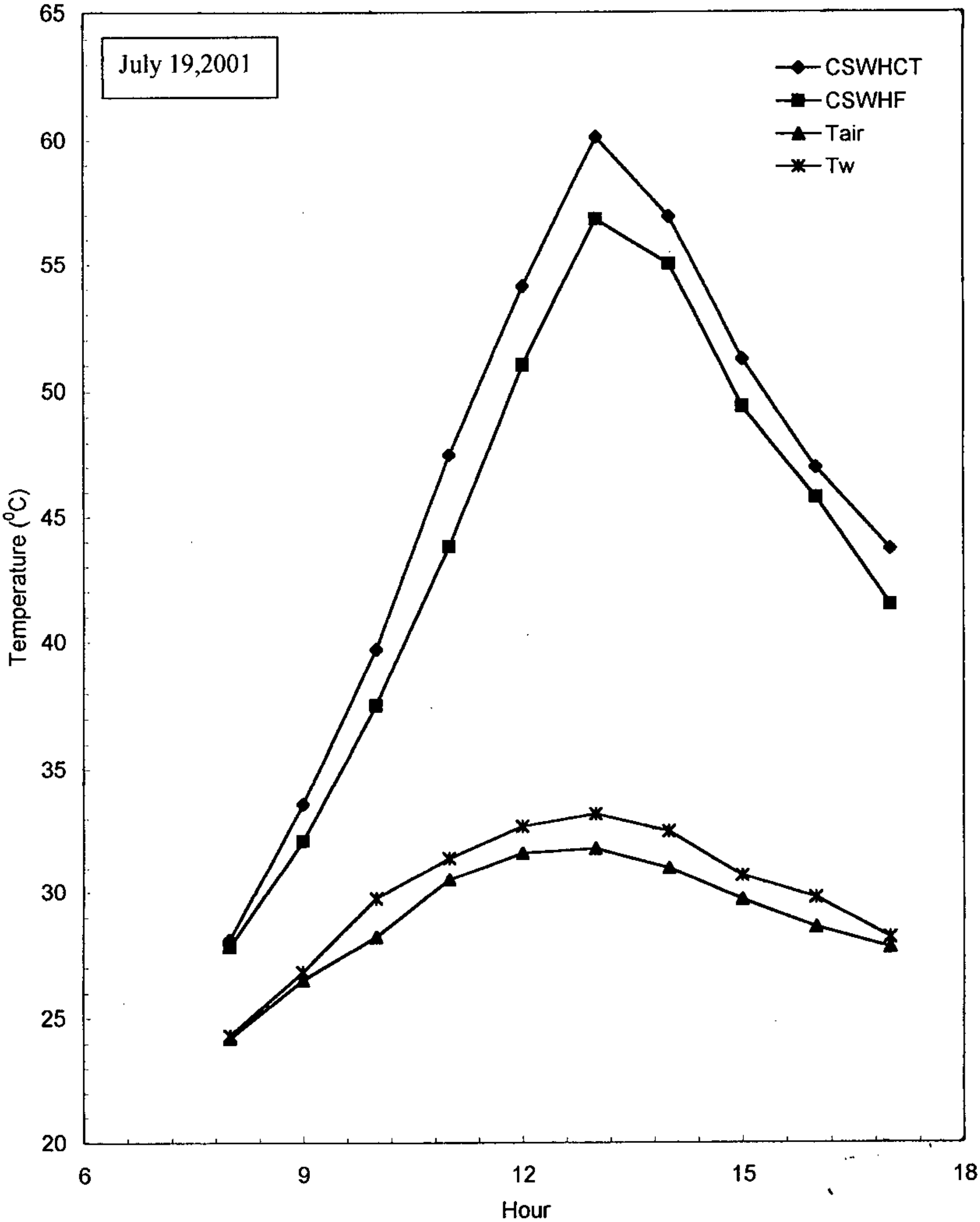

Fig. 5.16 Daily Temperature Distribution

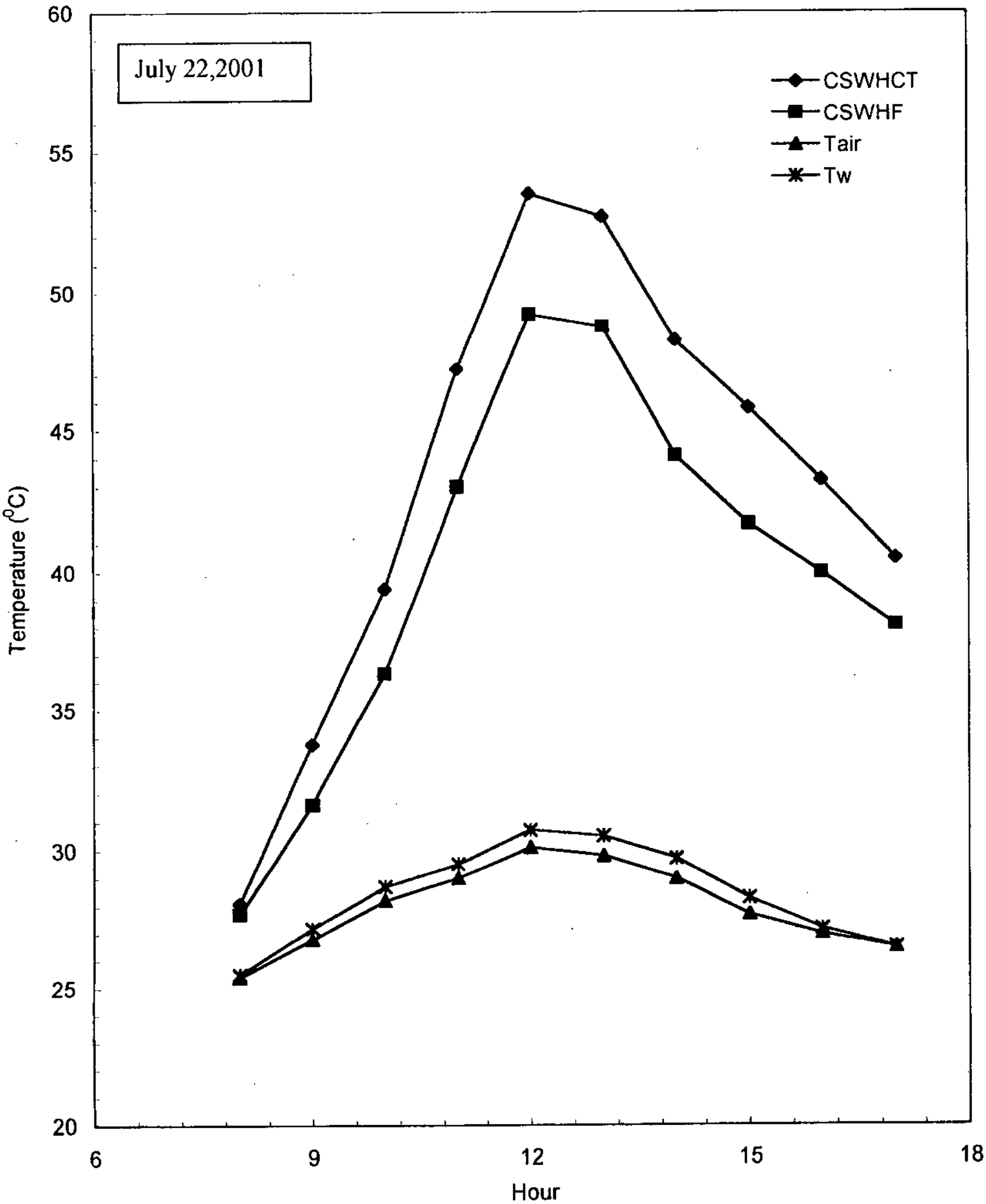

Fig. 5.17 Daily Temperature Distribution

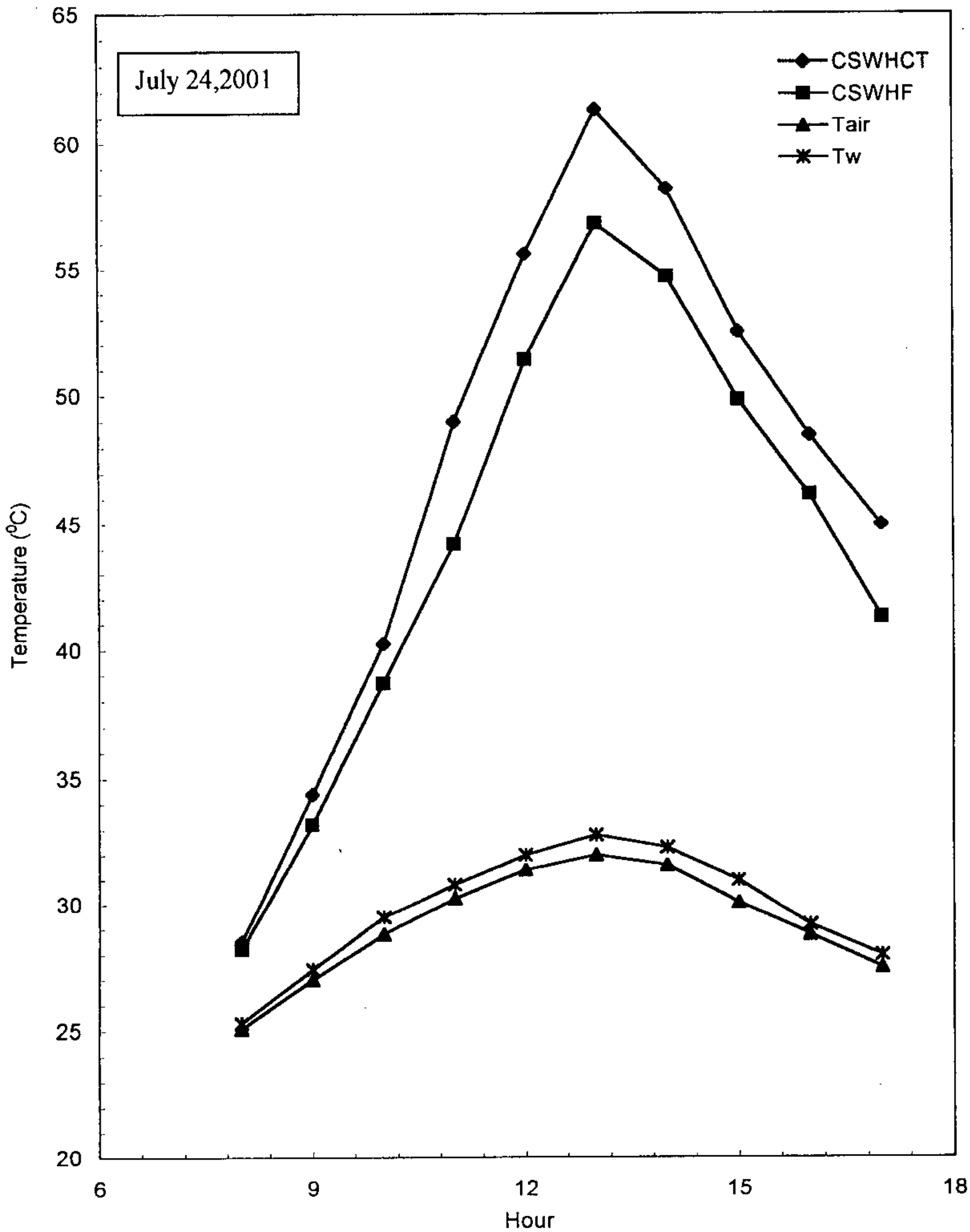

Fig. 5.18 Daily Temperature Distribution

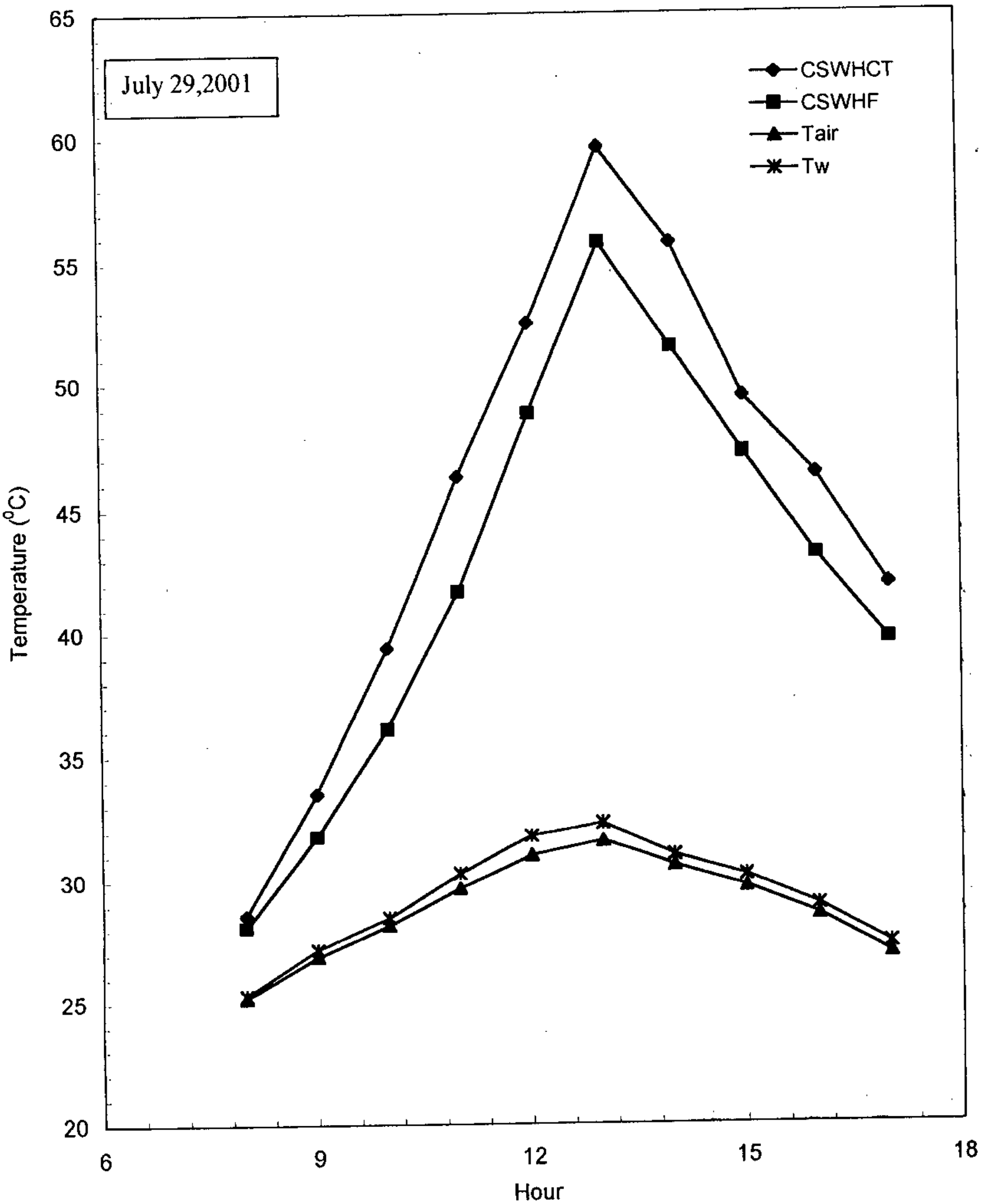

Fig. 5.19 Daily Temperature Distribution

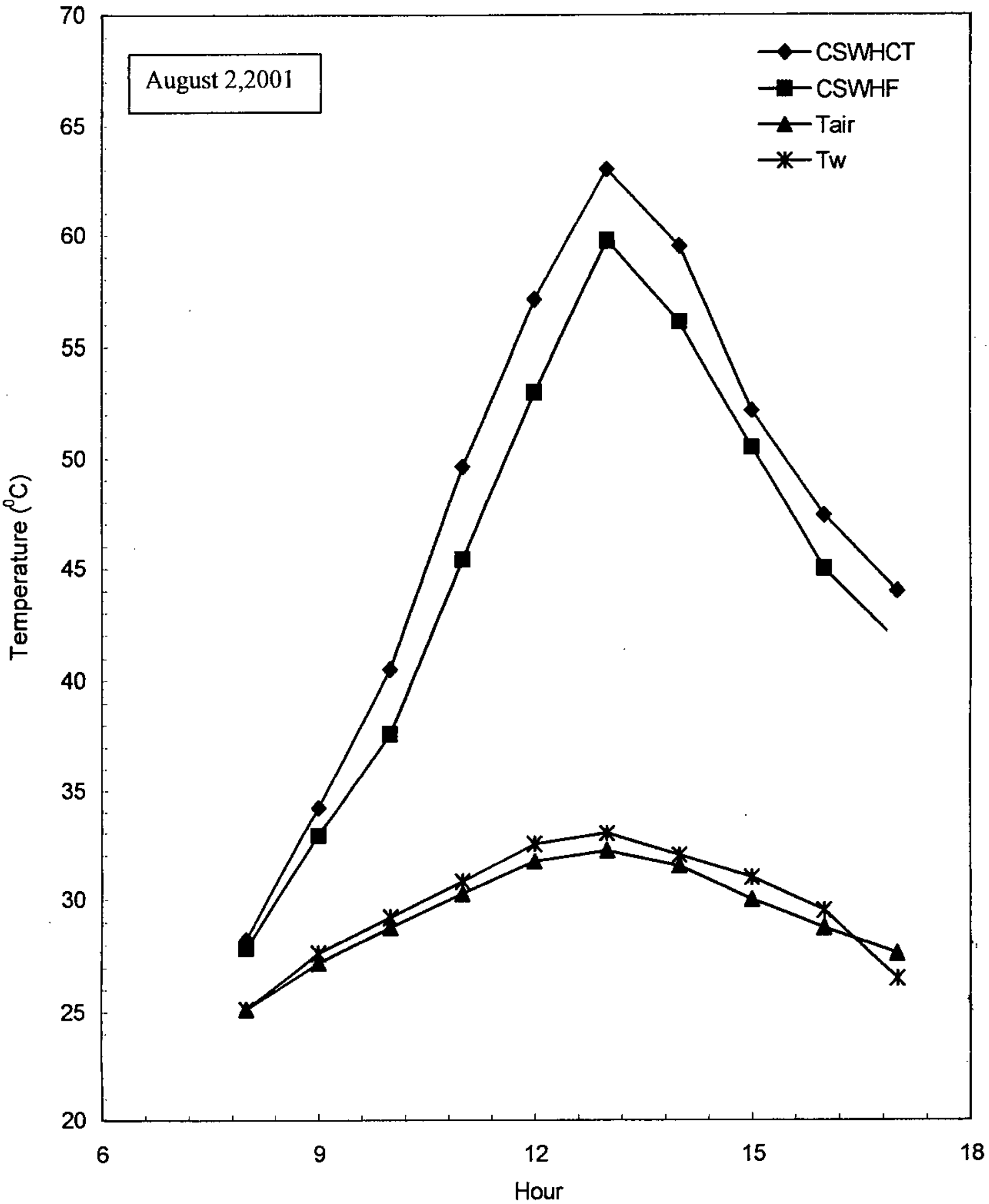

Fig. 5.20 Daily Temperature Distribution

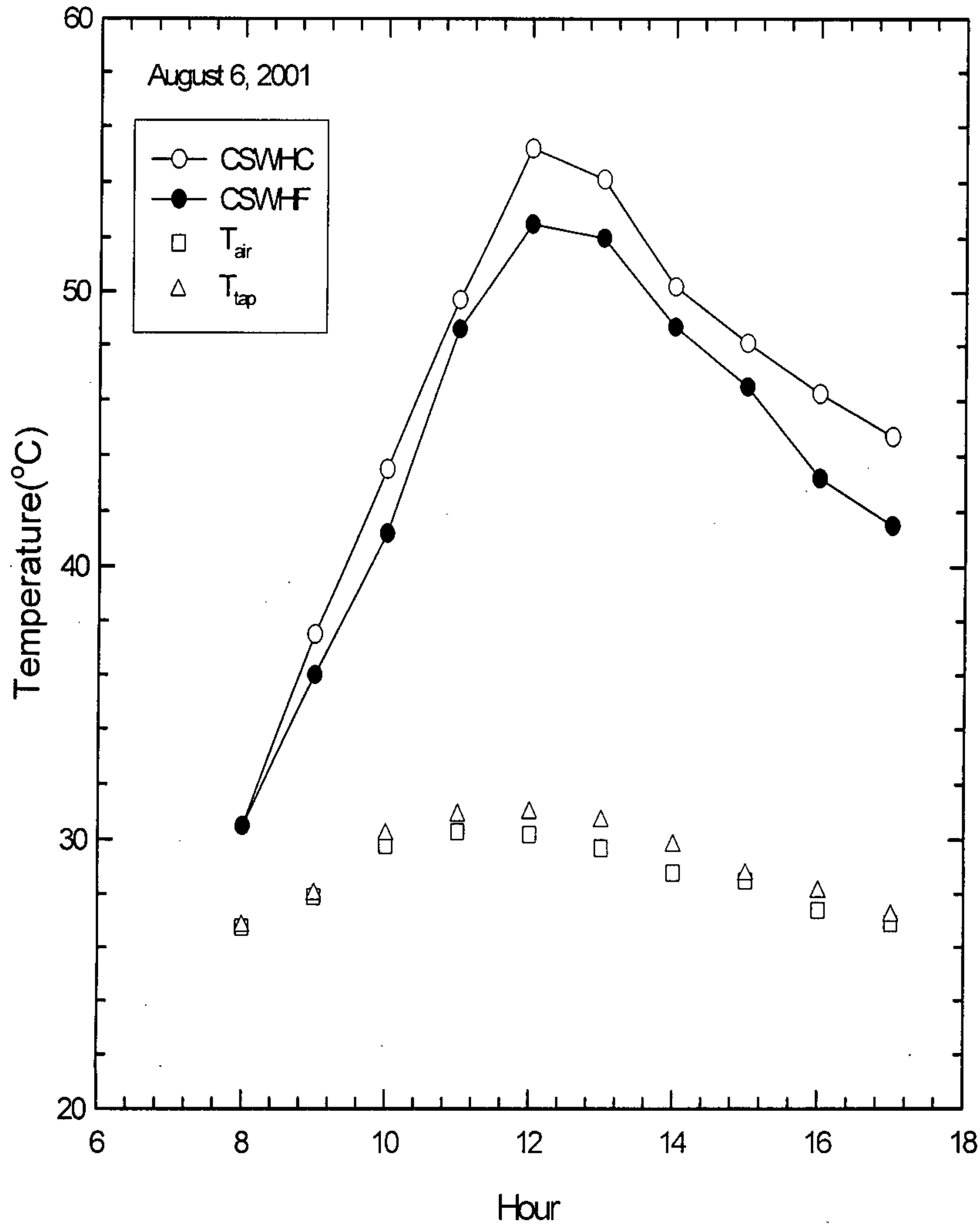

Fig. 5.21 Daily Temperature Distribution

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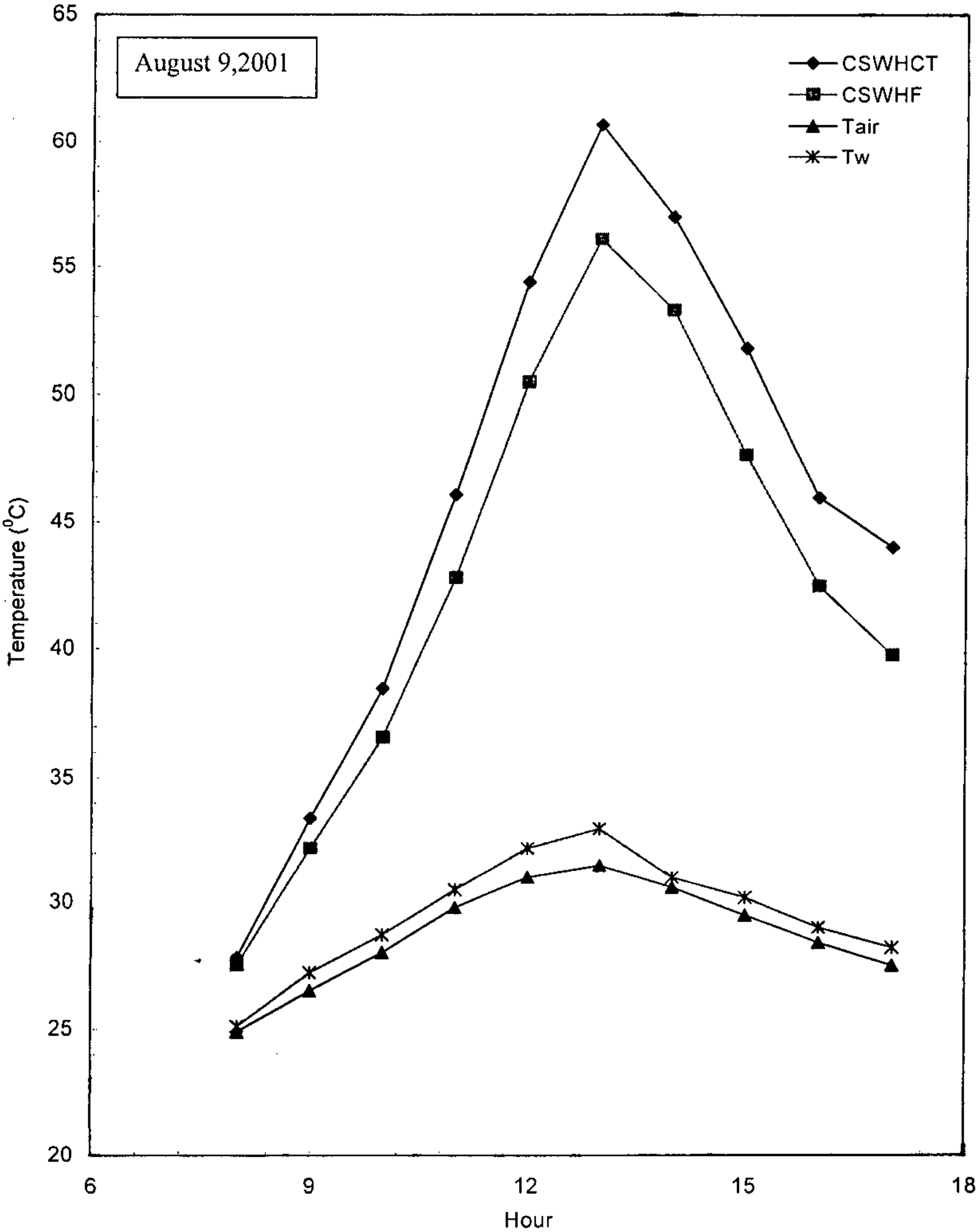

Fig. 5.22 Daily Temperature Distribution

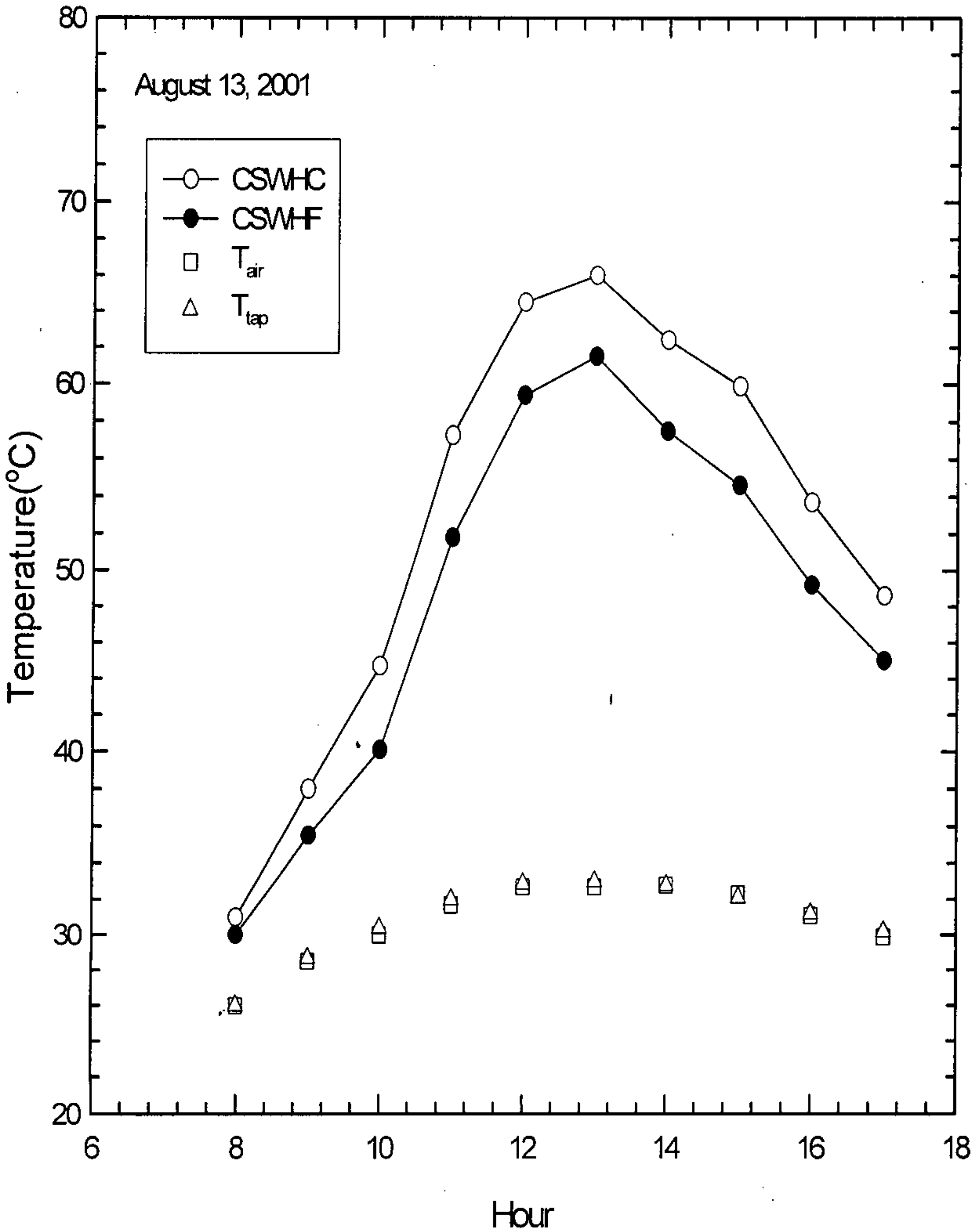

Fig. 5.23 Daily Temperature Distribution

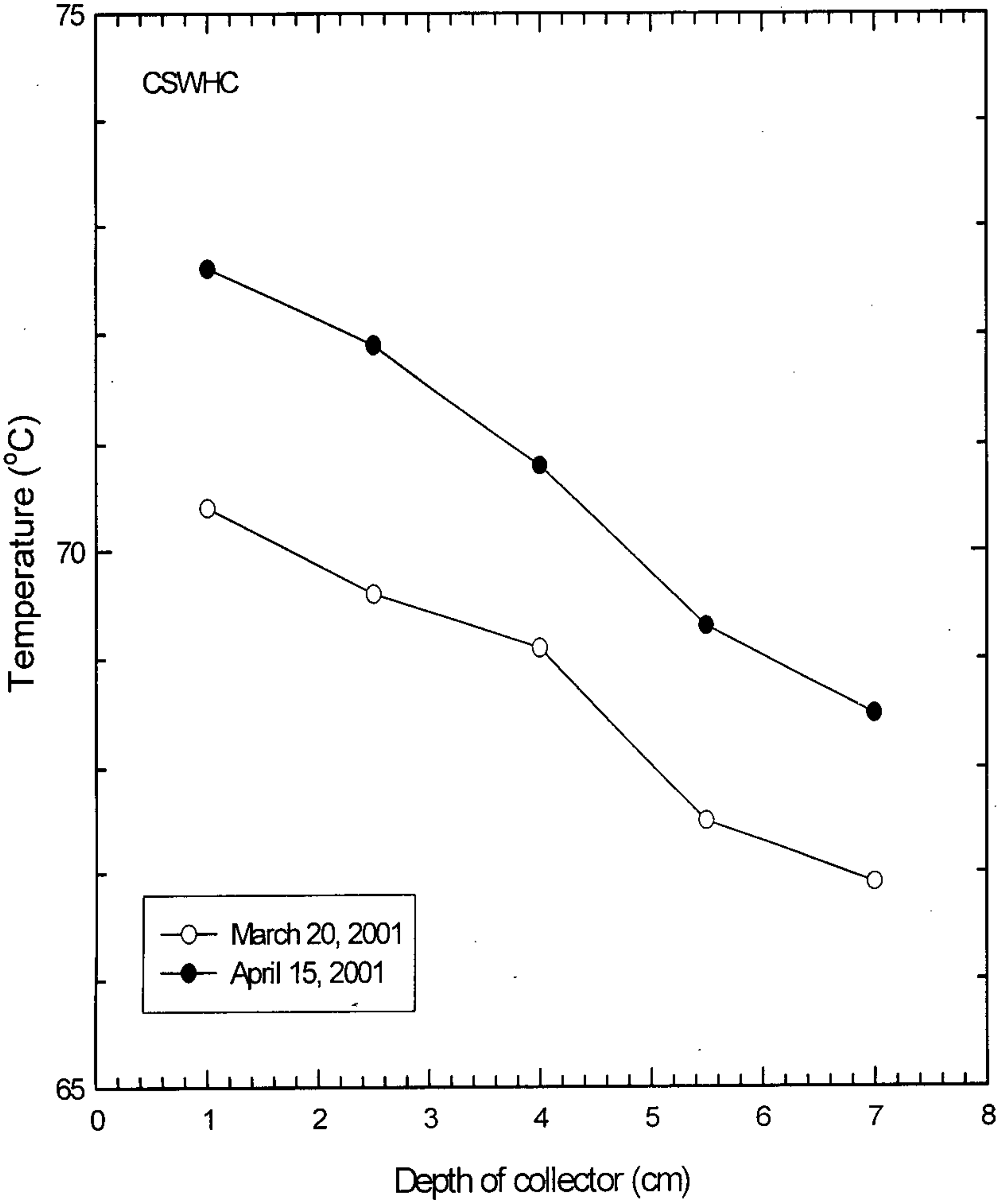

Fig. 5.24 Temperature Distribution of Water Along the Depth of Collector

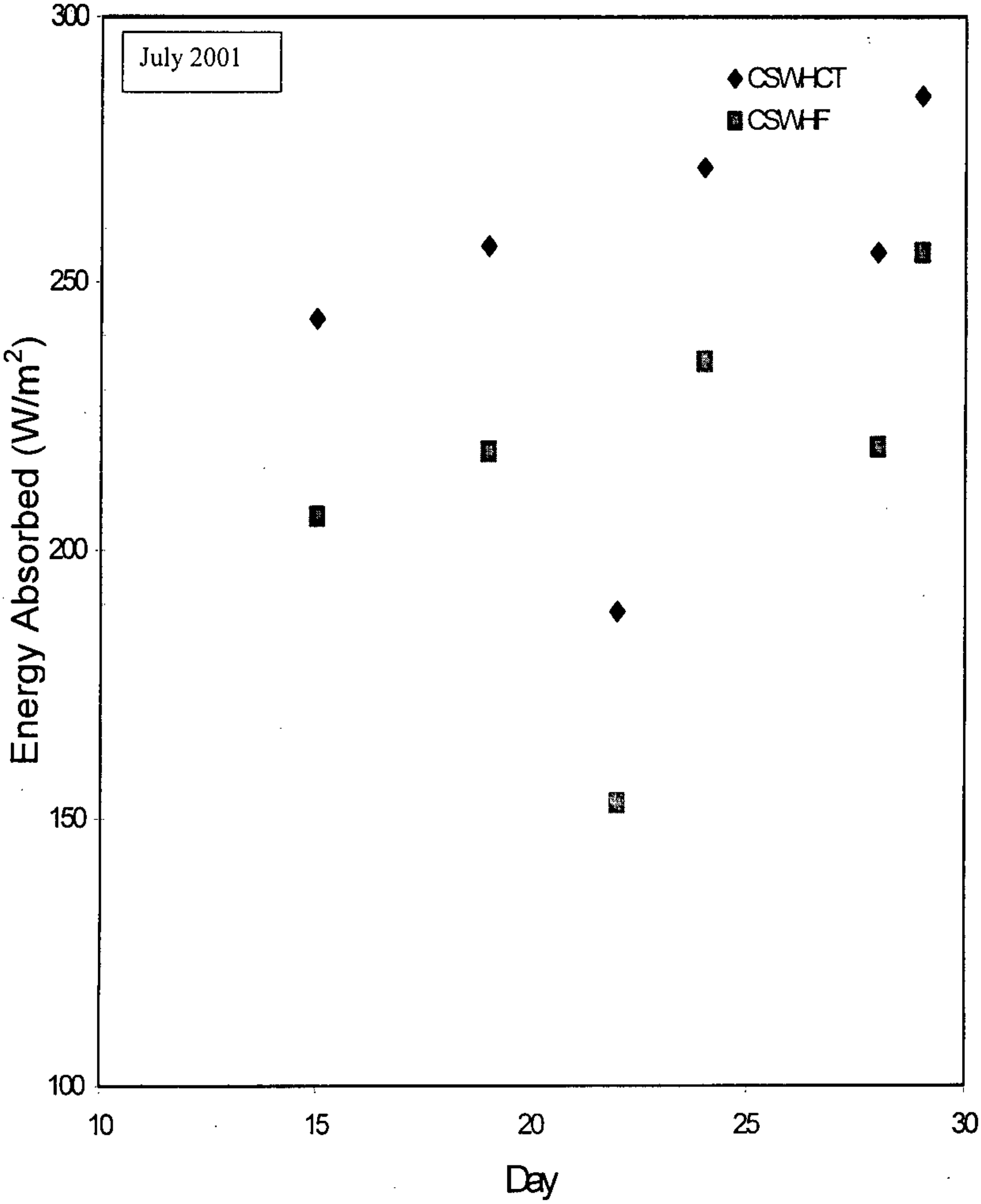

Fig. 5.31 Daily Average Energy Absorbed

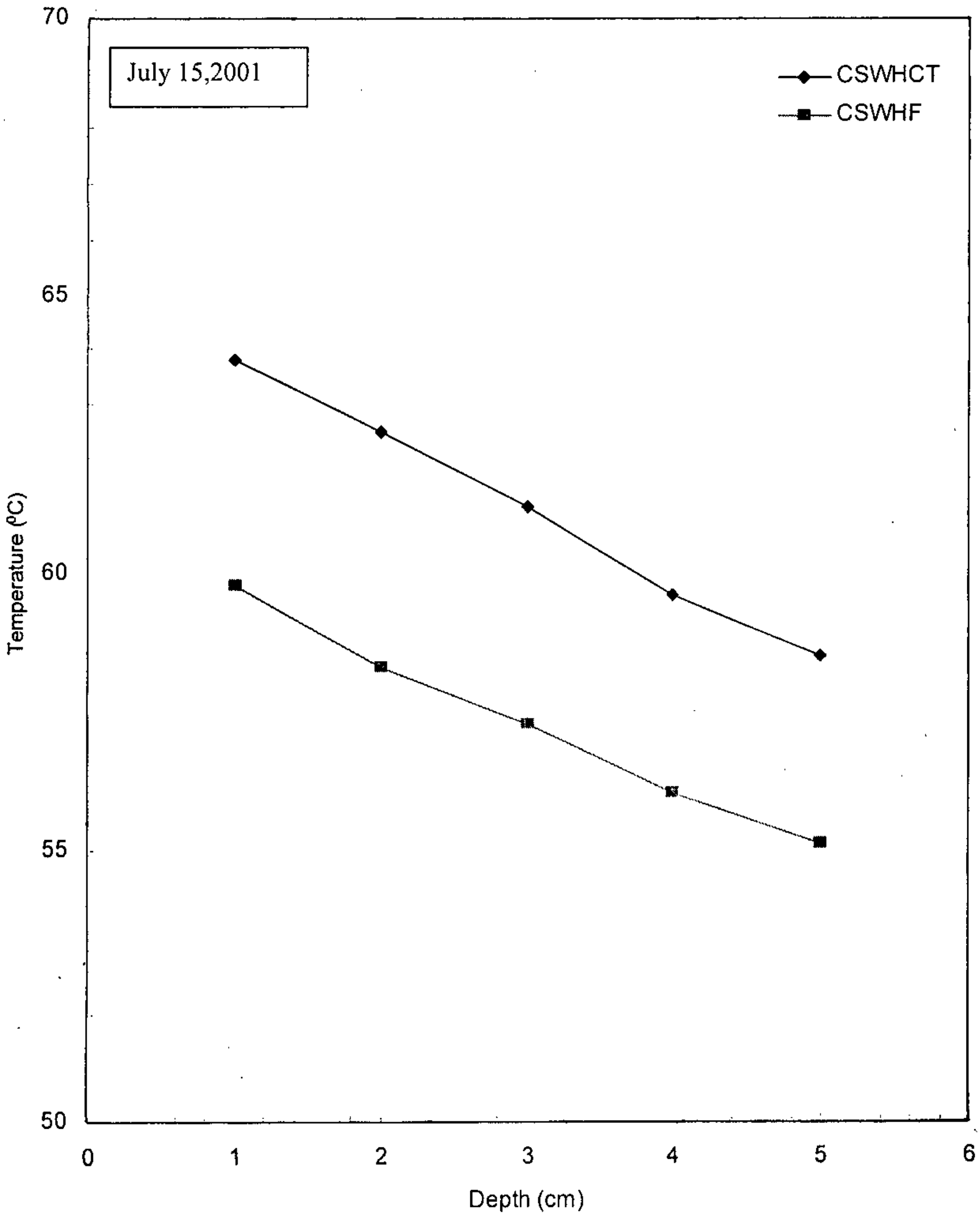

Fig. 5.25 Distribution of Temperature Along the Depth of Collector

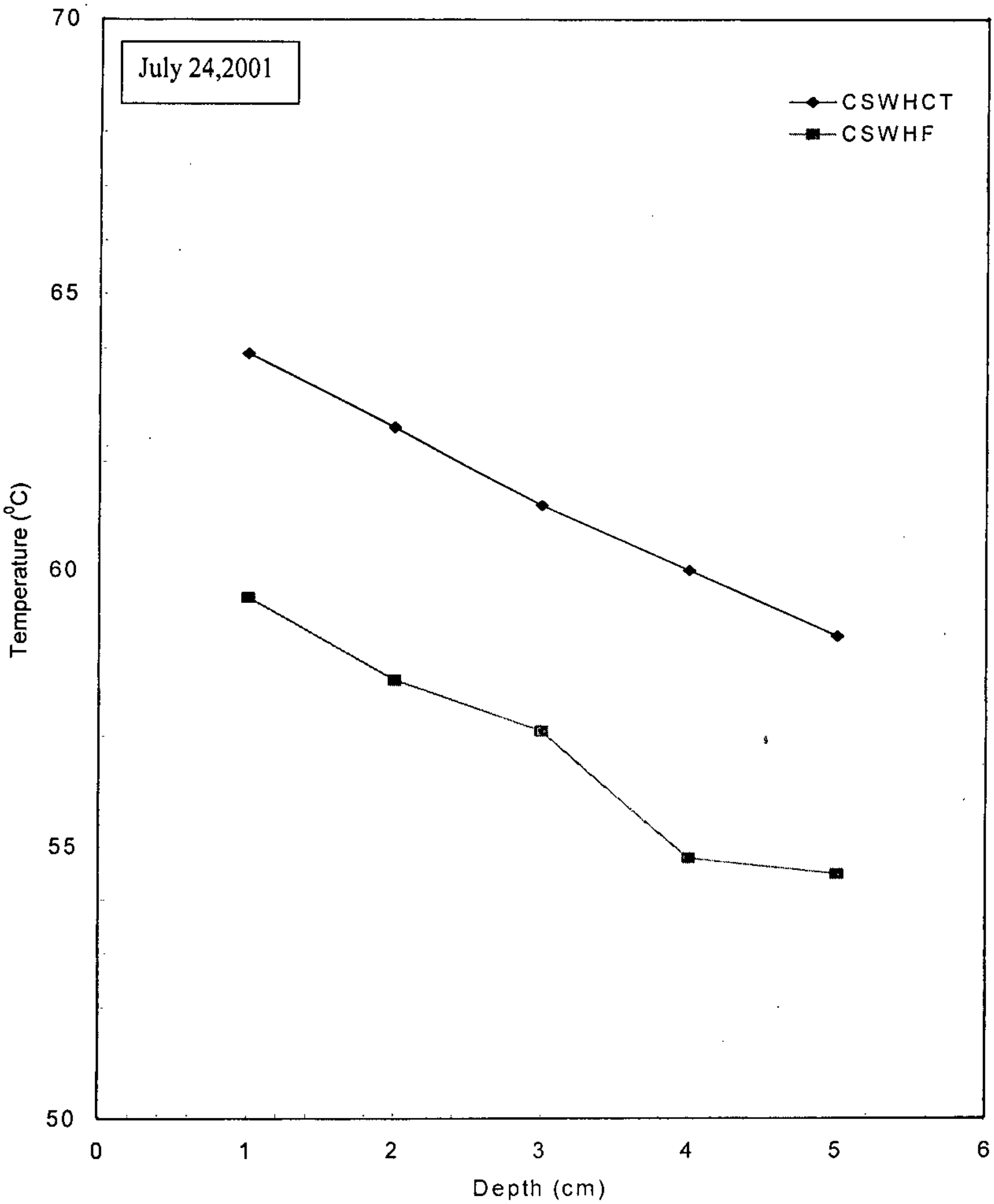

Fig. 5.26 Distribution of Temperature Along the Depth of Collector

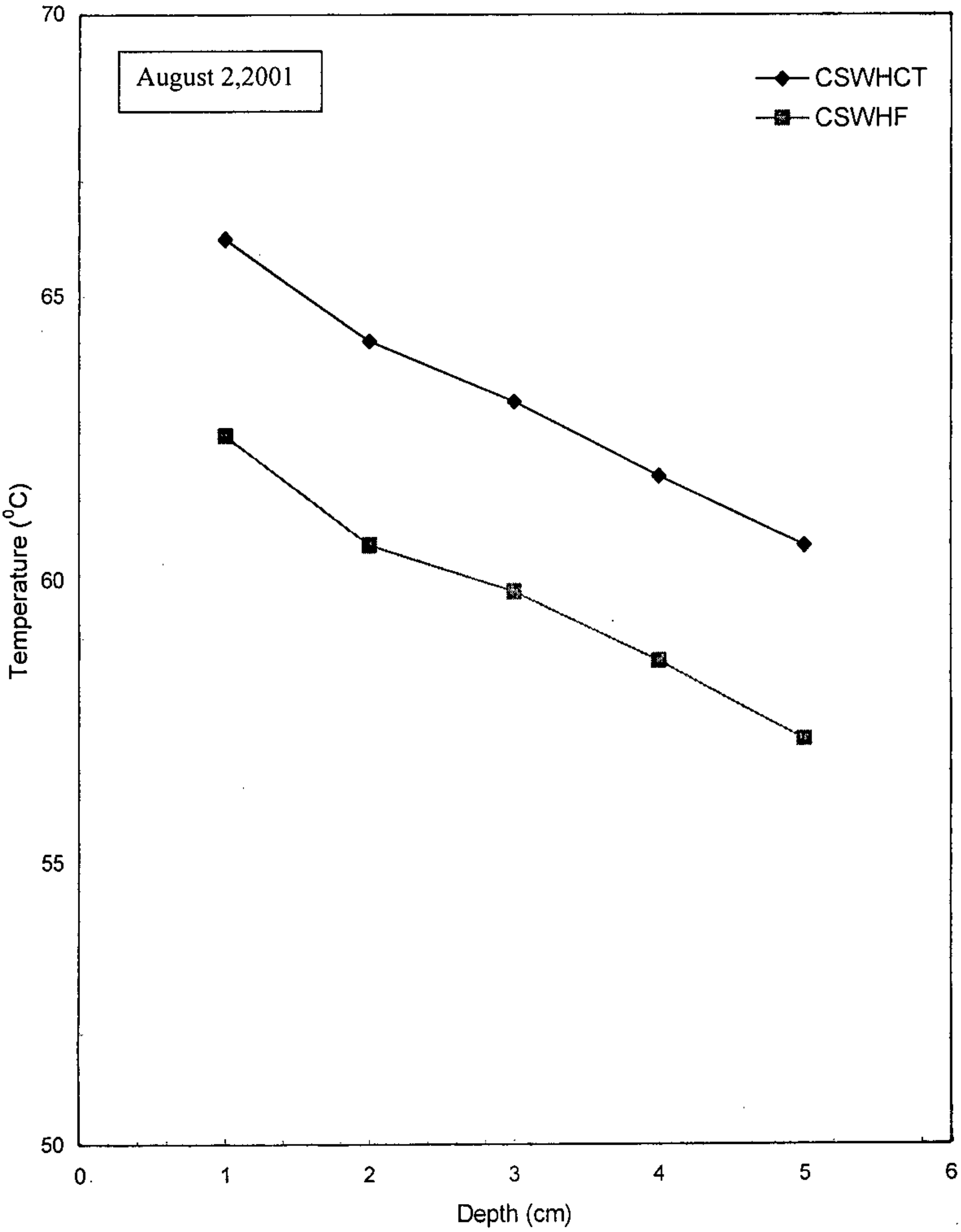

Fig. 5.27 Distribution of Water Temperature Along the Depth of Collector

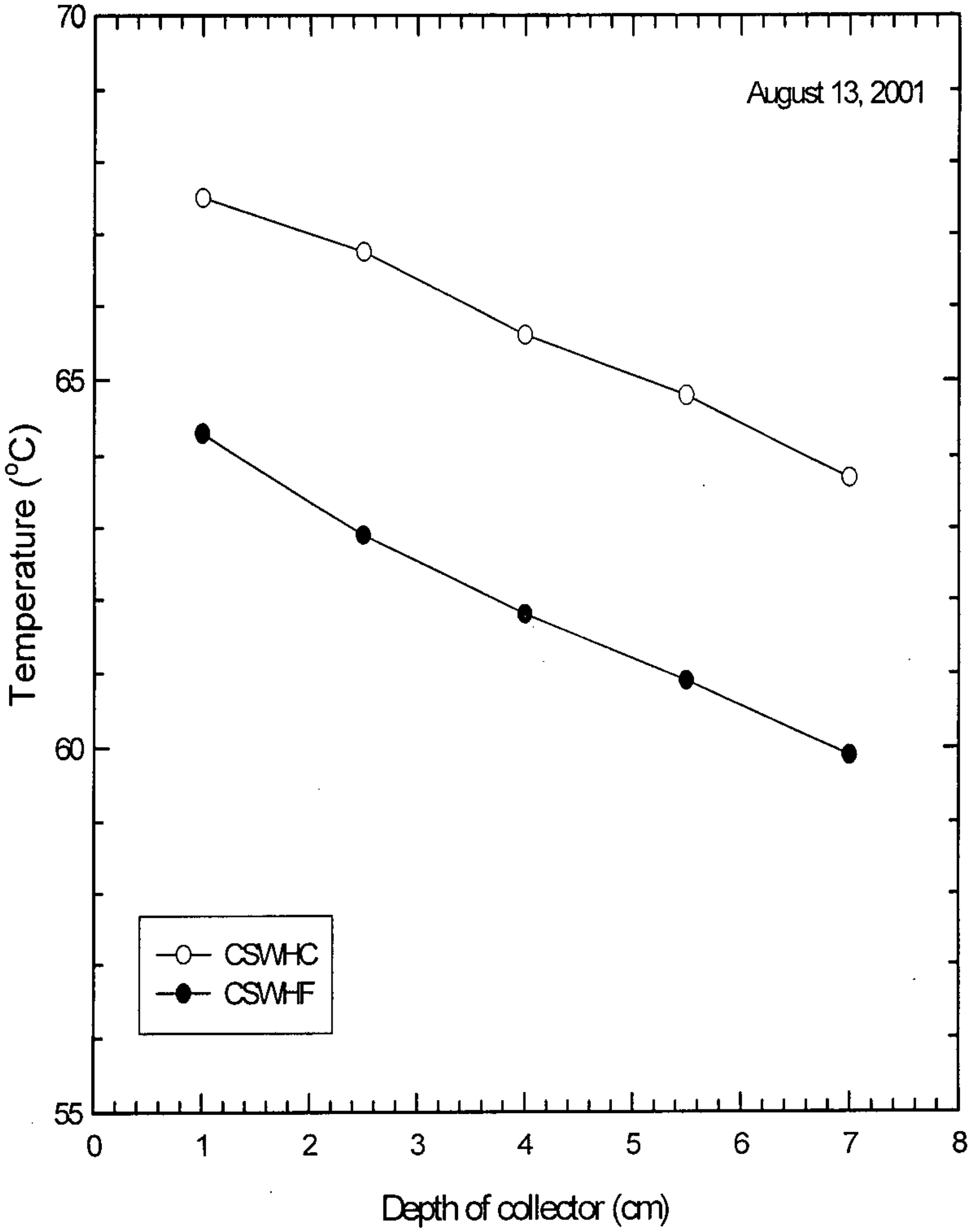

Fig. 5.28 Temperature Distribution of Water Along the Depth of Collector

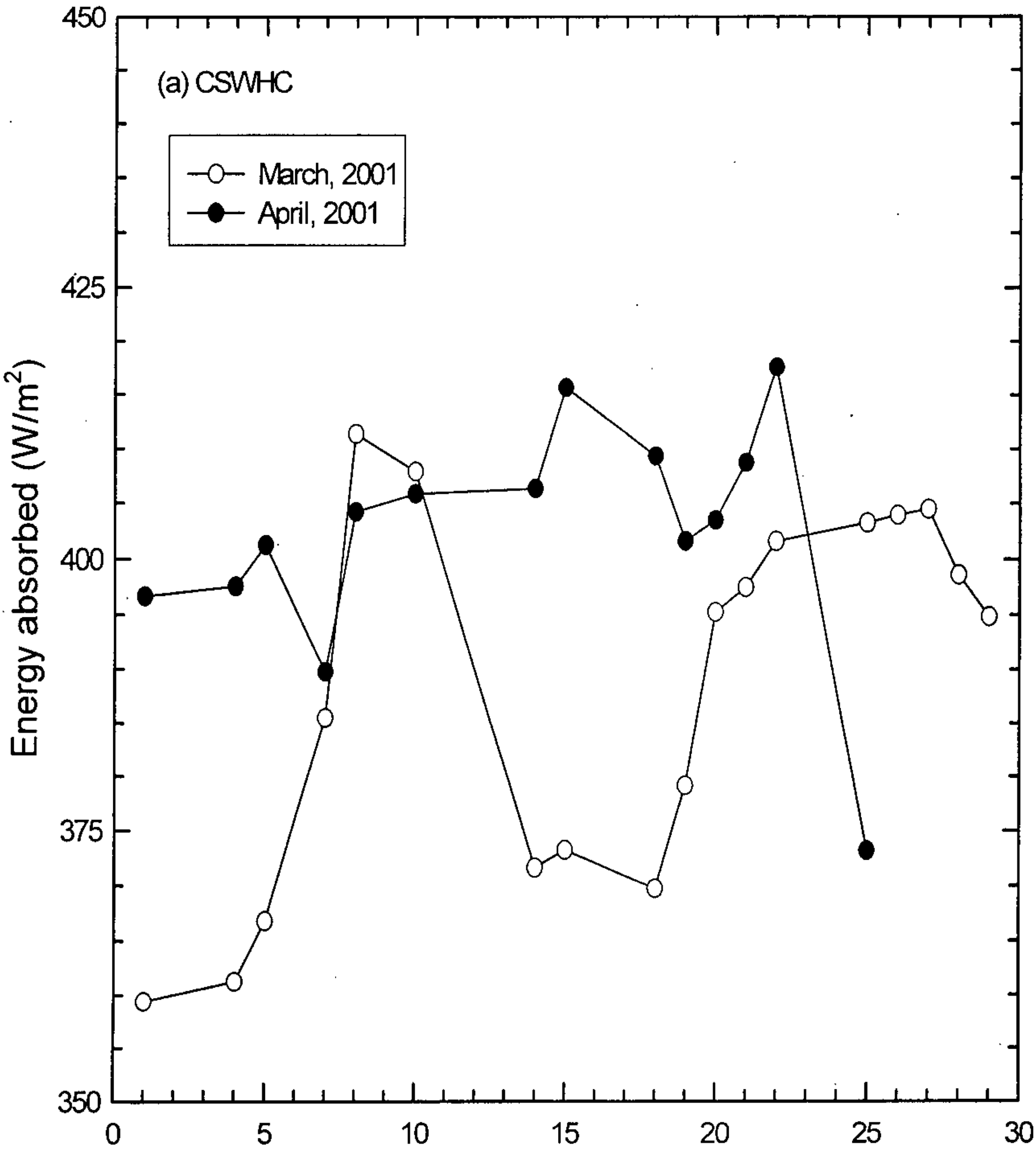

Fig. 5.29 Daily Average Energy Absorbed

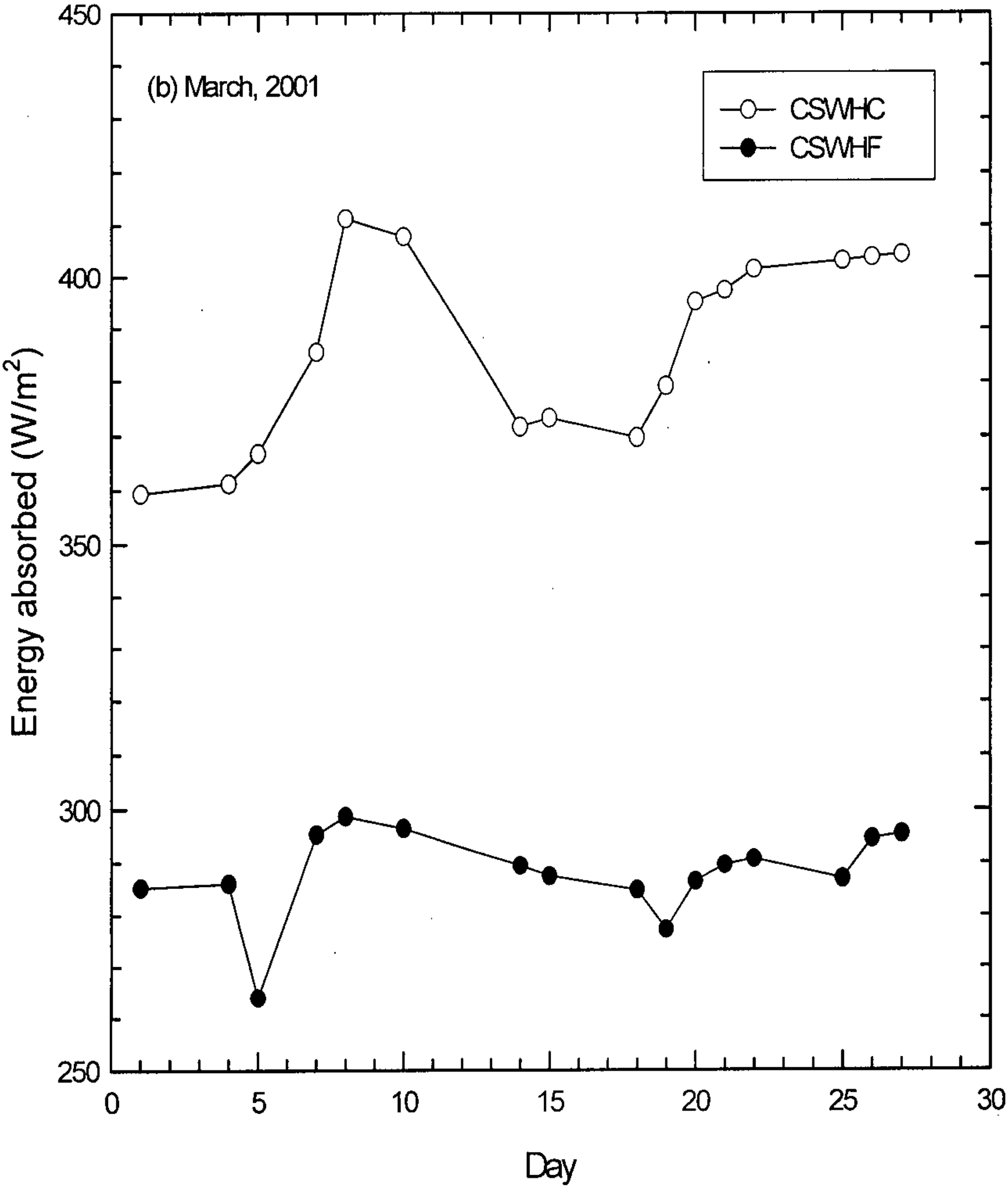

Fig. 5.30 Daily Average Energy Absorbed

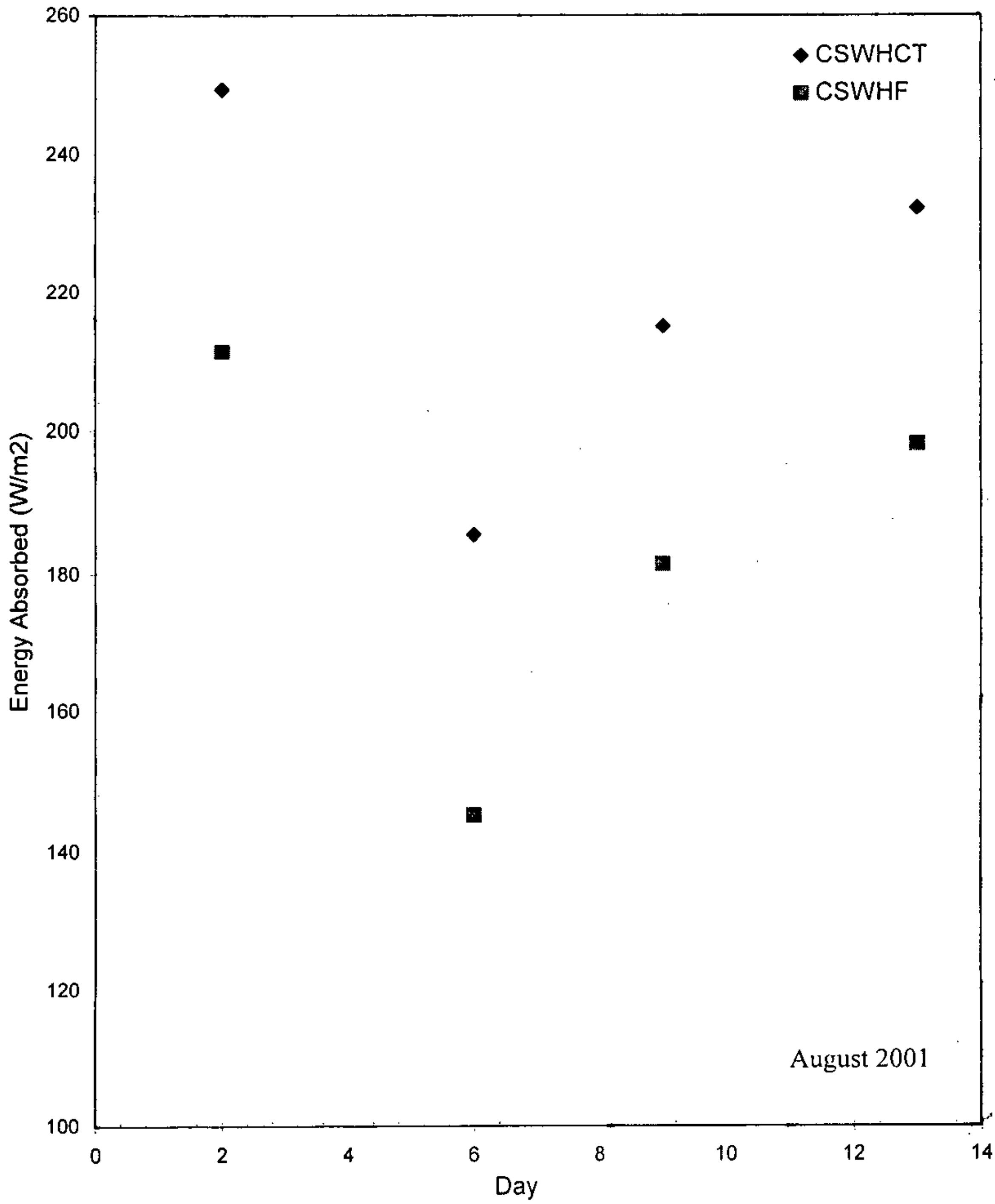

Fig. 5.32 Daily Average Energy Absorbed

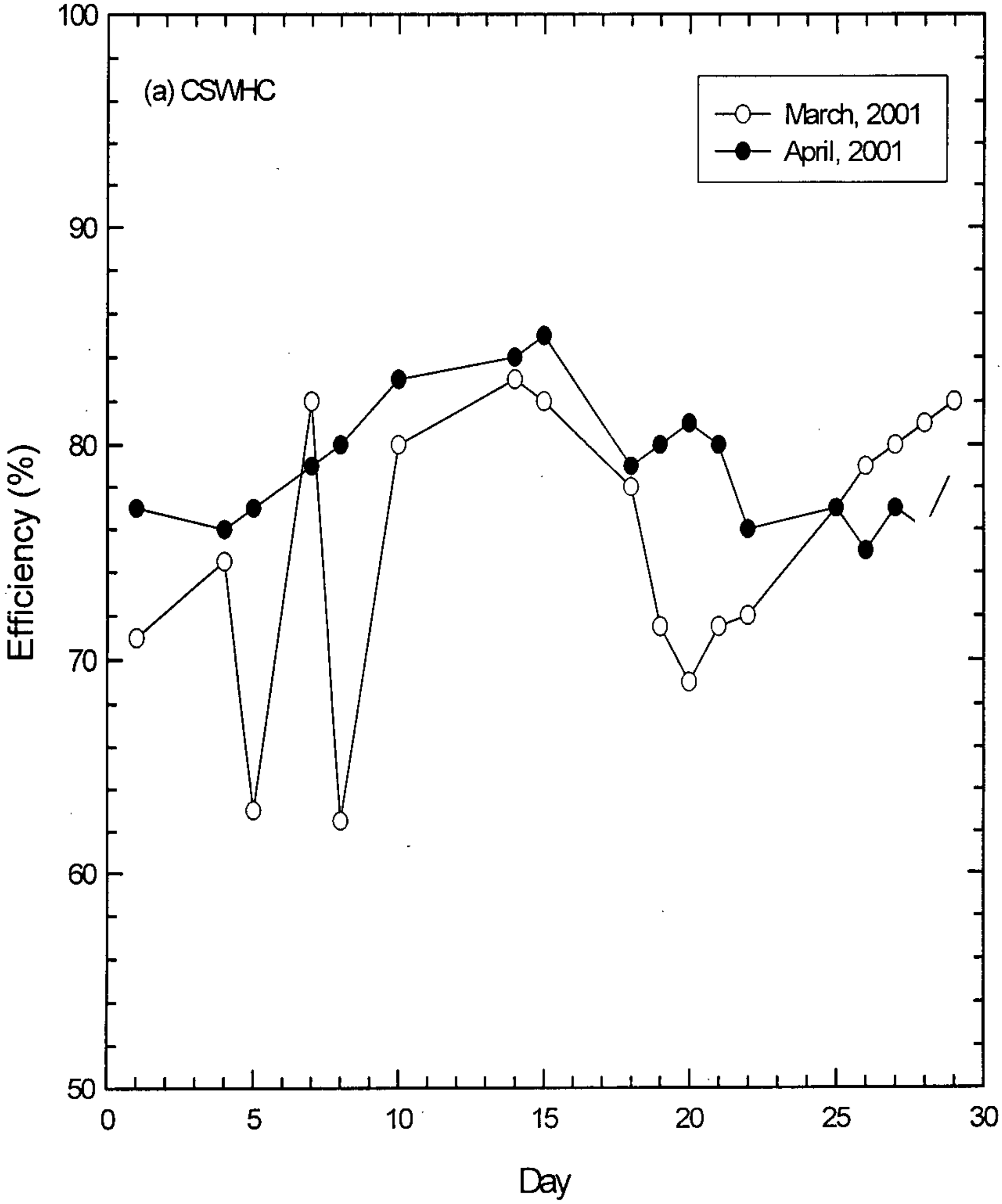

Fig. 5.33 Comparison of Performance

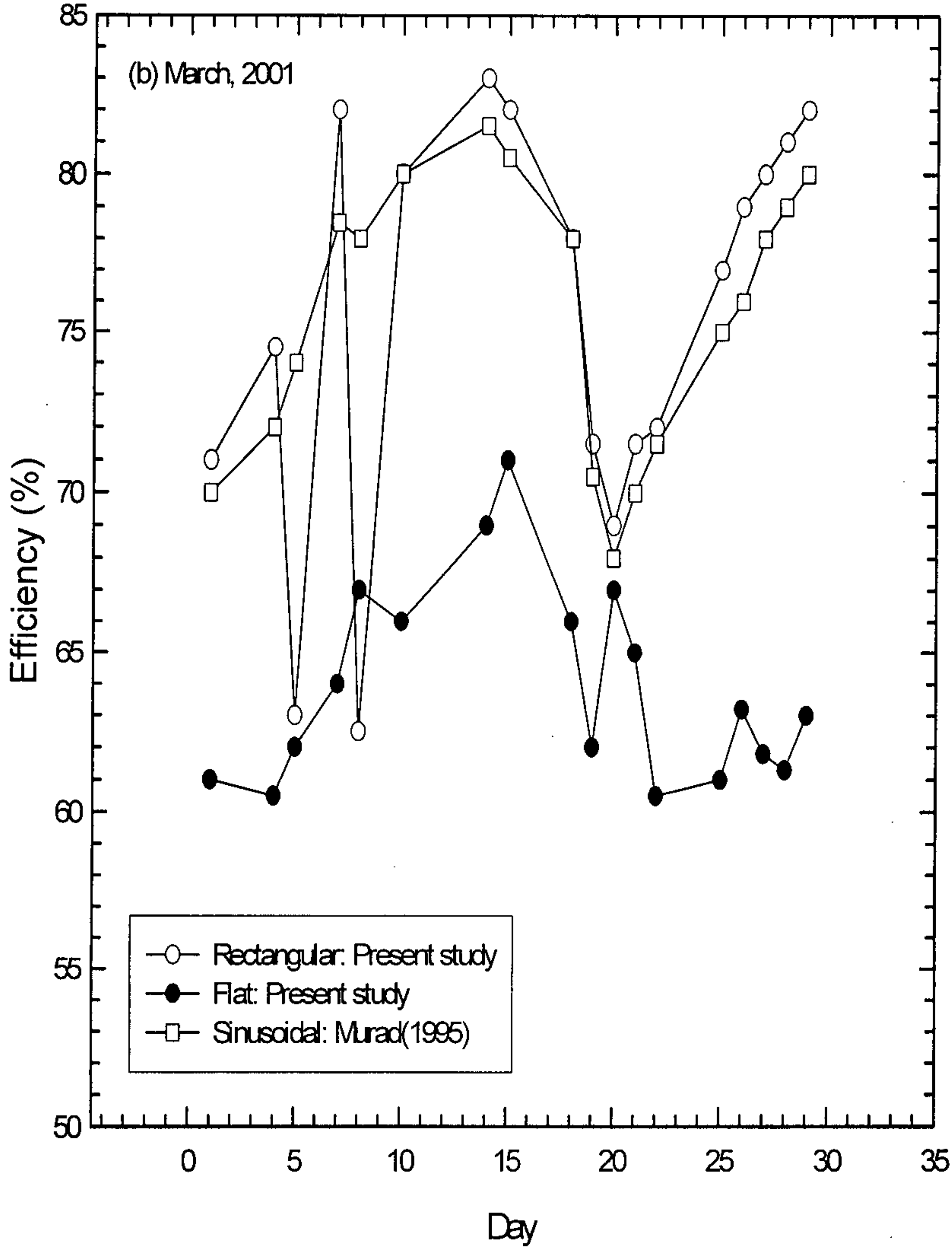

Fig. 5.34 Comparison of Performance

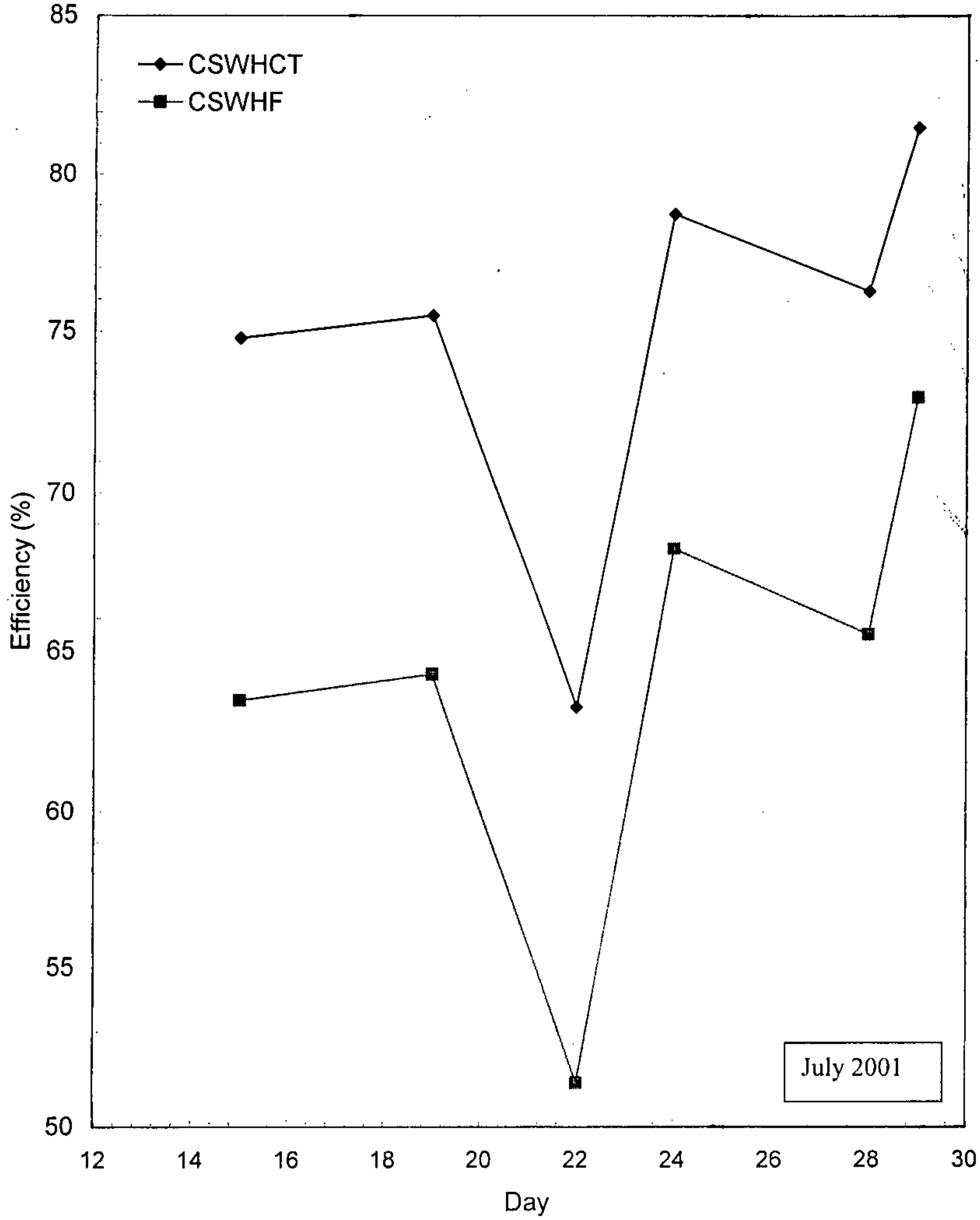

Fig.5.35 Performance comparison

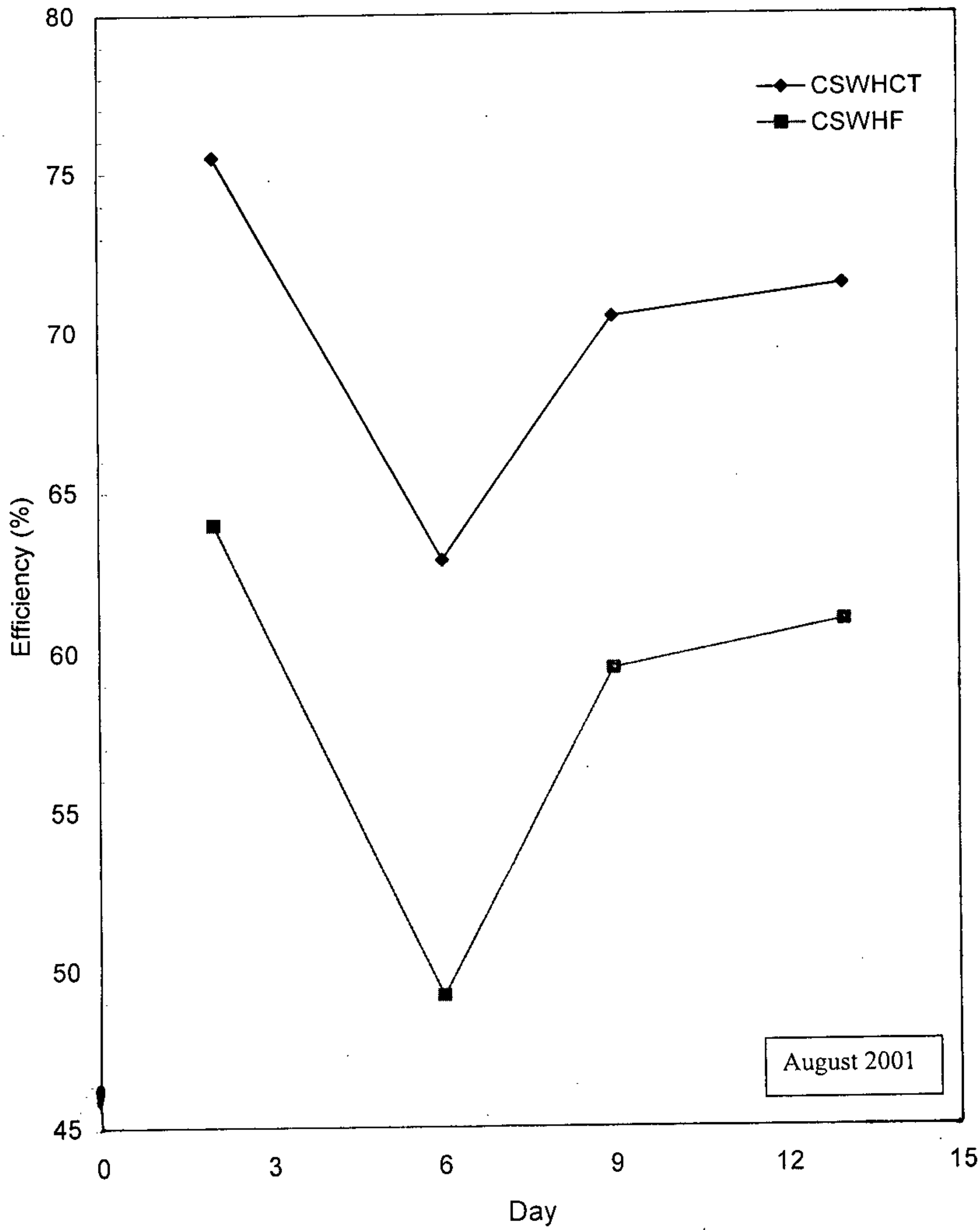

Fig. 5.36 Performance Comparison

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APPENDIX A

A.1 SAMPLE CALCULATIONS

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

$$\eta = \frac{\int (Q/A)\,dt}{\int I\,dt}$$

Where,

Q	=	$mc_p\Delta T$
m	=	mass flow rate = 124 kg/ hr
c_p	=	4.187 kJ/kg K
A	=	Collector area in m^2
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 suggested by Marshal-Adams (1978);

$$\eta = (Q/A)/I$$

$$= q/I$$

$$= Q/AI$$

$$= mc_p\Delta T/AI$$

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

Now, $q = mc_p\Delta T/A$

$$= \frac{124 \times 4.187}{1.443 \times 3600} \times \Delta T \quad (kW/m^2)$$

$$= 0.0999\,\Delta T \quad (kW/m^2)$$

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 C_p value of water were assumed constant within the temperature range between 15^0 C to 65^0 C, performance was assumed steady state. Temperature drops through covers, edge losses and heat losses due to convection were negligible.

For March 8, 2001

$$q = 0.0999\ \Delta T \quad (kW/m^2)$$

Where, ΔT = Rise in temperature of water in one hour.

$$q_1 = 0.0999 \times 6.1 \quad (kW/m^2)$$
$$= 0.61 \quad (kW/m^2)$$
$$q_2 = 0.0999 \times 2.7 \quad (kW/m^2)$$
$$= 0.27$$

Similarly, for 9 hours, Σq = 3.7125 (kW/m^2)

Daily average hourly heat output, $q_{av} = (3.7125\ (kW/m^2))/9$
$= 0.4125\ (kW/m^2)$

From Helali (1985)

$$1\ cal = 4.186\ J$$

Now, $I = X\ cal/cm^2.\ day$

$$X = [4.186\ J \times (100 \times 100)]/\ [m^2.\ day]$$
$$= X\ (\ 41860/\ m^2.day) \times (J/s) \times (hr/3600)$$
$$= 0.01163X\ \ kW/m^2.day$$
$$I_{av} = 0.01163\ X/N\ \ kW/m^2$$

Where, X = Solar Insolation in $cal/cm^2.day$

N = Day length of bright sun shine in hr.

<u>For example, for March 8, 2001</u>

Here, $X = 532.3\ \text{cal/cm}^2\text{.day}$

$N = 11.4$

$$I_{av} = 0.01163 \times X/N\ \text{kW/m}^2$$
$$= 0.01163 \times (532.3/11.4)\ \text{kW/m}^2$$
$$= 0.543\ \text{kW/m}^2$$

Efficiency,

$$\eta = (q_{av}/I_{av}) \times 100\%$$
$$= (0.4125/0.543) \times 100\%$$
$$= 76\%$$