ENVIRONMENTAL CONTROL IN GREENHOUSES FOR HUMID TROPICS

BY

BOBBY, T.
SINIJA, V.R.
SURESH, A.

PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **"ENVIRONMENTAL CONTROL IN GREENHOUSES FOR HUMID TROPICS"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellow-ship or other similar title of any other University or Society.

BOBBY.T

Place : Tavanur

Date : 31st May 1997

SINIJA.V.R

SURESH.A

CERTIFICATE

Certified that this project report entitled **"ENVIRONMENTAL CONTROL IN GREENHOUSES FOR HUMID TROPICS"** is a record of project work done jointly by Bobby. T, Sinija.V.R and Suresh.A under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

Place :Tavanur

Date : 31st May 1997.

Er. E.K. Kurien,

Assistant Professor,

Department of IDE,

KCAET, Tavanur.

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SINIJA. V. R

SURESH. A

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SYMBOLS AND ABBREVIATIONS

A	-	ampere
Agric	-	agriculture
am	-	ante meridian
ASAE	-	American Society of Agricultural Engineers
CIAE	-	Central Institute of Agricultural Engineering
cm	-	centimetre (s)
Ed	-	edition
Engg	-	engineering
elev	-	elevation
Fig	-	figure
GI	-	galvanised iron
h	-	hour(s)
Hort	-	horticulture
hp	-	horse power
Hz	-	hertz
i.e.	-	that is
J	-	journal
kW	-	kilowatt
lph	-	litre(s) per hour
lps	-	litre(s) per second
m	-	metre
ml	-	millilitre(s)
mm	-	millimetre(s)
m^3/h	-	cubic metre per hour
No.	-	number
pm	-	post meridian
ppm	-	parts per million
Proc	-	proceedings

PVC	-	poly vinyl chloride
Res	-	research
RH	-	relative humidity
rpm	-	revolutions per minute
Sl. No.	-	serial number
Temp	-	temperature
UV	-	ultra violet
V	-	volt
Vel	-	velocity
W	-	watt
W/m	-	watt per metre
^{o}	-	degree
$'$	-	minutes
$''$	-	seconds
:	-	isto
^{o}C	-	degree centigrade

INTRODUCTION

Agriculture is not only a noble profession to earn livelihood for Indians, but it is the backbone of our rich cultural heritage. The trade and business links with other countries, mainly concerned with agricultural products were set up in earlier centuries and still now our economy and export are mainly dependent on agriculture based products.

With independence, the production of food increased through the emergence of new land policies, efficient irrigation systems, improved seeds and use of fertilizers. This also led to the adoption of improved methods and technologies which has led to the development of the rural poor. The metamorphosis of traditional agriculture to a technology oriented process has made marked effects on production systems.

Apart from food production, high value farm products especially horticultural crops like fruits, vegetables, flowers and other floricultural products has gained vast export potential in the recent years.

The environment in which the crops grow, plays a decisive role in their production phenomena. To make optimum use of land, air and water resources, agriculture has to be in tune with the prevailing environment conditions. The choice of crop varieties and engineering practices to be adopted are very important.

Technological advancement by way of environment control using mulches, cloches and long tunnels and greenhouses has resulted in tapping full potential of crops. In these structures , environment factors like light, temperature and air composition that affect the plant growth can be modified . The plant growth and production is not only increased under the aegis of these structures but they can be produced regardless of the climate prevailing outside them. All types of plant except tall trees could be grown under the greenhouses and this accounts for the wider adaptability of these structures.

The greenhouse technology that originated in the seventeenth century in Holland was meant for the production of spring flowers in winter and fruits out of season. Later, these structures were fabricated with wooden frames with glass or oil paper cover with or without artificial heating used. In the nineteenth century, the lean-to-type greenhouses using glass sloping were introduced. This give birth to a trade channel to Netherlands and they have now become pioneers in greenhouse vegetables and cut flower production.

One of the major advantages of greenhouse are that the length of growing season can be increased. It is also possible to grow long season crops in places where summers are short. Moreover, more than one crop can be grown in the greenhouse in the same land in one growing season. The diseases in crops can be prevented as well as pest surveillance is easy. The emergence of cuttings and grafts can be enhanced in the controlled environment.

The importance of green houses in the Indian scenario is mainly concerned with the uncultivable lands which can be brought under cultivation which accounts to about 75 mha. The major hurdle in the wide spread implementation of this technology is that greenhouses required high investment as well as the short life of the covering material. This can be overcome by adoption of materials easily available near the area as well as modification of existing materials to suit the needs of the specific regions.

The extent of fluctuation in the parameters that has to be controlled in the green house are region specific and also crop specific. There fore, the same methods of climate control cannot be followed for different regions and the same crops required different types of climate control in different regions according to the external climate. So, greenhouse climate has to be studied in different regions and the parametric changes and their control has to be ascertained.

For this purpose this study was undertaken in the greenhouse of plasticulture development centre constructed in the instructional farm of K.C.A.E.T., Tavanur. The objectives of the present study are as follows:

1. To study the parametric variations in temperature, relative humidity and solar intensity both inside and outside the greenhouse with out effecting any cooling inside the greenhouse.
2. To study the changes in these parameters when different cooling methods were adopted.

REVIEW OF LITERATURE

A brief review of the study about the climatic conditions especially the changes in temperature, relative humidity, solar intensity, air exchange etc. inside the greenhouse are dealt in this chapter.

Of the various practices adopted for controlled environment agriculture, greenhouses are the most common because of their wider adaptability. The green houses gained importance because of the following advantages. (Khan *et al.*, 1995)

1. High productivity per unit area as the genetic potential is fully exploited.
2. Any crop can be grown in any place in any season of the year depending on the demand and the market.
3. Excellent quality produce free from any blemishes.
4. Higher extent of bud or graft take and extended period of grafting.
5. Easy to protect from pests and diseases.
6. Getting the produce early in the season with minimum requirement of water.

2.1 Protected cultivation

Protected cultivation aims at the creation of a modified environment which effects maximum production. The various forms of protected cultivation included cloches , low tunnels, growth chambers, mulches and greenhouses.

Cloches and low tunnels protect the plant or row plants from adversities such as cold climates, high winds, intense rains, hail and snow. They have no provision for artificial heating or cooling (Nelson, 1981).

Growth chambers have provision for controlling various parameters like temperature, humidity, ventilation and light are helpful in studying the growth dynamics of a particular crop under controlled environment. They also help in the study of the growth of microbes and other side effects of environmental control. This helps in furnishing of optimum parameters for plant growth which can be made use in the greenhouse design (Nelson, 1981)

Mulches are shallow layers at the soil surface which improve soil micro climate, heighten crop production, reduces the irrigation, frequency, reduces weed growth and prevent the injury from solar radiation, conserves moisture and reduces soil temperature and growth of soil borne pathogens(Khan *et al.*, 1995).

2.1.1 Greenhouses

A Greenhouse is a structure covered with transparent material that utilizes solar radiant energy to grow plants (Masterlez, 1977).

According to Dalrymple (1973), greenhouses are framed or inflated structures covered with transparent or translucent material in which crops can be grown under the conditions of atleast partially controlled environment and which are large enough to allow a person to walk within them to carry out agricultural operations. The transparent or translucent material acts like a selective filter which allows the solar radiations emitted by the objects within the greenhouse. This effect known as greenhouse effect, increases the temperature within the greenhouse. The level of carbondioxide as well as humidity increases inside the greenhouse due to the retention of radiant heat inside the greenhouse. Thus it reduces the water requirement of plants due to the increased humidity as a result of transpiration losses.

Mears (1990) had discussed the possibilities of greenhouse technology in India. The Indian subcontinent which lies between 40 ^{o} and 8^{o} north of equator, with regions of extreme temperature conditions where open field cultivation is not feasible, greenhouse technology makes a significant contribution. The spectra of agroclimatic zones in India and the need for modern research in controlled environment,commercial use of greenhouse in plant production, plant culture etc. necessitates greenhouse systems.

A greenhouse in a particular climate can create an environment suitable for certain species but it may not produce a same suitable environment at a different location. This means that the creation of specified environment related to the existing ambient conditions which intrun affects the method as well as the economic feasibility of creating such an environment.

2.1.1.1 Types of greenhouses

Different styles of greenhouse designed to meet specific needs described by Masterlez (1977) are

1. Lean-to greenhouse

These are usually extension of some buildings and can produce a wide range of plants. This design make best use of sunlight and minimizes the requirements for roof supports.

2. Detached or single span greenhouse

These may be of different shapes viz., zuonset, gothicarch, gable and dome shaped. The total incidence of solar energy is more in single span greenhouses. A single unit can cover a floor area upto $500m^{2}$.

3. Ridge and furrow greenhouse

These are also called multispan or gutter connected greenhouse. Ridge and furrow refers to two or more greenhouses connected to one another along the length of cave. The cave serves as a furrow or gutter to carry rain water away. The side wall is eliminated between greenhouses which results in a structure with single span greenhouses due to less energy consumption and low labour cost.

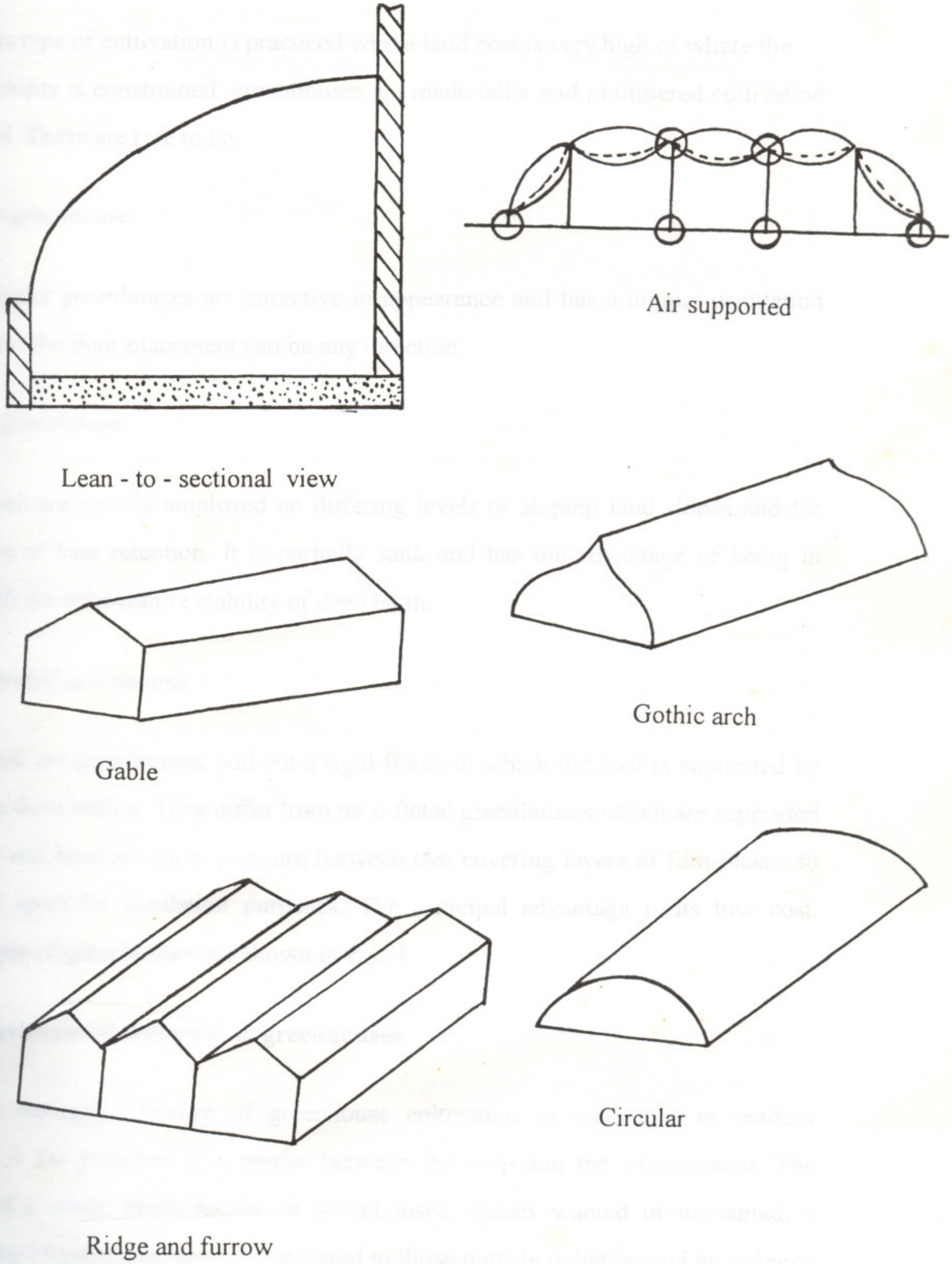


Fig . 1 Greenhouse shapes.

4. Tower greenhouse

This type of cultivation is practiced where land cost is very high or where the land availability is constrained, greenhouses are made taller and multitiered cultivation is practiced. These are rare today.

5. Circular greenhouse

Circular greenhouses are attractive in appearance and has a unique ventilation system. Here the door placement can be any direction.

6. Pit type greenhouse

These are usually employed on differing levels or sloping land slopes and for the purpose of heat retention. It is partially sunk and has the advantage of being in contact with the temperature stability of deep earth.

7. Air supported greenhouse

These are greenhouses without a rigid frame in which the roof is supported by air pressure from within. They differ from air inflated greenhouses which are supported by a frame and have air under pressure between two covering layers of film plastic to keep them apart for insulation purposes. The principal advantage is its low cost. Various types of greenhouses are shown in Fig. 1

2.1.2 Environmental control in greenhouses

The distinctive feature of greenhouse cultivation as compared to outdoor cultivation is the presence of a barrier between the crop and the environment. The presence of a cover, characteristic of greenhouses, causes wanted or unwanted, a change in the climatic condition as compared to those outside:radiation and air velocity are reduced, temperature and water vapor pressure of the air increase and fluctuations in carbondioxide concentration are much stronger. Each of these changes has its own impact on growth, production and quality of the greenhouse crop, some of them being detrimental. This passive changes in the greenhouse weather, traditionally referred to as greenhouse climate in combination with fluctuating outside weather conditions, force the grower into an active role with respect to climate conditioning (Bakker,1995)

2.1.2.1 Temperature

Kachru and Rajinder (1985) reported that desirable temperatures can be maintained in a greenhouse with a well designed cooling and / or heating systems. Various techniques viz., ventilation, roof shading, maintaining water film on the glass and evaporative cooling has been suggested for greenhouse cooling. For heating purposes one could use hot water or steam and run it through coils in various arrangements, forced hot air, infrared heat or electricity to increase the temperature in winter months.

Kempkes (1985) carried out studies to gain an insight into the vertical temperature differences in greenhouse. Temperature distribution was monitored with a network of 54 thermocouples in four compartments in which tomatoes were grown. The results showed that temperature differences produced differences in yield.

Tomalty (1988) recorded the maximum and minimum temperatures inside and outside a passive solar greenhouse located at Arcosanti in the Arizona desert. It was concluded that the greenhouse provided a better environment for vegetable growth than the outside environment.

Thomas(1989) recorded the maximum and minimum temperature, relative humidity and light intensity at 15 points inside a low cost greenhouse. They indicated that relative humidity and temperature profiles do not change significantly.

Galansauco (1992) studied on the physiological and production differences between greenhouse and open air bananas in Canary Islands. Temperature was the main factor governing banana growth and development. Greenhouse banana exhibited greater height.

Olympios(1992) during his studies on the effect of temperature, humidity and carbondioxide enrichment in raising cucumber seedlings in Mediterranean countries found that for maximum growth, high temperature must accompanied by high relative humidity.

Temperature is the only environment factor which has a direct effect on the sink strength of individual organs of the plants and consequently in commercial practice, temperature constraints are primarily used for control of biomas partitioning in greenhouse corps. Besides the effect on growth and development, temperature has effects on production through maintenance of the respiration. The average temperature has significant effect on growth and also the difference in day and night temperature affects the morphology ie. leaf area and to a large extent internode length. It has its own effects on the energy balance of the system (Bakker, 1995)

2.1.2.2 Humidity

Hand (1988) carried out investigations to find the effects of atmospheric humidity on greenhouse crops. He reported that ,from a crop production stand point the test strategy is to maintain a high humidity during the day to avoid too high a humidity at night. Such a regime will maximise the quality of output and minimise the risk of plant diseases.

Pelletier (1988) during the trails with cucumber grown with or without misting to maintain relative humidity at 70 per cent, the yield has increased and the plant losses are decreased.

In another trail the misting system was operated either when a minimum humidity (70 per cent) or a minimum temperature (26 to 30 °C) was reached. Control based on temperature was more difficult to achieve and gave high humidities leading to increased disease incidence although yield was not affected. In an unshaded house, misting decreased the air temperature by 8°C.

High humidity has significant impact on the energy balance of the crop as on average the major fraction of the incoming solar radiation is transferred to latent heat. Temporary shifting of this fraction to lower values implies a significant increase of convective and thermal heat exchange, consequently a much higher leaf temperature. Also, sudden changes in humidity can cause heat injury because of water uptake cannot match the transpiration rate. Long term exposure to high or low humidity have beneficial as well as detrimental effects on growth and production. The adhesion of stigma in the flower may be strongly influenced by the varying humidity as well as key processes such as pollination is also influenced by humidity. This constraint has its influence on incidence of pest and diseases and has a key role in maintaining the quality of product (Bakker, 1995).

2.1.2.3 Light

Amsen (1981) from his studies on environmental condition in different types of greenhouses reported that the light intensity was dependent not only on the covering material but also on the construction. The insulated houses showed a severe reduction of light.

Challa and Schapendonk (1984) for their studies on the quantification of effects of light reduction in greenhouses on yield found that young widely spaced plants, as opposed to older plants growing in a closed canopy. With young plants the effect of light on growth rate was less proportional while the rate of production of older plants was approximately proportional to light except for low irradiances.

El-Aidy (1984) reported that yield of tomatoes was higher under shade than in open. But such tendency was found to decrease with the increase in amount of shade, 40 percentage shade was best in this respect.

Smith *et al.,* (1984) analyzed the environment inside a plastic tunnel with or without 30 percentage shade cloth in South Africa. Tomato yields were best under 15 percentage shade in comparison to under plastic 40 percentage shade and in the open. Shaded plants grew taller, had more leaves in a given time, had a greater leaf area and a smaller root system.

Aage (1985) from his studies on the influence of light quality in controlled environment found that light quality or specific energy distribution is an important factor.

Chandra (1985) reported that plants growing in open fields became light saturated at about 32280 lux assuming that all the leaves are exposed to the same intensity. The radiant flux density of full sun light varies from 86080 to 1,07,600 lux on a clear day. In energy units, the requirement is 80 to 120 W/m plant height.

Weimann (1985) in his study on light transmissivity of different film coverings on greenhouses reported that the transmissivities differ between 52 to 70 percentage of outside radiation and dependent on the age and layers of the film and the greenhouse construction.

El-Cizawy *et al.*, (1989) carried out a field trial during the later summer on tomato plants to study their performance under shading in Egypt. They found that increased shading significantly increased plant height and leaf area. The number of days for sowing and flower appearance increased as the shading level increased. The maximum yield was optioned under 35 percentage shading. The quality of roots were also high at 35 percentage shading.

Zanen and Ing Maurizio(1990) remarked that photosynthesis measured as released carbondioxide depends on the light intensity and increases with luminosity. The increase was found in a definite range beyond which there was no effect.

Light may be considered the most important environmental factor in the greenhouse culture as it influences a wide range of processes related to photosynthesis, energy balances including transpiration, phase transitions and morphology. In general, low light intensity is the most important environmental restraint to maximum photosynthesis and growth. The opening and closure of stomata, thereby the transpiration is affected by the light intensity (Bakker, 1995).

In order to achieve good growth of plants inside the greenhouse, there should be sunshine of desired quantity and intensity. In some circumstances, artificial light may be provided to supplement the deficit. Thus light in greenhouse is to be regulated so that an excess of it does not harm the crop. Light control in addition to other parameters can be used for enhancing or delaying the maturity of crops. (Bakker, 1995)

2.1.2.4 Carbondioxide

Gaastra (1959) showed that an ambient level of carbondioxide (330ppm), the increase in the rate of photosynthesis with light intensity is dependent of temperature over the range of 20-30°C whereas at an elevated level of carbondioxide photosynthesis increases with temperature.

Keimball and Mitchell (1978) from experiments on carbondioxide enrichment of tomatoes in unventilated greenhouses in an arid climate reported that, enriching air with carbondioxide in conventionally ventilated greenhouse in an arid climate can increase tomato yields by about 10 per cent. In unventilated greenhouses, carbondioxde enrichment can increase yield by 50 per cent.

Heij and Uffelen (1984) conducted studies on the effect of carbondioxide concentration on growth and production of greenhouse vegetable crops. The carbondioxide concentration was set up below and above the ambient level. Maximum growth rate values were found at 800ppm.

Zipori *et al.*, (1987) conducted studies on intermittent enrichment in closed greenhouses. Carbondioxide was applied during parts of the day when temperature was above 30°C in alternating cycles of enrichment and ventilations. High yields were obtained.

Olympios (1992) conducted studies on the effect of temperature, humidity and carbondioxide enrichment in raising cucumber seedlings. It was concluded that for maximum growth, high temperature must be accompanied by high relative humidity and this combination allow higher rates of carbondioxide injection.

Carbondioxide has a marked effect on photosynthesis, growth and yield. Green plants convert carbondioxide into food in the presence of light and thus it is an inevitable raw-material. Normal air contains approximately 300ppm of carbondioxide in it and its concentration tends to increase with increase in solar radiant energy and barometric pressure. As humidity and temperature increase, carbondioxide levels tend to decrease and in a greenhouse carbondioxide level depletes due to high temperature and humidity (Bakker, 1995).

As the photosynthesis rate decreases, the yield and quality deteriorates. Thus carbondioxide management becomes an important and primary environmental factor to be controlled in greenhouses. The control of carbondioxide level in the greenhouse can provide significant means of controlling the water loss from plants and simplify the control of relative humidity in greenhouses.

2.1.3 Growth and production of crops

The rate of transpiration is lowered by the continued effect of lowering temperature and increasing relative humidity. This maintains the turgidity of guardcells which result in the opening of stomata and carbondioxide diffuses rapidly into the leaves. The rate of photosynthesis is enhanced in the presence of relatively high light intensity and also the rate of respiration is reduced. Thus high yields of high quality plants obtained if the plants are managed properly at all phases (Pandey&Sinha,1986).

Tskelev and Stoilov (1990) carried trials over 3 years on a fluorescent polythene film to establish light and temperature conditions in the greenhouse in Bulgaria. Four greenhouses were used, two for raising tomato seedlings and the other two for early tomatoes. Standard LDPE was used as control. The seedlings showed more vigorous growth at an early stage under fluorescent film. They had a better root system, thicker growth at an early stage under fluorescent film. They had a better root system, thicker stem, more leaves and large leaf area. Total yield was 23.4 per cent greater resulting in higher income.

2.1.4 Greenhouse heating

In colder climates, heat is lost through the covering materials or by infiltration through the leak points or by radiation from warm objects inside the greenhouse. In order to maintain the heat loss from the greenhouse, heat is supplied at the same rate using steam, forced hot air, infrared radiations, electricity etc. (Masterlez, 1977).

2.1.5 Greenhouse cooling

India, being a tropical country requires cooling as an environmental control measure in greenhouses. The air temperature and humidity can be maintained at desirable levels by natural convection or forced movement of air inside the greenhouse with or without the evaporation of water for cooling (Masterlez., 1977).

2.1.5.1 Ventilation

The process of exchanging air inside the greenhouse with outside air is known as ventilation of the green house. It is required to be done to remove surplus solar heat, to remove transferred water vapor and to supply carbondioxide. The volume of air exchanged per unit floor area is called the ventilation rate. Sometimes it is expressed as *internal* air volume exchange per unit of time, (Bakker, 1995)

2.1.5.1.1 Forced ventilation system

Natural ventilation has its own limitations regarding the ventilation rate and the air exchange for high ventilation rates, other means of forced ventilation system are to used. Exhaust fans of sufficient capacity can lower the temperature by 3 to 6°C and a larger reduction in temperature is affected using some evaporative cooling system.

Forced ventilation system can be accomplished by ventilation through perforated convecting tubes or by evaporative cooling (Bakker, 1995).

2.1.5.2 Evaporative Cooling

As water evaporates, heat is absorbed and this is the principle employed in evaporative cooling of greenhouses. The degree of cooling obtained from an evaporative system is directly related to the wetbulb depression that occurs with a given set of climatic conditions (Masterlez, 1977).

Landsberg *et al.,* (1979) made a computer analysis of the efficiency of evaporative cooling in which the air entering the greenhouse was cooled to the wetbulb temperature of the outside air. The results showed that in a greenhouse filled with freely transpiring plants, the air temperature in a glass house could be reduced by 10 to 15 per cent inspite of a high level of solar radiation.

Monteiro (1981) studied the effects on air water fogging systems on the greenhouse climate. Results indicated that the evaporative cooled greenhouse lowered its temperature by an average of 3 °C.

Abdulla (1986) conducted experiments on performance in a fan and pad cooled greenhouse at Saudi Arabia. Environmental conditions were monitored outside and at three locations along the centre line of the multispan, fan and pad evaporatively cooled greenhouse. These measurements showed a horizontal temperature gradient of 4.3 °C from the wetted pad to the exhaust fan and a vertical temperature gradient of 4.2 °C from the greenhouse to a height of 1.5m.

Chandra *et al.,* (1989) conducted experiments on evaporative cooling of plastic greenhouses. An experimental plastic covered greenhouse of 4 X 6m floor dimension was installed with a fan and pad system of evaporative cooling. Measurements of temperature, humidity, solar radiation inside and outside the green house and water consumption was made to study the resulting greenhouse thermal environments. The observed greenhouse temperatures were found to be within 2 °C of those predicted by a simple thermal analysis.

Garzoli (1989) reported that the evaporative cooling is normally the most effective means of cooling. It is based on the process of heat absorption during evaporation of water.

Bailey (1990) developed a simulation model to predict the temperature and vapour pressure deficits obtained in greenhouse with fan and pad cooling. The inside greenhouse temperature gradient between cooling pad and air extract fans is influenced by the extend of crop cover, the amount of external shading and the types of greenhouse cladding. Placement of exhaust fans should not be more than 7.5m apart, otherwise warm areas may develop.

Boulard and Baille (1993) proposed a greenhouse climatic model, incorporating the effects of natural ventilation and evaporative cooling. Linearization of the greenhouse heat and water balance equation leads to a simple system of two equations with two unknowns which represent quite well the complex coupling mechanism between ventilation and fog observed insitu. The model predicts that a minimum inside temperature can be reached for a certain combination of these cooling process. Crop temperature and transpiration were also estimated using the Penman Monteith approach and the energy balance of the crop. Good agreement between measured and computed values of air temperature, air humidity, crop temperature and transpiration was observed..

Govindan *et al.,* (1993) constructed a low cost greenhouse at the instructional farm of K.C.A.E.T., Tavanur. The salient feature of that pentagonal shaped greenhouse was the fan and pad evaporative cooling system used to control the temperature inside the greenhouse as desired. It was also possible to maintain the relative humidity at sufficient levels inside the greenhouse. The pad resistance was found to be 5mm of standard water guage.

Ajayambika (1995) built and tested a low cost greenhouse at the instructional farm of K.C.A.E.T., Tavanur.The size of the greenhouse was 12X3m and the structure was gable shaped. A fan of maximum air flow rate of 10450 m^3/h and a pad of size 3000 X 1200mm was found necessary to satisfy the cooling requirement. The maximum temperature recorded inside the greenhouse was 47.6 °C without cooling and 38.5°C with cooling. The polythene cover transmitted 60 per cent of the solar radiation incident on it. The average efficiency of the pad was 65 per cent.

Majumdar *et al.,* (1995) conducted study on the prediction of the cooling pad temperature in a fan and pad cooling system used in greenhouse. Measurements of pad temperature have been made in an experimental greenhouse employing a fan and pad cooling system. The results indicated that the pad temperature to be lower than the wet bulb temperature of the surrounding ambient air. An analysis of relevant energy exchanges permitted the formation of a differential equation, which estimated the time-dependent pad temperatures when solved numerically. The predicted and measured pad temperatures were within 2 °C.

2.1.5.2.1 Fan and Pad system

It is a mode of evaporative cooling in which the warm air from greenhouse is removed by the exhaust fans and the cool air is drawn in through the pads. The cooling has a greater effect. on the area of pads provided (Masterlez, 1977)

The air exchange rate from a greenhouse is measured in cubic metres of air per hour. Normally a rate of 144m^3/h/m^2 area is sufficient for a green house under 300 m in elevation with an interior light intensity of 53800 lux and a temperature rise of 4 °C from pad to the fans. The rate of air removal is increased with increase in elevation of the green house site, as air density decreases with increasing elevation. Thus, a larger volume of air has to be drawn through the greenhouse than at low elevation to effect equivalent cooling. . The correction factors for the change in elevation are given in Table 1 (Masterlez 1977).

The heat of air inside the green house also increases with the intensity of incident solar radiation and so it also affects the rate of air removal. from green house. Intensity of 53800 lux is accepted as a desirable level of crop in general. A 4°C increases in air temperature between the fan and the pad can be tolerated across the greenhouse. The correction factor for the solar intensity as well as air temperature is shown in Tables 2 & 3. (Masterlez - 1977).

The pad and fan should be placed on opposite walls. The distance between the pad and fan is an important consideration in determining which walls to use. A distance of 30 to 60m is best. When the distance is reduced below 30m, the cross sectional velocity becomes lower and the air often develops a clammy feeling. Factor (F vel) used to compensate for this are listed in Table 4 (Masterlez,1977).

Table 1. Correction factor for the elevation (m) from sea level

Elevation (m) Under	300	450	600	900	1200	1500	1800	2100	2400
F_{elev}	1.00	1.04	1.08	1.12	1.16	1.20	1.25	1.30	1.36

Table 2. Correction factor for the maximum interior light intensity(lux)

Light intensity (lux)	43050	48420	53800	59180	64560	69940	75320	80700	86080
F_{light}	0.8	0.9	1.00	1.10	1.20	1.30	1.40	1.50	1.60

Table 3 . Correction factor for pad to fan temperature variation (°C)

Temperature (°C)	6.0	6.0	4.4	4.0	3.3	3.0	2.0
F_{temp}	0.70	0.78	0.88	1.00	1.17	1.40	1.75

Table 4. Correction factor for pad to fan distance (m)

Distance(m)	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21	22.5	24.0	26.0	27.5	28.5	31
F_{vel}	2.24	2.00	1.83	1.69	1.58	1.48	1.41	1.35	1.29	1.24	1.20	1.16	1.12	1.08	1.05	1.02	1.00

MATERIALS AND METHODS

This chapter deals with the details of the greenhouse, the different conditions created and the various parameters measured inside as well as outside the greenhouse.

3.1 Constructional details

3.1.1 Location

The study was undertaken in the greenhouse constructed by the Plasticulture Development Centre in the instructional farm of KCAT, Tavanur in the year 1996-97. It is situated at 10 ° 53' 33"N latitude and 76°E longitude.

3.1.2 Orientation

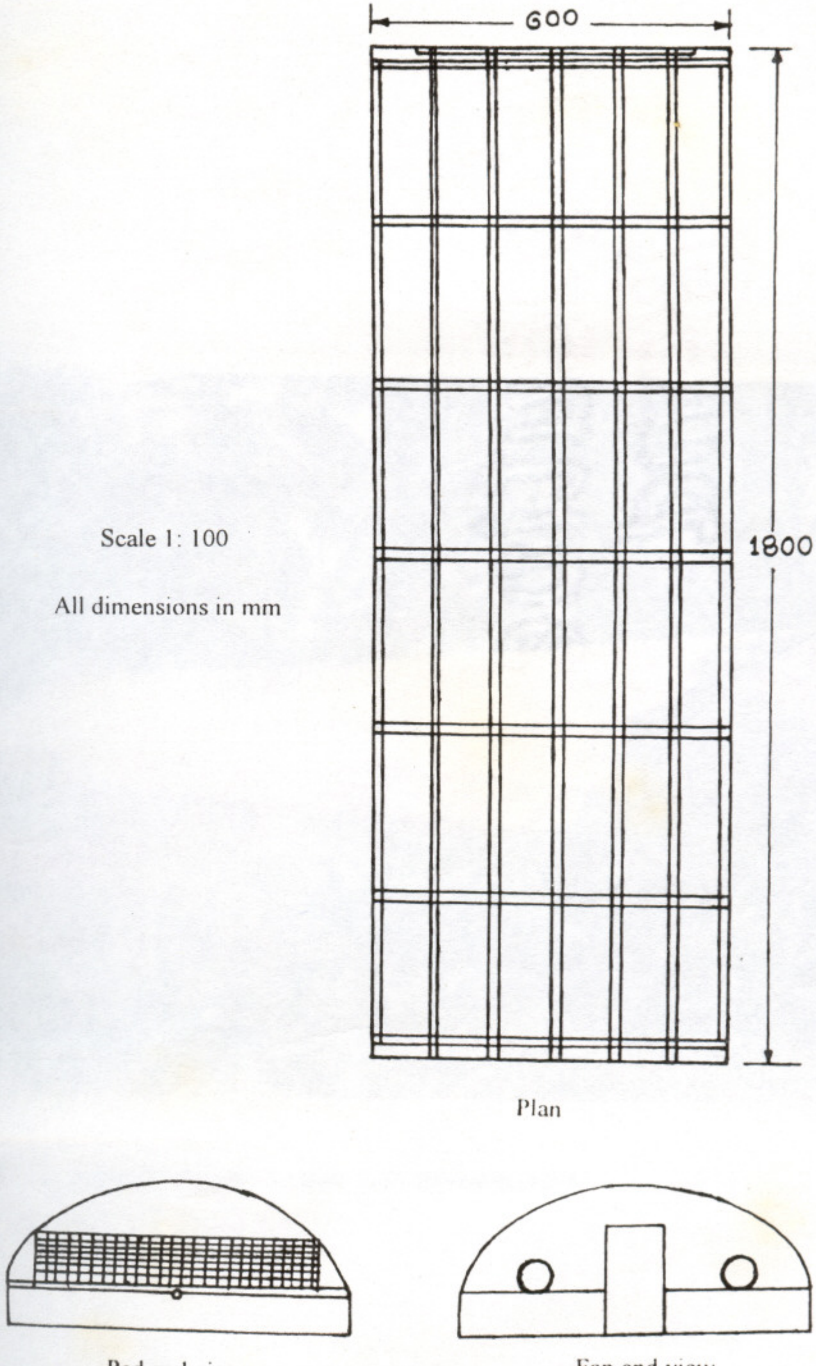
The greenhouse was oriented in the east-west direction which provided maximum solar radiation throughout the year.

3.1.3 Shape

The greenhouse had a circular roof with floor area 18 X 6m. The specification of the greenhouse are given in Appendix - I. Fig. 2 shows the plan and elevation of the greenhouse. Plate 1 shows the longitudinal view of the greenhouse.

3.1.4 Structure

The greenhouse had a cement plastered brick masonry wall of 135mm. thickness on four sides with an opening 1.1m for the door. The gutter provided on the opposite wall drains the water falling from cooling pad into the storage tank. The masonry wall also supports the door, cooling pad, fan and structure of the greenhouse. The structure is made of G.I.Pipes at a spacing of 3.0m and interconnected using angle iron pieces. Angle Iron structures are also provided to hold the exhaust fan as well as cooling pad. The glazing material used for this green house was ultra violet stabilised polyethylene sheets.



Elevation

Fig . 2 Plan and elevation view of the greenhouse

3.1.5 Cooling system

The cooling system consists of the following parts:

3.1.5.1 Cooling pad

The cooling pad placed on the western end of the greenhouse is made of coir mat of 150mm thickness compressed between two wire meshes of 1 inch size. The pad is moistured using the water pumped from the storage tank. The water is dripped on the pad through the tap type drippers placed over the cooling pad. The water draining from the cooling pad flows into the tank through the gutter. The specification of the cooling pad is given in appendix II. Plate 2 and 3 shows the pad end view of the greenhouse and cooling pad with drippers respectively.

The discharge of water on to the pad was computed by measuring discharge from one dripper and multiplied by the number of drippers.

3.1.5.2 Mist

The green house was provided with four lines of mist at a spacing of 1.5 m and the lines were spaced 2m apart (Plate 4) There are 48 numbers of mist outlet and the total discharge was measured. The water supply for operating the mist was delivered from the pump.

3.1.5.3 Water supply system

The water from the storage tank was pumped using 0.5 hp pump and the outlet from the pump was expanded and provided into a screen filter which filtered the incoming water. The outlet from filter was divided into sections, one for moistening the cooling pad and the other for the mist. Both sections could be operated seperately with the valves provided. Specifications of the pump is given in Appendix IV.

3.1.5.4 Fans

Two fans were provided on the eastern side of the greenhouse at a distance of 1.85 m from sides and at a height of 1.1 m from the ground on either side of the door. The specification of fans are presented in Appendix III. Plate 5 shows the fan end view of the greenhouse.

The amount of air removed from the greenhouse is calculated as follows :

Amount of air removed = Area of fan X Velocity of air

Air velocity is measured by using an anemometer.

3.2 Parameters measured

The parameters measured for the study are temperature, relative humidity and solar intensity. The instruments and the method of measurements are dealt in detail.

3.2.1 Temperature and relative humidity

Temperature and relative humidity inside and outside are measured using a digital RH-temperature metre. The temperature reading were given in degree Celsius and relative humidity was furnished in percentage. This instrument was used to measure the parameters both inside as well as outside the greenhouse.

A dry bulb and wet bulb thermometers were also provided both inside and outside the greenhouse to measure the relative humidity and temperature.

For measuring the temperature at different layers, thermometers were hung at the centre of the green house at 0.5 m interval. The measurements using the dry and wet bulb temperatures were also taken by keeping thermometers at the centre. The RH-temperature meter was also kept at the centre of the greenhouse for measurements. The temperature as well as relative humidity measurements were taken at intervals of 1 h.

3.2.2 Solar Intensity

The intensity of solar radiation was measured using a digital lux meter. The values of solar intensity was also taken along with temperature and relative humidity at 1 h interval by keeping the instrument at the centre of the greenhouse.

3.3 Experimental conditions inside the green house

The main objectives of this study were, to study the parameter variations namely in temperature , relative humidity and solar intensity both inside and outside the greenhouse with out effecting any cooling inside the greenhouse.

To study the changes in these parameters when different cooling methods were adopted.

3.3.1 Static Condition

The variation in temperature, relative humidity and solar intensity was noted round the clock in one hour interval and they were compared with the corresponding readings outside the greenhouse.

The hourly variations in temperature at 0.5 m interval along the cross section of the green house was also measured.

3.3.2 Cooling methods

The variations in different parameters, when different cooling methods adopted were noted with the tomato plants inside the greenhouse.

3.3.2.1 Removal of greenhouse air using two exhaust fans.

The heated air from the greenhouse during the peak temperature period was done by operating the two exhaust fans provided, for a period of 30 minutes. The variation in temperature and relative humidity were noted. The build up of temperature for 30 minutes after switching off the fan were also studied. The temperature, relative for 30 minutes after switching off the fan were also studied. The temperature, relative humidity and solar intensity changes inside and outside the greenhouse were also noted.

3.3.2.2 Evaporative cooling by operating one exhaust fan and cooling pad

The maximum temperature that was effected in the greenhouse was found and one fan and the cooling pad was operated for 30 minutes and changes in temperature and relative humidity was noted. The variations in temperature and relative humidity after switching of the fan and pad were also noted. The temperature, relative humidity and solar intensity were also measured round the clock at one hour interval both inside and outside the greenhouse.

3.3.2.3 Evaporative cooling using two fans and cooling pad.

The cooling was effected inside the greenhouse during the peak hours of insolation and variations in temperature was noted. The changes in temperature after switching off the cooling system was also studied and the changes in temperature, relative humidity and solar intensity were noted for 24 h.

3.3.2.4 Maintaining temperature inside the greenhouse between 30-35 °C

For proper growth of the tomato plants inside the greenhouse, the temperature was tried to be maintained in between 30-35 °C using fan and pad cooling system. The variations in temperature, relative humidity and solar intensity inside and outside were measured.

3.3.2.5 Misting

In order to maintain the desired temperature and relative humidity, the misting system was operated and the parameter variations were noted.

Plate 1. Longitudinal view of greenhouse

Plate 2. Pad end view

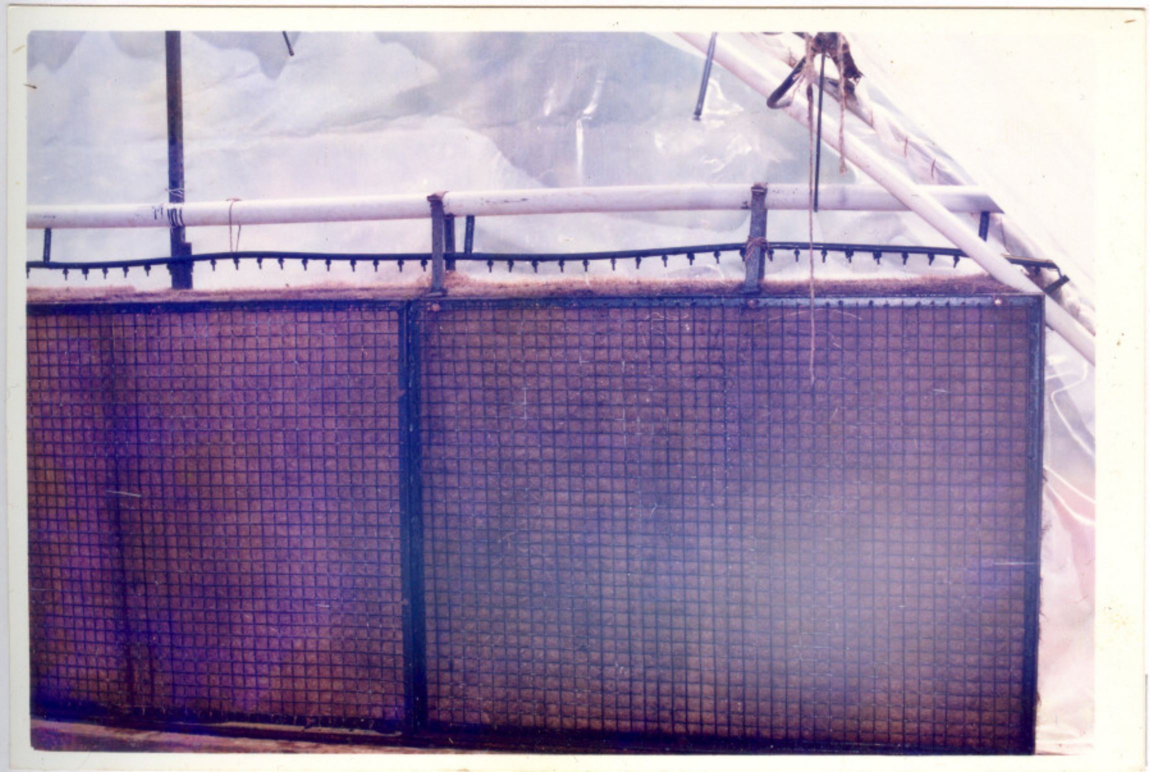


Plate 3. Cooling pad with drippers

Plate 4. Mist System

Plate 5. Fan end view

RESULTS AND DISCUSSION

The knowledge of the micro climate and the variations in various parameters are essential for the cultivation of crops inside the greenhouse. The extent of variation that is possible and the methods of varying these parameters can contribute to the choice of crop varieties. The changes in parameters namely temperature, relative humidity and solar intensity under different conditions are discussed in this chapter.

4.1 Static condition

The variation in temperature, relative humidity and solar intensity inside as well as outside are represented in Fig. 3a and 3b. This shows that the temperature increases with increase in the solar intensity and reaches a peak value when the sun is at the zenith. During this period, the relative humidity goes down and reaches a lower value when there is high insolation. The maximum values of temperature were found in between 12.00 noon and 2.00 pm. The maximum temperature obtained was 47.8 °C inside the greenhouse and during night it reduced to 22 °C. The relative humidity fell to a lower value of 46.8 per cent and it built up with lowering of temperature. The temperature inside the greenhouse at different layers was measured in 1 h interval and is shown in Fig.4. This shows there is no considerable variations in temperature in different layers inside the greenhouse.

The solar intensity inside the greenhouse varied in the same manner as outside intensity but showed a reduction of 40-60 per cent due to the interference of the cladding material.

4.2 Cooling effects

4.2.1 Removal of air from the greenhouse using two fans

The air from the greenhouse was expelled at the rate of 1.66 m^3/s for 30 minutes during the peak hours of solar intensity and the changes in relative humidity and temperature in comparison with the values of relative humidity and

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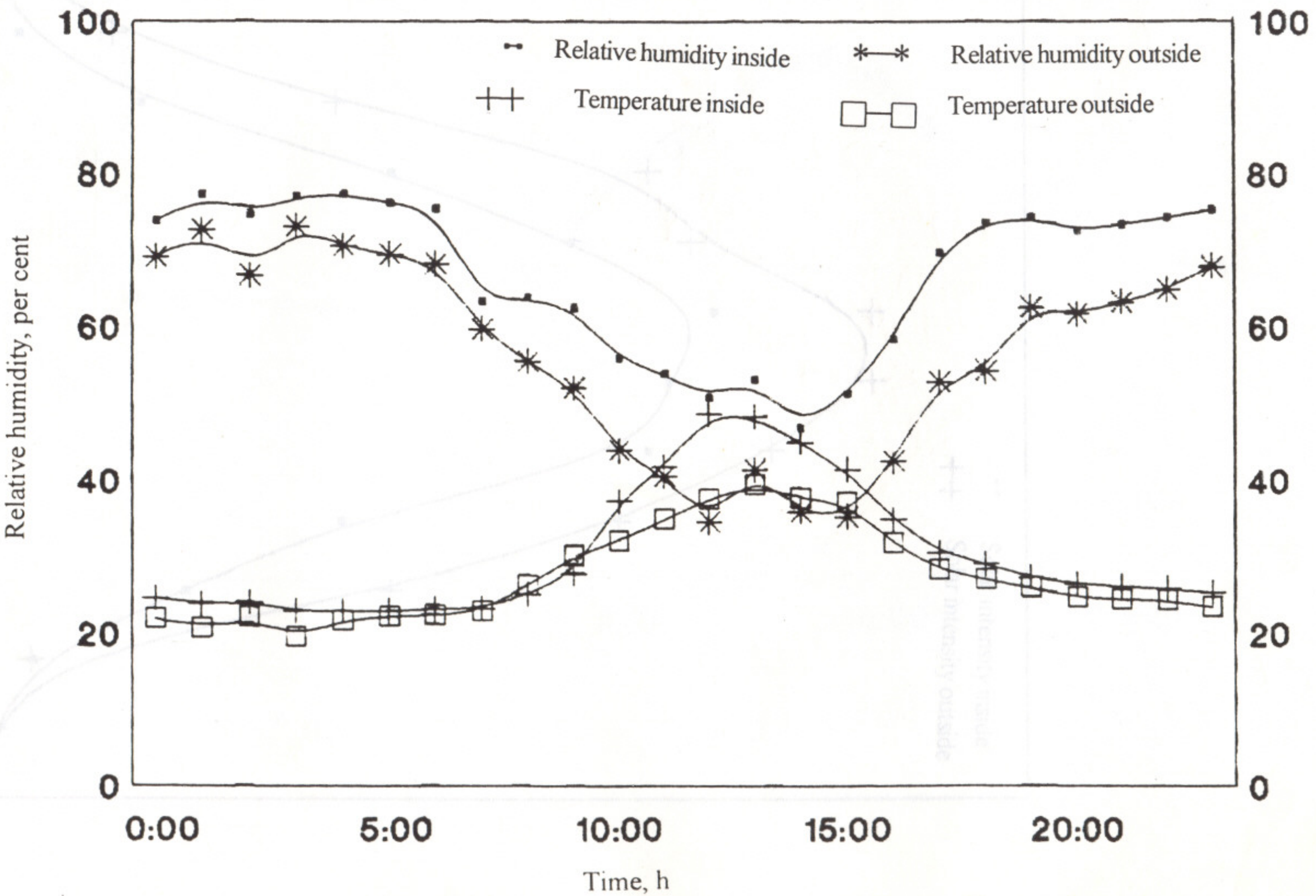

Fig. 3a Variations in relative humidity and temperature under static condition on 03. 01. 1997

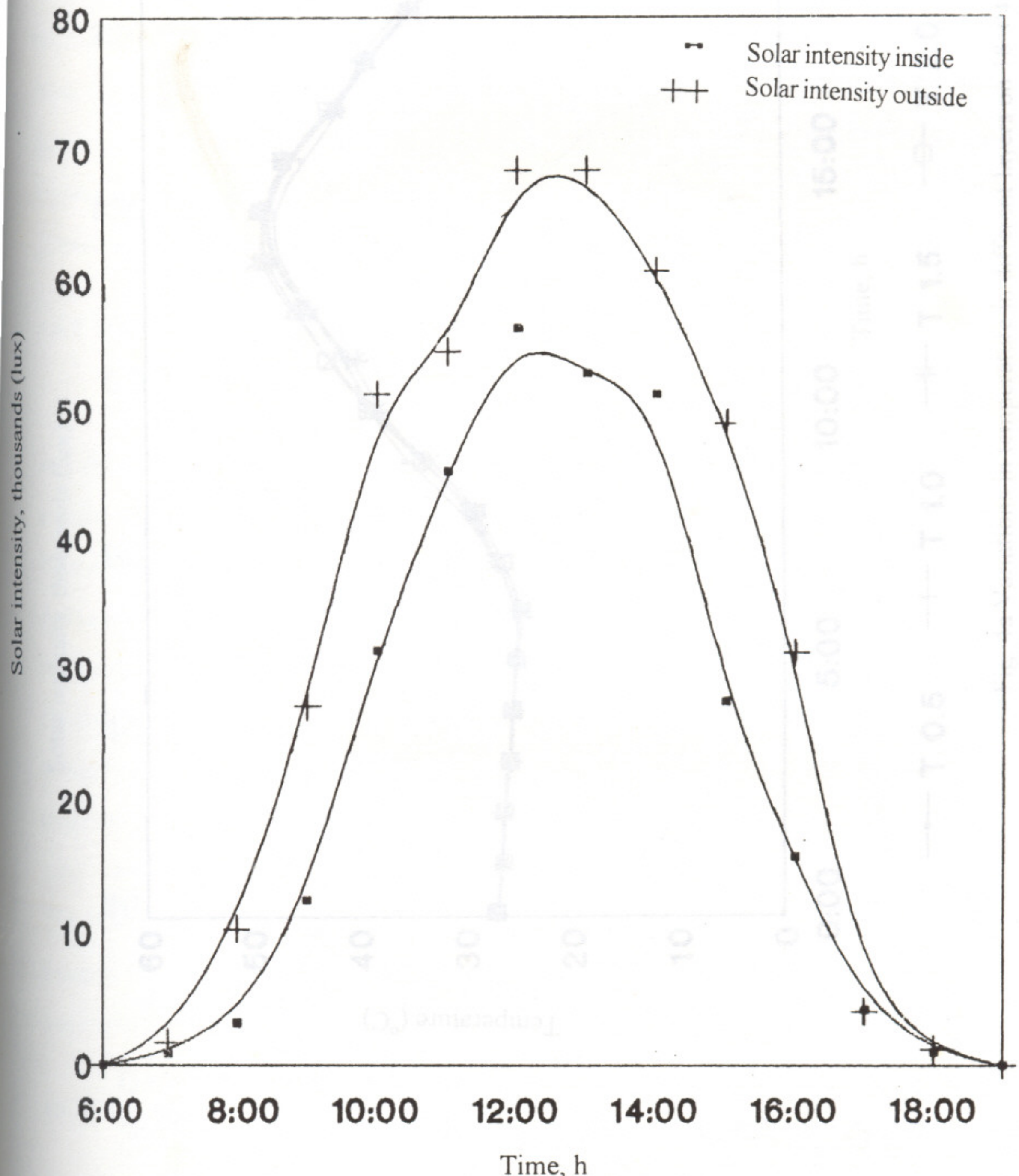

Fig. 3b Variation in solar intensity on 03. 01. 1997.

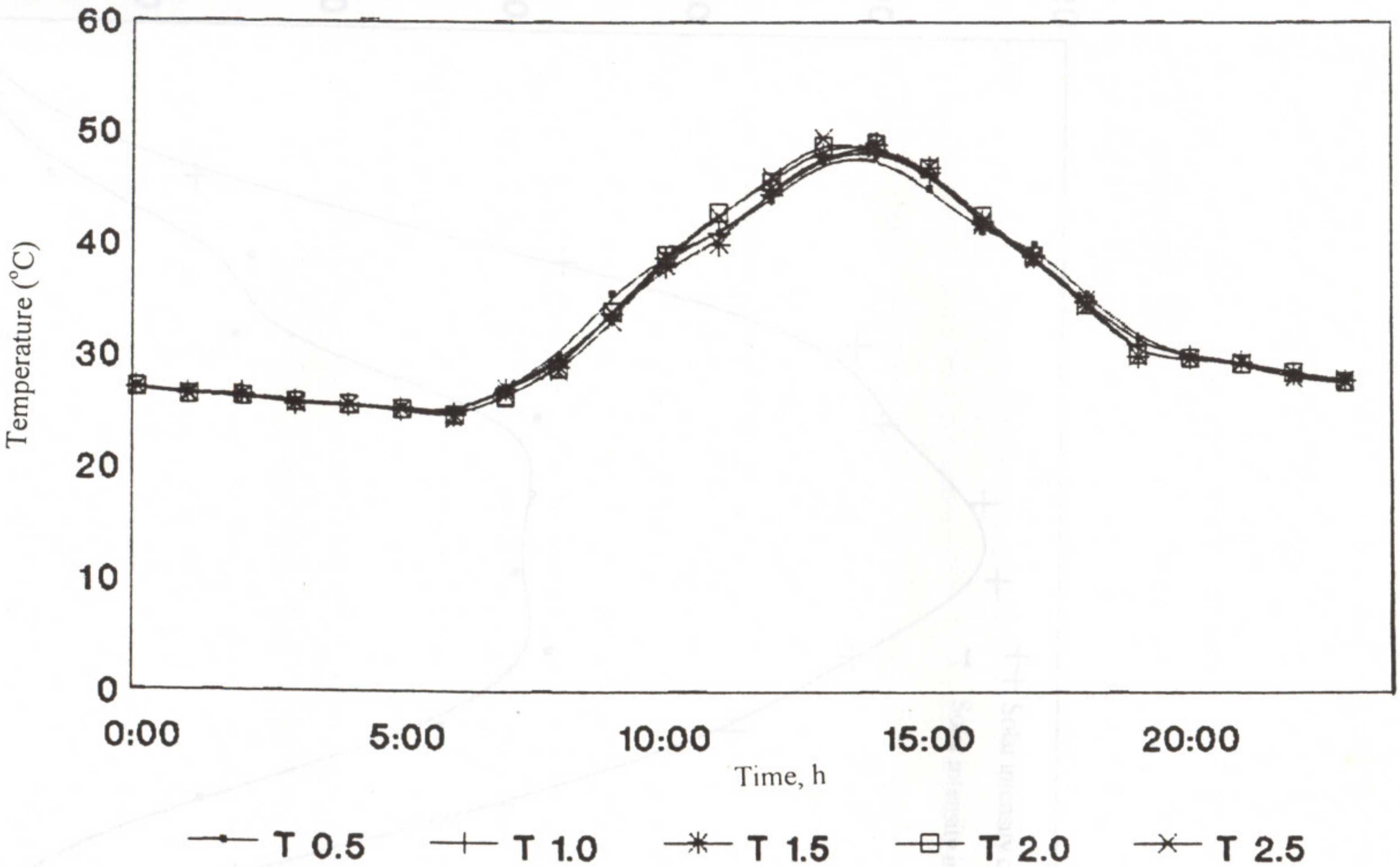

Fig. 4a Variations in temperature in different layers on 18. 04. 1997.

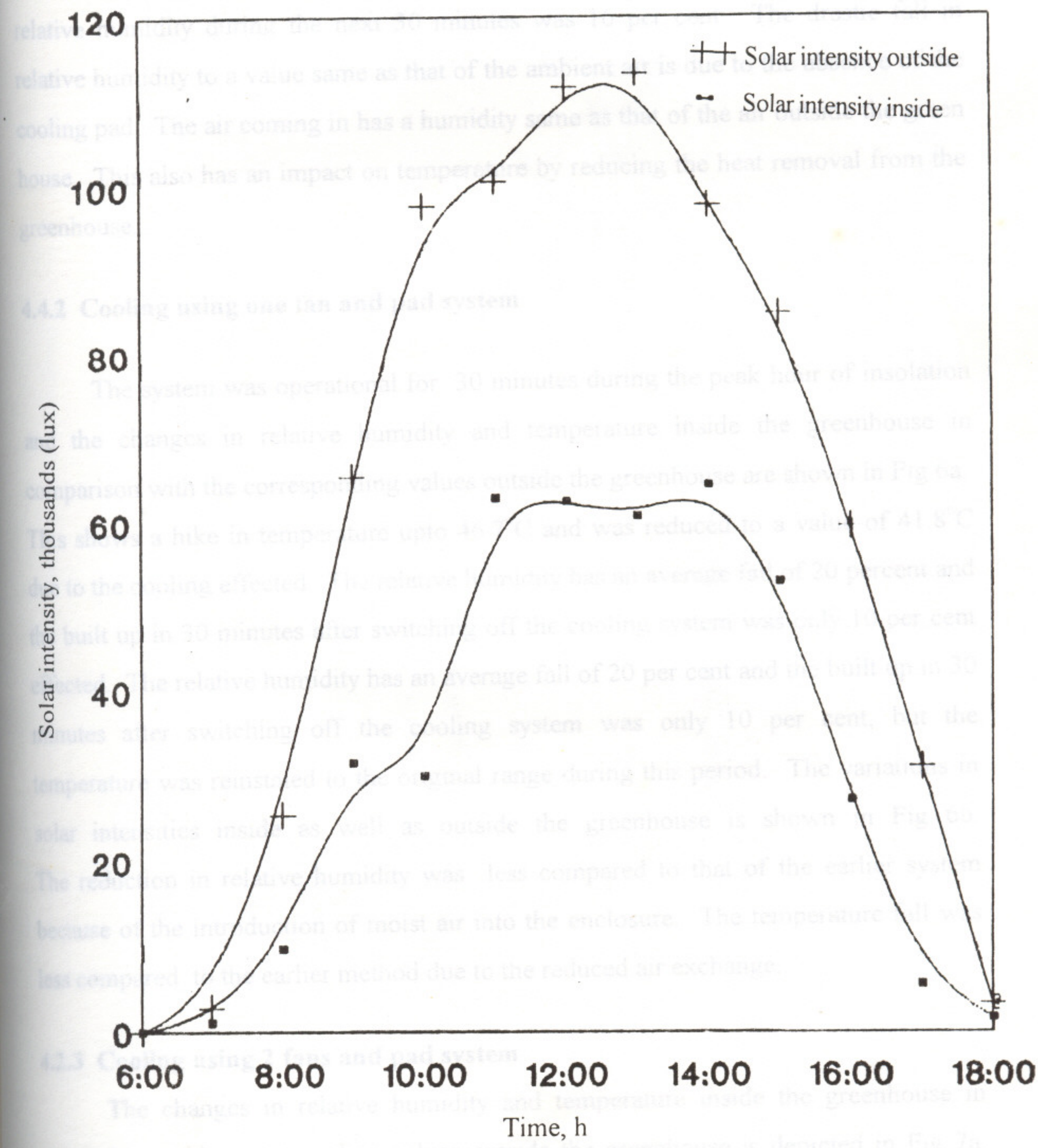

Fig. 4b Variation in solar intensity on 18. 04. 1997.

humidity and temperature in comparison with the values of relative humidity and temperature outside are shown in Fig 5a. The variation in solar intensity inside as well as outside the greenhouse is shown in Fig.5b.

The reduction in temperature which effected during air removal is only 8 °C and the built up of temperature was 7 °C in the next 30 minutes after switching off the fans . The relative humidity was reduced by 23per cent during this period. The built up of relative humidity during the next 30 minutes was 16 per cent. The drastic fall in relative humidity to a value same as that of the ambient air is due to the absence of the cooling pad. The air coming in has a humidity same as that of the air outside the green house. This also has an impact on temperature by reducing the heat removal from the greenhouse.

4.4.2 Cooling using one fan and pad system

The system was operational for 30 minutes during the peak hour of insolation and the changes in relative humidity and temperature inside the greenhouse in comparison with the corresponding values outside the greenhouse are shown in Fig.6a. This shows a hike in temperature upto 46.7°C and was reduced to a value of 41.8°C due to the cooling effected. The relative humidity has an average fall of 20 percent and the built up in 30 minutes after switching off the cooling system was only 10 per cent effected. The relative humidity has an average fall of 20 per cent and the built up in 30 minutes after switching off the cooling system was only 10 per cent, but the temperature was reinstated to the original range during this period. The variations in solar intensities inside as well as outside the greenhouse is shown in Fig 6b. The reduction in relative humidity was less compared to that of the earlier system because of the introduction of moist air into the enclosure. The temperature fall was less compared to the earlier method due to the reduced air exchange.

4.2.3 Cooling using 2 fans and pad system

The changes in relative humidity and temperature inside the greenhouse in comparison with corresponding values outside the greenhouse is depicted in Fig 7a.

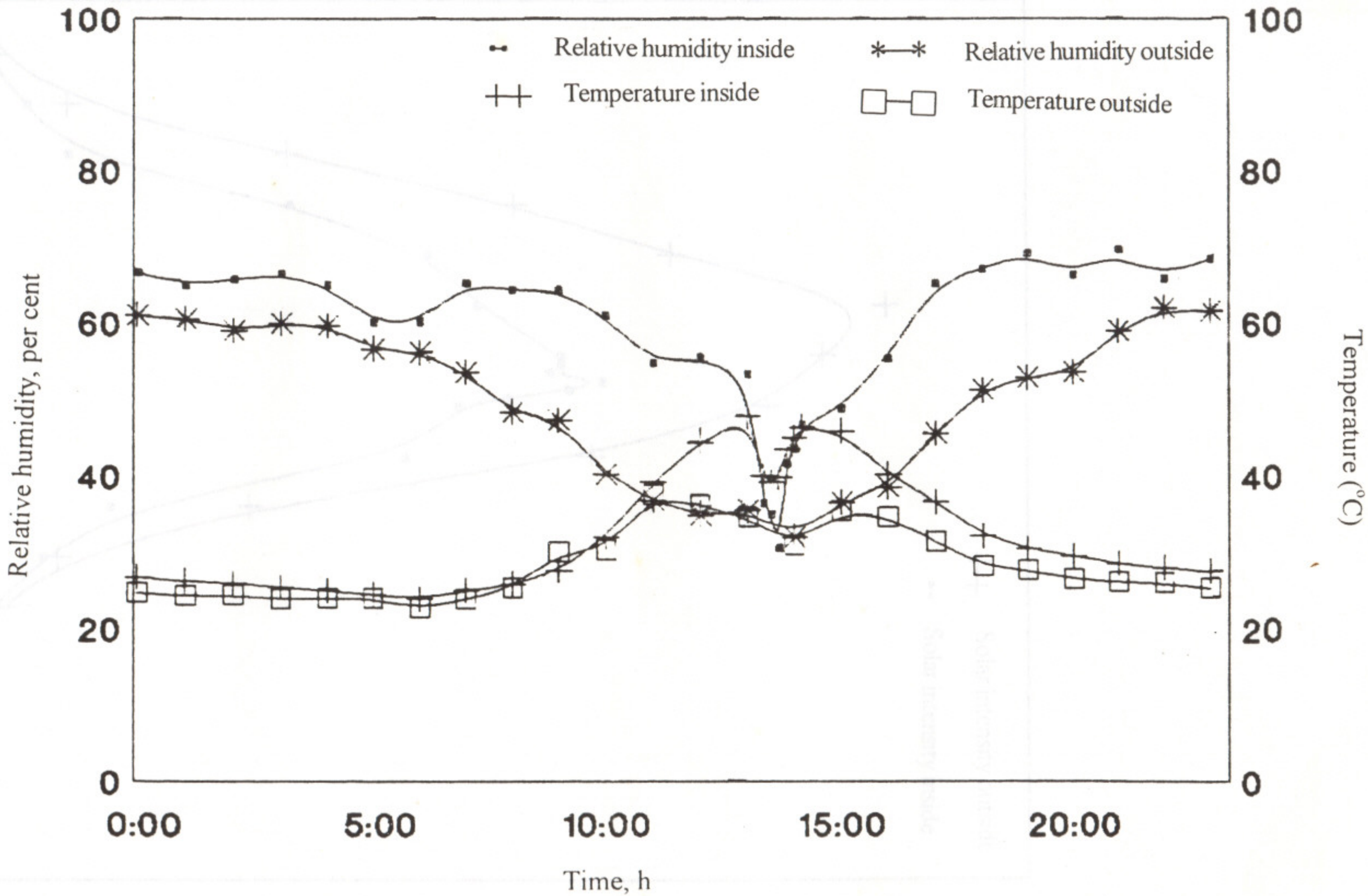

Fig. 5a Variations in relative humidity and temperature when two fans were operated for 0.5h on 17.01. 1997.

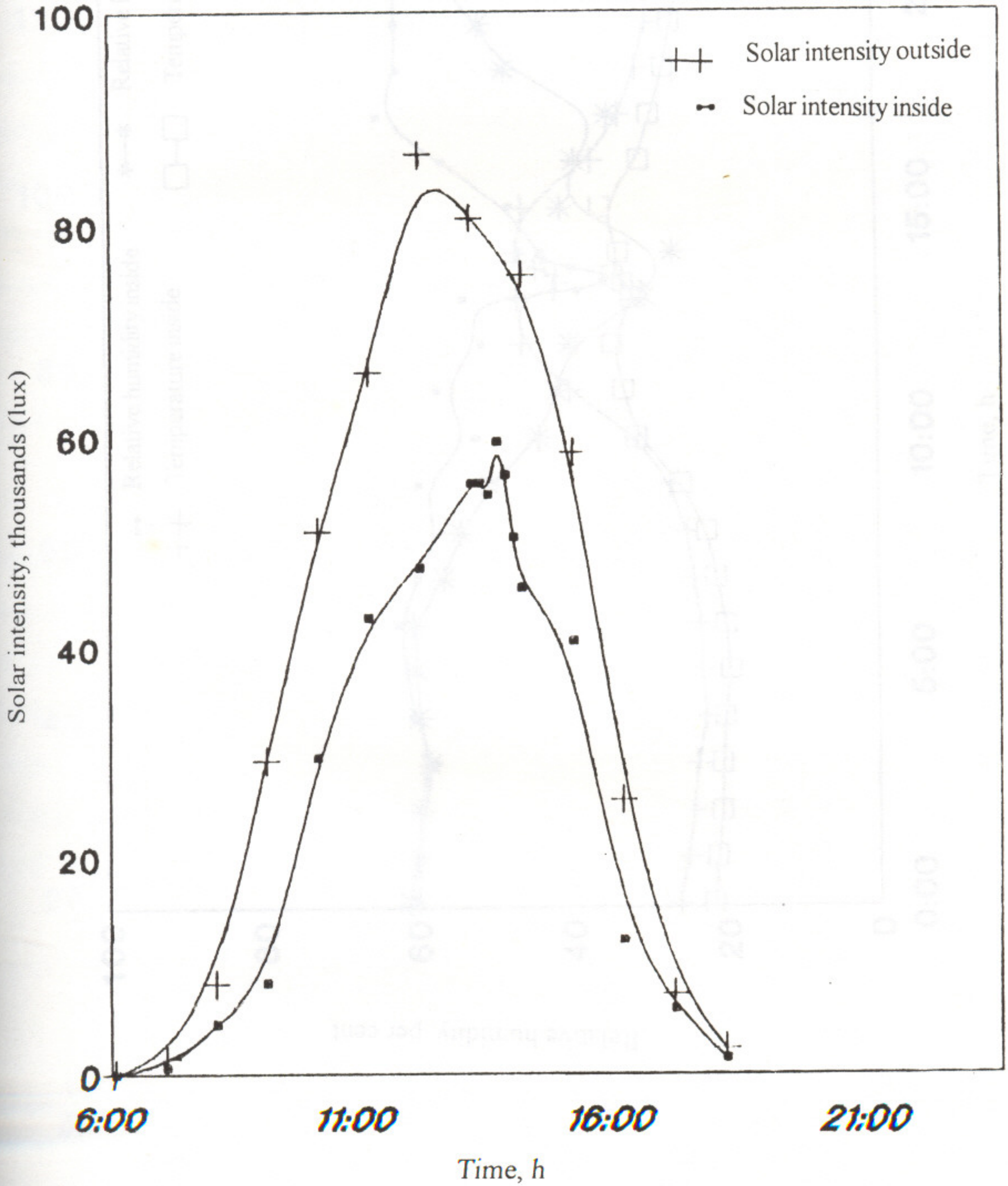

Fig. 5b Variation in solar intensity on 17.01. 1997.

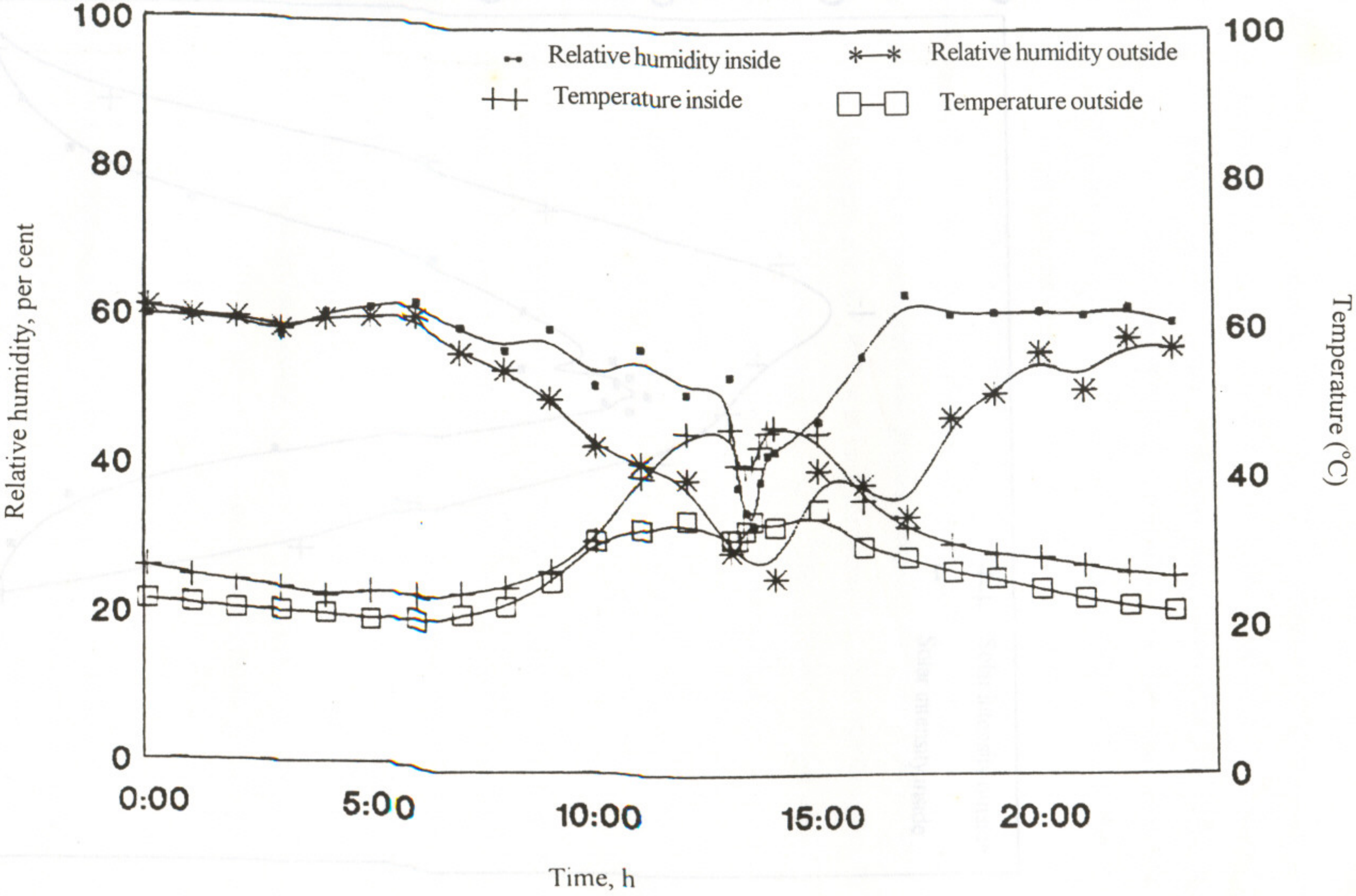

Fig. 6a Variations in relative humidity and temperature when one fan and pad system were operated for 0.5h on 20. 01. 1997.

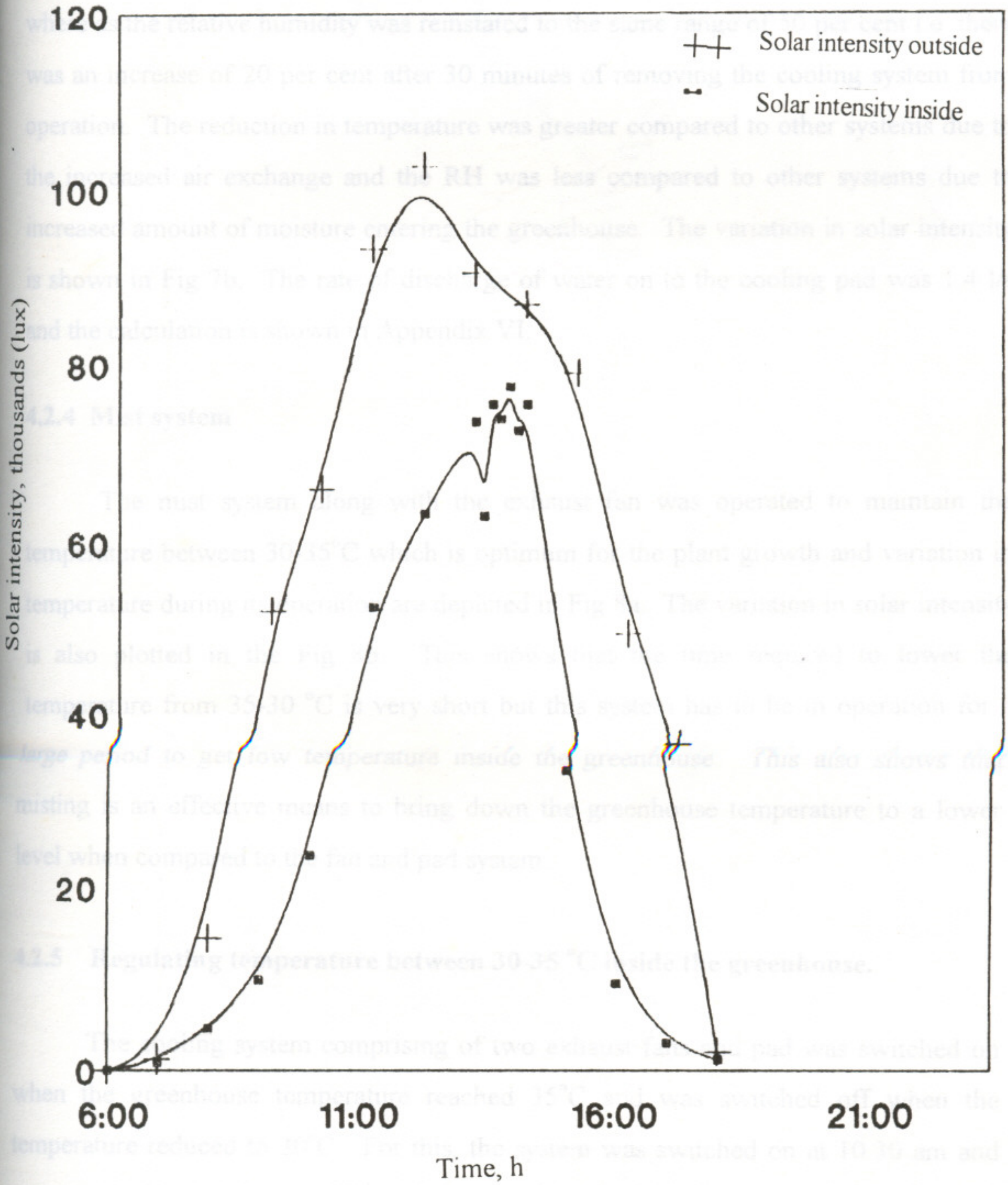

Fig. 6b Variation in solar intensity on 20. 01. 1997.

The air from greenhouse was removed using 2 fans and pad system. The air entered into the greenhouse through the moistened cooling pad. The temperature that had built upto 47.7°C had reduced to 34.2°C within 30 minutes. The temperature again increased to 43.8 °C within 30 minutes This shows that there was an average decrease of 9-13 oC in green house temperature and an average decrease of 15-20 per cent in relative humidity during this period. The built up of temperature was around 8°C where as the relative humidity was reinstated to the same range of 50 per cent i.e. there was an increase of 20 per cent after 30 minutes of removing the cooling system from operation. The reduction in temperature was greater compared to other systems due to the increased air exchange and the RH was less compared to other systems due to increased amount of moisture entering the greenhouse. The variation in solar intensity is shown in Fig 7b. The rate of discharge of water on to the cooling pad was 1.4 l/s and the calculation is shown in Appendix VI.

4.2.4 Mist system

The mist system along with the exhaust fan was operated to maintain the temperature between 30-35°C which is optimum for the plant growth and variation in temperature during its operation are depicted in Fig 8a. The variation in solar intensity is also plotted in the Fig 8b. This shows that the time required to lower the temperature from 35-30 °C is very short but this system has to be in operation for a large period to get low temperature inside the greenhouse. This also shows that misting is an effective means to bring down the greenhouse temperature to a lower level when compared to the fan and pad system.

4.2.5 Regulating temperature between 30-35 °C inside the greenhouse.

The cooling system comprising of two exhaust fans and pad was switched on when the greenhouse temperature reached 35°C and was switched off when the temperature reduced to 30°C. For this, the system was switched on at 10.30 am and was operated upto 4.30 pm. The variations in relative humidity and temperature inside as well as outside the greenhouse is shown in Fig 9a. The variatons in solar intensity

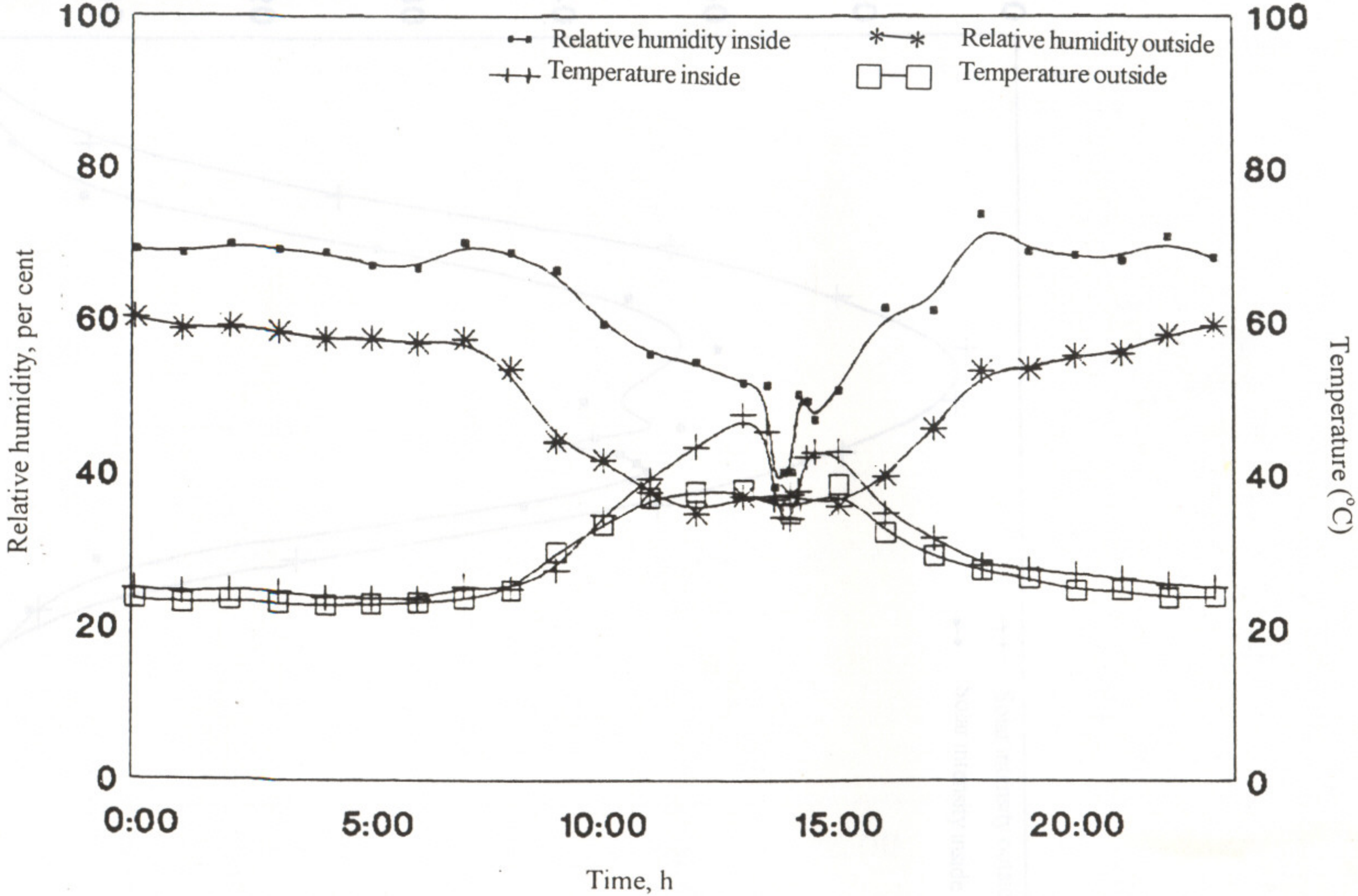

Fig. 7a Variations in relative humidity and temperature when two fans and pad system were operated for 0.5h on 12. 01. 1997.

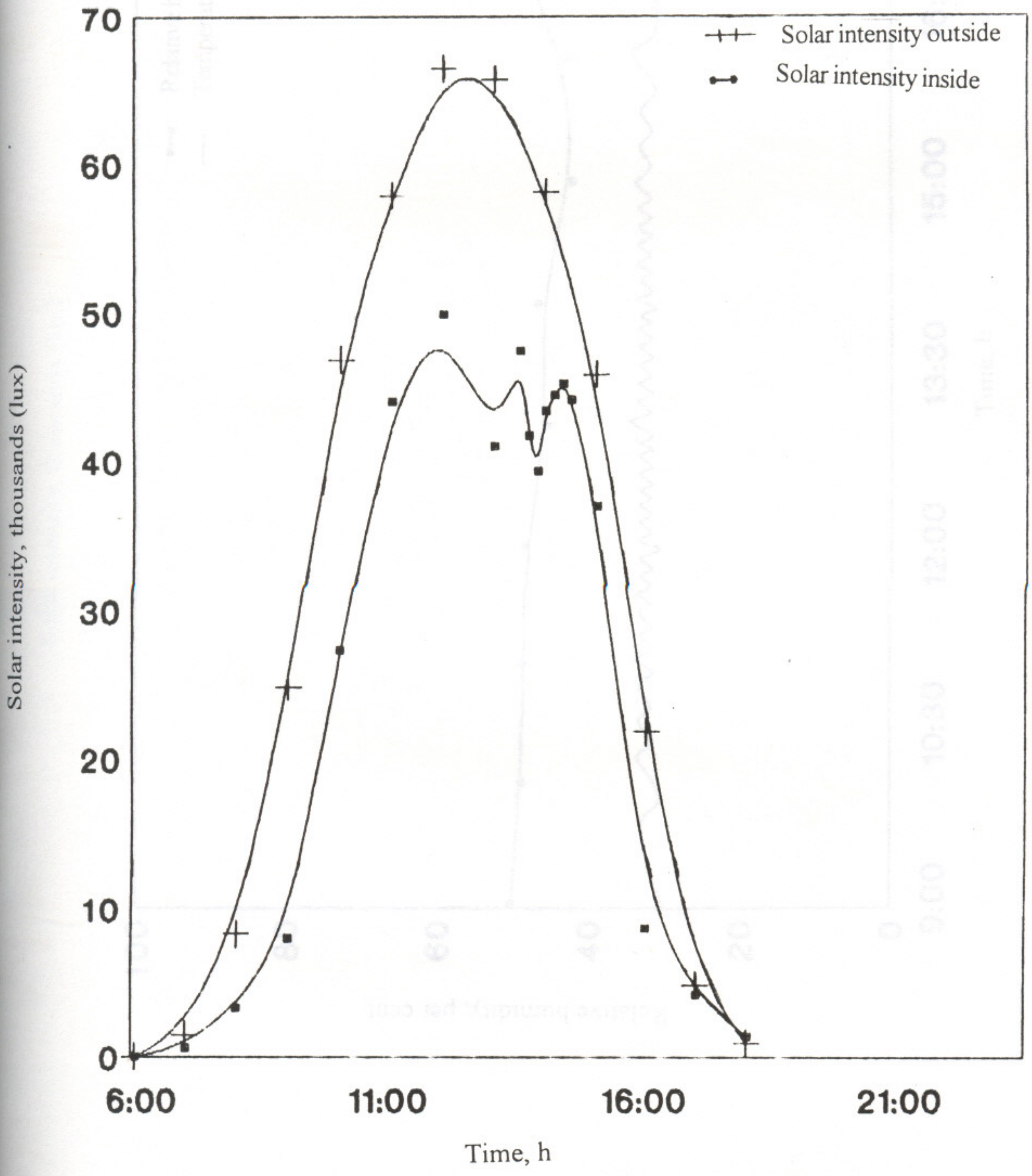

Fig. 7b Varition in solar intensity on 12. 01. 1997.

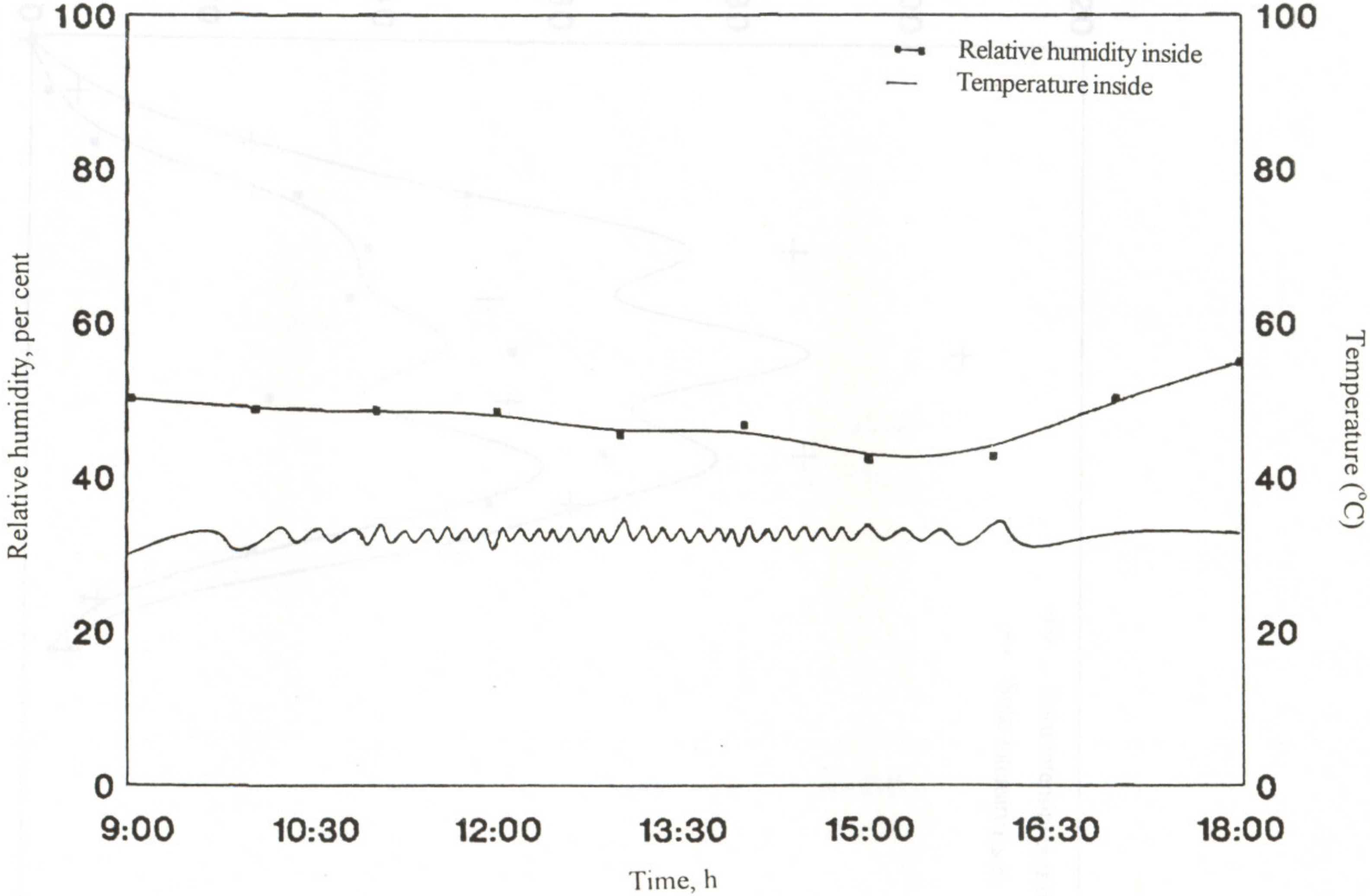

Fig. 8a Maintenance of temperature inside the greenhouse between 30 - 35 °C using mist system on 19. 04. 1997.

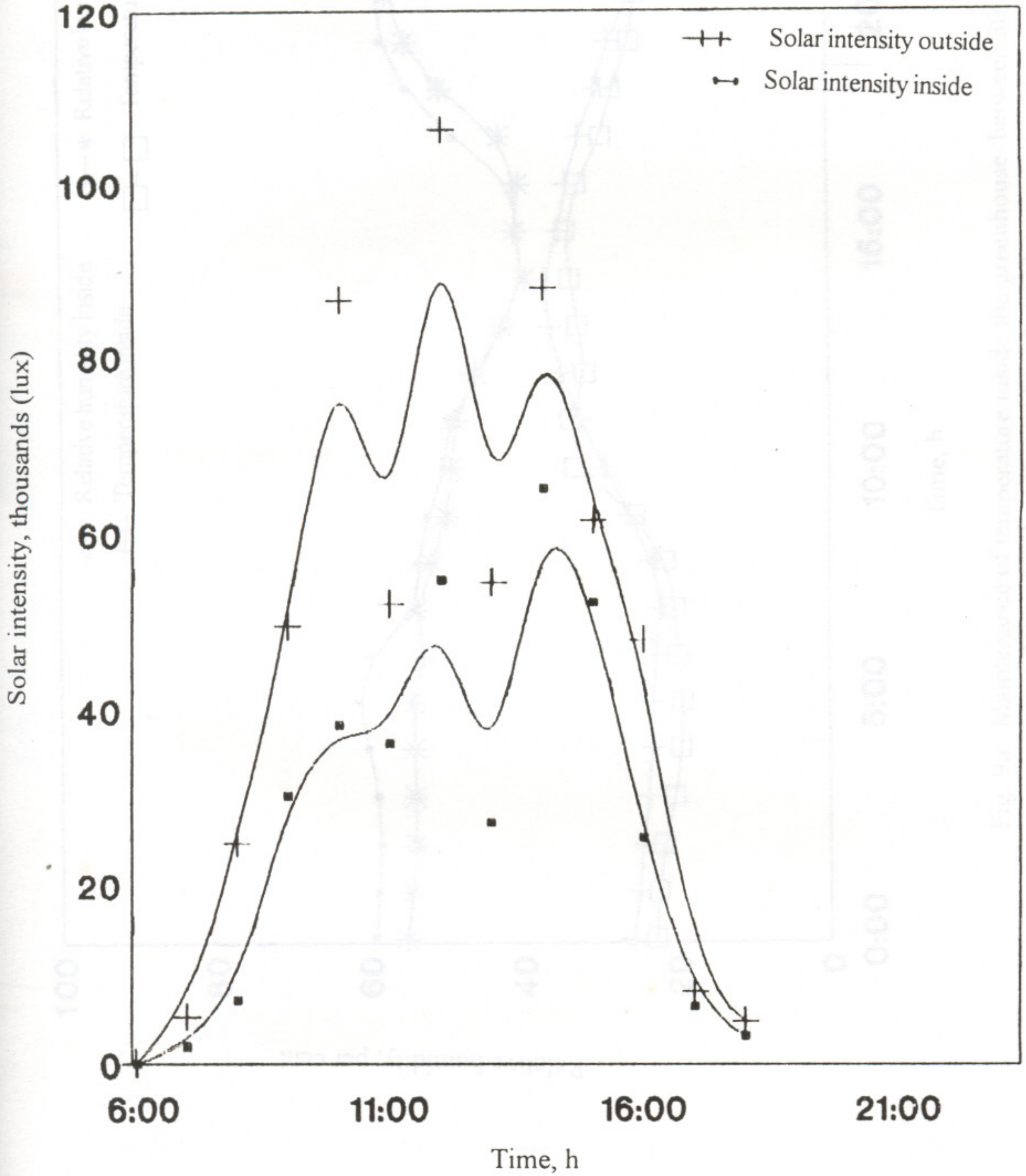

Fig. 8b Variation in solar intensity on 19.04. 1997.

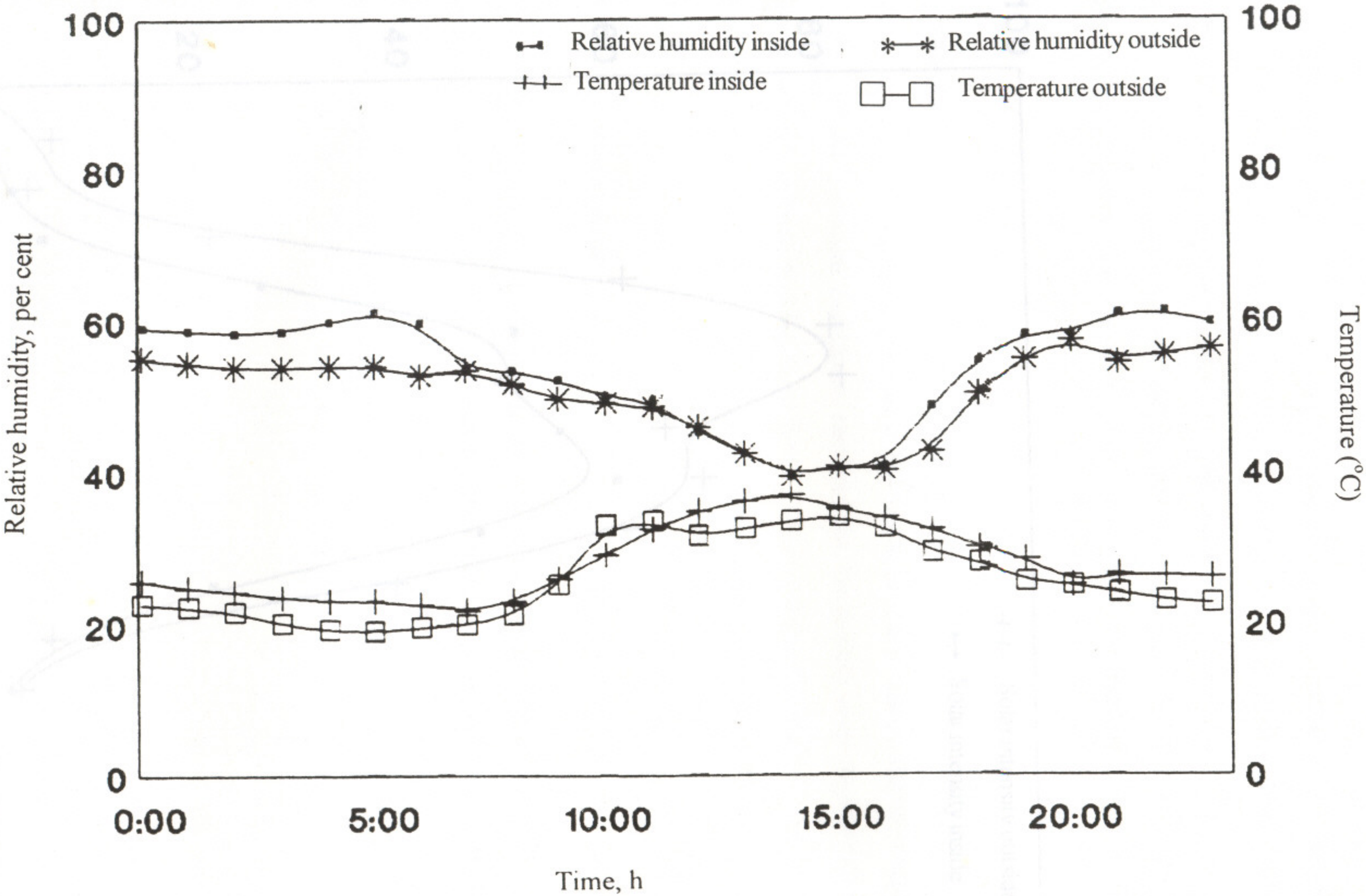

Fig. 9a Maintenance of temperature inside the greenhouse between 30 -35 °C using fan and pad system on 10. 02. 1997.

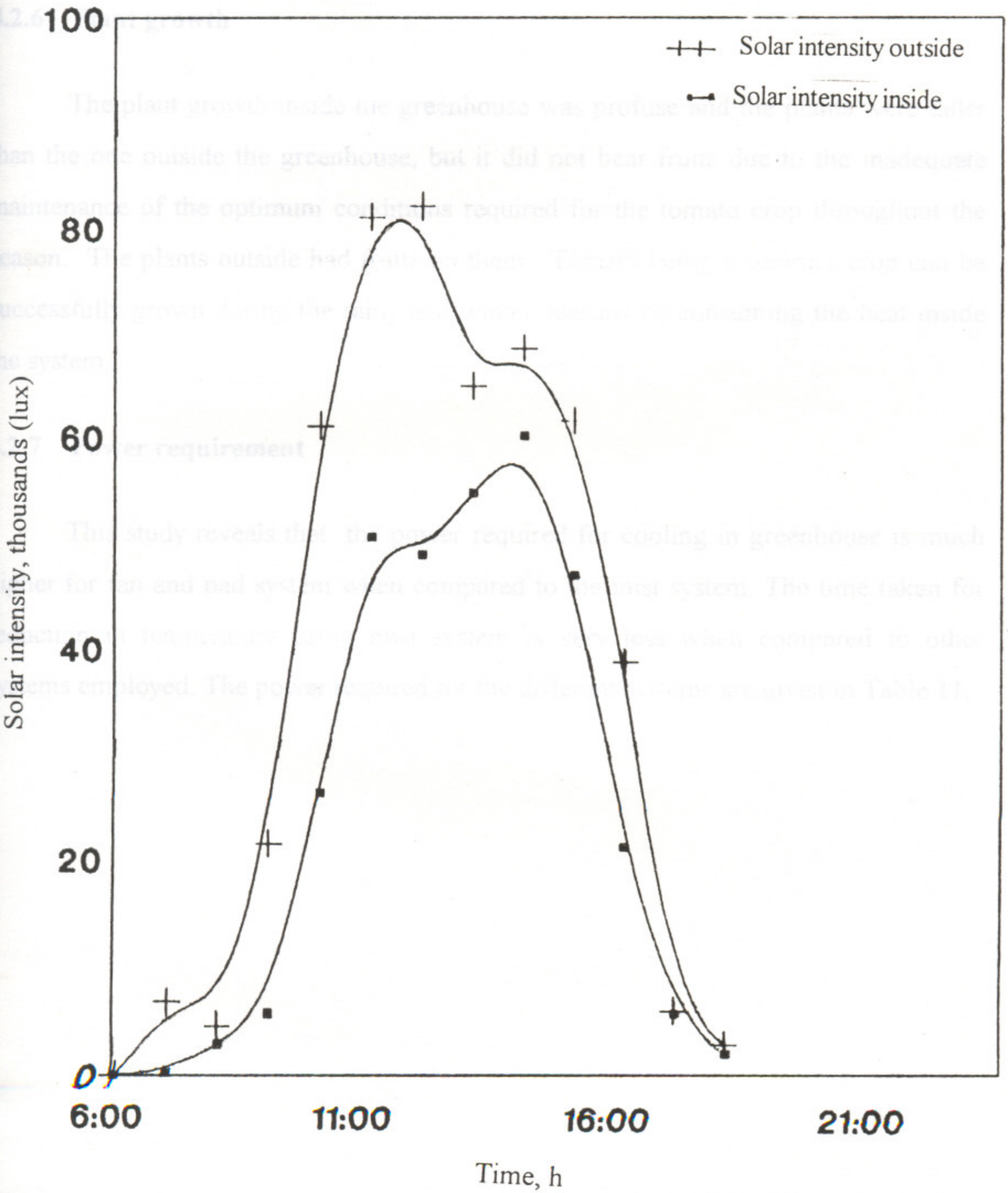

Fig. 9b Variation in solar intensity on 10. 02. 1997.

inside as well as outside the greenhouse is shoen in Fig 9b. This shows that the temperature had a slight increase to 37°C when the cooling system was still in operation. This shows that this type of cooling system is sufficient to maintain the temperature optimum for crop growth, but insufficient to maintain the required relative humidity inside the greenhouse for which other means are to be adopted.

4.2.6 Plant growth

The plant growth inside the greenhouse was profuse and the plants were taller than the one outside the greenhouse, but it did not bear fruits due to the inadequate maintenance of the optimum conditions required for the tomato crop throughout the season. The plants outside had fruits on them. Tomato being a summer crop can be successfully grown during the rainy and winter seasons by consuming the heat inside the system.

4.2.7 Power requirement

This study reveals that the power required for cooling in greenhouse is much higher for fan and pad system when compared to the mist system. The time taken for reduction in temperature using mist system is very less when compared to other systems employed. The power required for the different systems are given in Table 11.

SUMMARY AND CONCLUSION

The growth and production of crops are dependent on the climatic factors like light, temperature, air composition and humidity. Controlled greenhouse micro climate not only provides favourable environment for optimum growth and production of crops but also permit the production regardless of the climate prevailing outside the greenhouse .

In humid tropics, the greenhouse cooling is an important process for the climatic control rather than by other means. The variations in the micro climatic parameters when different methods were effected was studied. The changes in temperature, relative humidity with increase in solar intensity was noted with different cooling system adopted inside the greenhouse.

The variations in temperature, relative humidity and solar intensity without any cooling effected was noted and the period of maximum variations was noted in between 12 noon and 2 pm Cooling using different methods was adopted during this period. The temperature in different layers showed no significant variations in the values. The variation in values of solar intensities showed a reduction in intensities inside the greenhouse compared to the values outside.

The removal of air from the greenhouse using two fans showed a reduction in the micro climate conditions to that prevailing outside due to the introduction of ambient air into the greenhouse. The air coming into the greenhouse was not cooled at the pad end.

When one fan and pad system was operated the temperature didnot reduce to the extend as in the earlier case because of the reduced air exchange. The reduction in relative humidity was less because the air entering the greenhouse passed through the moistened cooling pad.

The cooling using two fans and pad system showed that there was considerable reduction in the greenhouse inside temperature but reduction in relative humidity was less compared to other systems. This was accomplished by the increased air exchange and moist air entering the greenhouse.

The mist system with exhaust fan could maintain 30-35°C inside the greenhouse and the time of operation for maintaining the optimum conditions were very short. This showed that mist system was an effective means to bring down the greenhouse temperature to a lower level when compared to the fan and pad system.

The fan and pad cooling system was operated to maintain 30-35 °C inside the greenhouse. This system could maintain the optimum condition but it was less suitable compared to the mist system as it required less power to create the same conditions inside the greenhouse. This also shows that mist system can be used to maintain a comparatively wider range of temperatures inside the greenhouse.

This study reveals that mist system is an efficient means to maintain a wide range of temperatures inside the greenhouses in humid tropics compared to the other types of cooling systems employed during this study.

This study can also be extended to find out the optimum conditions required for different crops to be grown in greenhouses in humid tropics. This can also be used find out the appropriate cooling system for achieving optimum conditions inside the greenhouse. The system can be automated either using a time switch or using sensor so that it is operated only in the required intervals. Major reduction in cost can be achieved by adopting natural ventilation techniques for reducing the temperature inside the greenhouse.

REFERENCES

Aage Anderson (1985) The influence of light quality on plant growth in controlled environment. *Acta Hort*, **174**:205-209.

Abdulla (1986) Performance and tomato yield in cooled greenhouse at Al-Hassa, Saudi Arabia. *Acta Hort*, **17**(4):63-67.

Ajayambikadevi,S.J (1995) Design, fabrication and testing of a low cost greenhouse. Unpublished M.Tech thesis, K.C.A.E.T., Tavanur.

Amsen,M.G. (1981) Environmental conditions in different types of greenhouse. *Acta Hort,* **115**(1):99-104.

Bailey,B.J. (1990) The environment in an evaporatively cooled greenhouse. *Acta Hort,* **287**:59-66.

Bakker,J.C. (1995) Greenhouse climate control: constraints and limitations. *Acta Hort,* **399**:25-33.

Boulard,T. and Baille, A. (1993) A simple greenhouse climate control model incorporating effects of ventilation and evaporative cooling. *Agricultural and Forest Matoerology*. **66**:145.157.

Challa,H. and Schapendonk,A. (1984) Quantification of effect of light reduction in greenhouses on yield. *Acta Hort*, **148**:501 - 510

Chandra.p (1985) applications of greenhouse technology. proc of summer institute on greenhouse design and environmental control.CAIE Bhopal

Chandra.P.singh, J.K.., and Majumdar. M.(1989) Some results of evaporatively cooling a plastic greenhouse. *J.Agric.Engg.* **26** (3) : 274 - 28

Darlymple, D.G. (1973) A global review of greenhouse food production FAE report No: 89, Economic Res.Services, USDA, Washington.

El - Aidy, F. (1984) Research on the use of plastics and shadenets on the production of some vegetable crops in Egypt. *Acta Hort*. **154**: 109 - 113.

El - Cizawy, A.M., El - Hubbask, K.M., Mohammed, S.S. and Gomma, H.M (1989) Effect of different shading levels on tomato plants. *Acta Hort*. **323** : 92 - 97

*Gaastra, P. (1959) Photosynthesis of crop plant influenced by light, carbondioxide and temperature. Mededland Bounhog School, Wageningen. **59** (3).1-68

Galansouco, V. (1992) Physiological and production differences between greenhouse and open air bananas in Canary Island. *Acta Hort*, **296**: 141 - 143

Garzoli,J. (1989) Cooling of greenhouse in tropical and subtropical climates. *Acta Hort*, **257**: 93 - 100

Govindan. S., Jenet, P.V., Jissy, K.J. and Manojkumar, T.S. (1993) Design, Fabrication and testing of a low cost greenhouse, unpublished B.Tech Project report, K.C.A.E.T., Tavanur

Hand, D.W. (1988) The effect of atmospheric humidity on greenhouse crops. *Acta Hort*. **229** : 38 - 42

Heij and Uffelen Vom, J.A.M. (1984) Effect of carbondioxide on growth and production of glasshouse vegetable crops. *Acta Hort*. **148** : 591 - 599

Kachru and Rejinder (1985) Greenhouse temperature control techiques. Proc.of the summer institute on greenhouse design and environmental control, CIAE Bhopal

Keimball, B.A and Mitchell, S.T. (1978) Carbondioxide enrichment of tomatoes in unventilated greenhouses in an arid climate. *Acta Hort*. **87**:131-136

Kempkes,F. (1985) Vertical temperature differences in greenhouses. *Acta Hort*. **170** : 118 - 119

Khan, M.M., Kariyanna, Krishnamanohar, R., Shyamalamma, S., and Ikramullah, M. (1995) Low / medium cost greenhouses and plastic mulching. Department of Horticultue, Lalbagh, Bangalore.

*Landsberg, J.J., White,B. and Thorpe,M.R. (1979) Computer analysis of the efficiency of evaporative cooling for glass houses in high energy environments. *J.Agric. Engg. Res*. **24** : 29 - 39

Majumdar, G., Chandra,P., and Singh, J.K. (1990) Prediction of cooling pad temperature in a fan pad cooling system used in greenhouse. Proc. of XI International congress on"The Use of Plastics in Agriculture"., New Delhi.

Masterlez, J.W. (1977) *The greenhouse environment*, Wiley and Sons Inc., New York, Ed.I.pp.1-30

Mears, D.F. (1990) Oppertunities for colloborative Indo - US greenhouse research Proc. of XI International congress on 'The Use of Plastics in Agriculture'., New Delhi

Monteiro, A.A. (1981) Influence of evaporative cooling systems on greenhouse environment. ASAE paper No. 81 : 4027

Nelson, P.V. (1981) *Greenhouse Operation and Management,* Reston Publishing company Inc. Reston, Virginia. Ed.2. : pp 109 - 128

*Olympios, C.M. (1992) The effect of temperature, humidity and carbondioxide enrichment in raising cucumber seedings. *Acta Hort*. **303** : 71 - 78

Panday, S.N., Sinha, B.K. (1986) *Plant physiology,* Vani educational book. New Delhi Ed, 2 pp. 140 - 185

*Pelletier, B. (1988) cucumber in soilless culture control of humidity in the green house by misting. Infos No. 57 : 6 - 8

Smith, I.E., Savage, M.J. and Mills, P. (1984) Shading effects on greenhouse tomatoes and cucumbers. *Acta Hort.* **148** : 491 - 500

*Thomas Varghees, T. (1989) A low cost greenhouse, *Indian Cocoa, arecanut spices J.* NRCS, Calicut **12** (3) : 94 - 95

*Tomalty, R. (1988) The climate of a passive solar greenhouse in a semi-arid region. In Arid Lands today and tomarrow 89 - 95

Tskelev, G and Stoilov, S. (1990) Fluorescent film for the cultivation of tomatoes in Bulgaria, *Plasticulture* **86**(2) 47-51.

Weimann, G. (1985)Light transmissivity of different film coverings of greenhouses. *Acta Hort* **170** : 52 - 57.

Zenen, Ing. Maurizio (1990) Synergy between plastic research and protected cultivation. Proc. of XI International Congress on plastics in Agriculture, New Delhi.

Zipori, I, Dayan, E and Samuel, D. (1987) Intermittent enrichment of tomatoes in commercial size greenhouses with carbondioxide, Proc. of the French - Israeli Symposium on greenhouse Technology, Israel.

* Originals not seen.

Mears, D.F. (1990) Oppertunities for colloborative Indo - US greenhouse research Proc. of XI International congress on 'The Use of Plastics in Agriculture'., New Delhi

Monteiro, A.A. (1981) Influence of evaporative cooling systems on greenhouse environment. ASAE paper No. 81 : 4027

Nelson, P.V. (1981) *Greenhouse Operation and Management,* Reston Publishing company Inc. Reston, Virginia. Ed.2. : pp 109 - 128

*Olympios, C.M. (1992) The effect of temperature, humidity and carbondioxide enrichment in raising cucumber seedings. *Acta Hort*. **303** : 71 - 78

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*Tomalty, R. (1988) The climate of a passive solar greenhouse in a semi-arid region. In Arid Lands today and tomarrow 89 - 95

Tskelev, G and Stoilov, S. (1990) Fluorescent film for the cultivation of tomatoes in Bulgaria, *Plasticulture* **86**(2) 47-51.

Weimann, G. (1985)Light transmissivity of different film coverings of greenhouses. *Acta Hort* **170** : 52 - 57.

Zenen, Ing. Maurizio (1990) Synergy between plastic research and protected cultivation. Proc. of XI International Congress on plastics in Agriculture, New Delhi.

Zipori, I, Dayan, E and Samuel, D. (1987) Intermittent enrichment of tomatoes in commercial size greenhouses with carbondioxide, Proc. of the French - Israeli Symposium on greenhouse Technology, Israel.

* Originals not seen.

APPENDIX I

Specification of greenhouse

Length	= 18.00m
Width	= 6.00m
Height at the centre	= 2.65m
Height of the door	= 2.00m
Width of the door	= 1.00m
Width of the gutter	= 0.11m
Slope of the gutter	= 1 in 75
Depth of the gutter	= 0.10m

APPENDIX II

Specification of cooling pad

Length	= 4.90m
Height	= 0.90m
Thickness	= 0.15m
Mesh size	= 0.025m square mesh

APPENDIX III

Specification of fan

Diameter	= 0.66m
RPM	= 920
Rated current	= 2.65A
Voltage	= 230 V
Circuit	= 1 phase, 50 Hz
Power	= 560 W
Make	= Almonard

APPENDIX IV

Specification of pump

HP	= 0.5
RPM	= 2800
Head	= 15m
Pump size	= 25 x 25mm
Voltage	= 230 V
Power	= 0.37 kW
Current	= 2.8 A
Make	= Dhara Monoblock pump

APPENDIX V

Volume of air expelled

Number of revolutions per min. of anemometer	= 3.00
One revolution	= 100 m/ min.
Velocity of air expelled	= 300 m/ min.
Diameter of fan	= 0.65 m
Area through which air is expelled	= $0.3318 m^2$
Volume of air expelled	= area x velocity of air
	= $1.66 m^3 /s$

APPENDIX VI

Rate of discharge on to the cooling pad

Discharge through one dripper	= 946.7ml/ min.
Total number of drippers	= 90
Dicharge on to the cooling pad	= $946.7 \times 90 \times 10^{-3} / 60$
	= I.4 lps

APPENDIX VII

Discharge from mist emitter

Discharge from one emitter	= 800 ml/ min.
No. of emitter lines	= 4
No. of emitter in each line	= 12
Discharge of mist system	= 800 x 4 x12 / 60 x 1000.
	= 0. 64 lps

APPENDIX VIII

able 5a. Variations in different parameters under static conditions on 03-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	73.8	24.6		69.1	21.9	
1.00am	77	23.9		72.7	20.7	
2.00	74.6	24.1		66.7	22.1	
3.00	77	22.9		73.1	19.5	
4.00	77.4	22.9		70.6	21.7	
5.00	76.2	22.9		69.5	22.2	
6.00	75.3	23.2	2	68.2	22.4	2
7.00	63.3	23.3	809	59.7	22.9	1638
8.00	63	25.1	3110	55.5	26.3	10200
9.00	62.9	27.8	12430	52	30.1	27000
10.00	55.8	37.3	31300	43.8	32.1	51200
11.00	53.9	41.8	45200	40.5	34.9	54500
12.00	50.8	48.6	56300	34.6	37.5	68400
1.00 pm	53.1	48.3	52800	41.3	39.4	68400
2.00	46.8	44.9	51200	35.8	37.6	60700
3.00	51.2	41.3	27400	35.2	37.1	49000
4.00	58.4	34.9	15800	42.5	31.8	31200
5.00	69.7	30.6	41400	52.8	28.3	4010
6.00	73.6	29.1	936	54.2	27.1	1141
7.00	74.3	27.3	1	62.5	25.9	2
8.00	72.6	26.5		61.7	24.7	
9.00	73.3	26.1		63.1	24.1	
10.00	74.3	25.8		64.8	24.3	
11.00	75.2	25.3		67.8	23.4	

Table 5b. Variations in different parameters under static conditions on 04-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	73.7	25.2		66.3	23.4	
1am	74.2	25.4		66.7	23.9	
2.00	74	25.1		67.1	24.3	
3.00	73	24.6		67.8	23	
4.00	73.8	25.		66.1	22.8	
5.00	73	24		63.7	22.4	
6.00	73.2	24.1		62.9	22.6	
7.00	74.4	2.5	680	67.8	22.4	1445
8.00	70.9	24.6	5080	62.5	25.2	9160
9.00	69.7	26.9	8760	53.2	28.9	29600
10.00	55.9	38.3	38900	51.5	31.4	49500
11.00	54.1	44.1	51400	40.5	34.1	68200
12.00	58.8	40.3	12350	41.4	31.5	12900
1.00 pm	60.3	38.8	66500	40.9	33.5	64600
2.00	50.6	47.8	52000	37.4	37.5	70200
3.00	48.2	47.4	46100	33.4	36.7	60800
4.00	64.2	34.7	19200	44.6	33.8	47200
5.00	67.5	31.1	2680	46.1	28.8	3160
6.00	71.8	28.9	1162	55.5	27.3	1082
7.00	71.1	27.2	2	60	25	2
8.00	75.3	26.7		63.7	23.6	
9.00	71	26		62.6	24.5	
10.00	72.2	25.9		64	23.7	
11.00	74.4	24.5		64.9	23.5	

Table 5c. Variations in temperature at different layers inside the greenhouse on 13-04-1997

	Inside						Outside	
Time	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Solar intensity lux	Temperature (°C)	Solar intensity lux
12.00	27	27	26.9	26.9	26.9		26.2	
1.00 am	26.5	26.4	26.4	26.3	26.3		25.8	
2.00	26.4	26.4	26.3	26.2	26.2		25.6	
3.00	25.8	25.8	25.6	25.7	25.7		25.4	
4.00	25.6	25.6	25.5	25.5	25.5		25.2	
5.00	25.3	25.3	25.1	25.1	25.1		24.6	
6.00	25.5	25.5	25.3	25.3	25.3		24.8	
7.00	27	27	27	26.2	26.5	1075	26.2	2810
8.00	30	29.5	29	28.8	28.5	9700	27.3	25500
9.00	35.5	33.7	33.8	33.9	33	31700	32.7	65500
10.00	39	38.8	38	39	38.8	30100	35.2	97700
11.00	41	41	40	42.8	42.5	63000	35.8	100700
12.00	44	44.5	45	45.6	46	62500	37.1	116700
1.00 pm	47.5	47.9	48	48.8	49.5	60800	36.7	113400
2.00	48	48.5	49	48.5	48.5	64500	33.5	97800
3.00	45	46.5	46.9	46.8	47	53000	33.2	84900
4.00	41.2	41.9	42.1	42.6	41.8	27200	30.1	59600
5.00	40	39.1	39	39	38.7	5470	29.6	31100
6.00	35.5	34.9	35	34.6	34.5	1580	28.2	3220
7.00	31.6	31.1	30	30.1	30		27.9	
8.00	30	30	29.8	29.8	29.8		27.1	
9.00	29.6	29.5	29.5	29.3	29.4		26.8	
10.00	28.5	28.5	28.4	28.5	28		26.5	
11.00	27.9	27.8	27.8	27.6	27.6		26.1	

Table 6a. Variations in different parameters when two fans operated for 0.5h without cooling pad on 17-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	66.6	26.75		61	23.5	
1am	64.9	26.25		60.5	23	
2.00	65.7	26		59	22	
3.00	66.4	25.5		59.9	22	
4.00	65	25		59.7	22	
5.00	60	24.5		56.6	21	
6.00	60	24		56.1	21	
7.00	65.2	25	564	53.5	22	1470
8.00	64.3	25.8	4470	48.3	24.2	8140
9.00	64.2	27.6	8200	47.2	27.1	29200
10.00	60.9	32	29500	40.2	32.8	51100
11.00	54.7	39.2	42800	36.8	33.8	66000
12.00	55.4	44.4	47600	34.8	34	86600
1.00 pm	53.3	47.8	55600	35.5	33	80600
Two fans operated from 1.15 to 1.45 pm						
1.15	53.3	47.8	54600			
1.20	36.4	40	55000			
1.25	35.7	39.5	59500			
1.30	34.9	39.2	56800			
1.35	34.3	39.5	56400			
1.40	32.8	39.8	53000			
1.45	30.6	40	50500			
1.55	41.6	43.5	45700			
2.00	43.5	45	55000	32	35.2	75200
2.05	48.4	45.8	53600			
2.15	46.6	46.3	40600			
3.00	48.7	45.8	12300	36.5	36.4	58500
4.00	55.3	40.2	5940	38.5	33	25600
5.00	65.2	36.6	1385	45.5	30	7340
6.00	67.1	32.8		51.2	28.8	2280
7.00	69.1	30.5		52.8	25.5	
8.00	66.3	29.5		53.5	25	
9.00	69.6	28.4		59	24.5	
10.00	65.8	28		62	24.3	
11.00	68.4	27.5		61.5	24.9	

Table 6b. Variations in different parameters when two fans operated for 0.5h without cooling pad on 18-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	60.4	27		57.5	24	
1.00 am	59.8	27		56.8	24.5	
2.00	60.1	26.5		57.8	24.5	
3.00	61.5	26.5		59.4	24.3	
4.00	62.5	26.5		59.6	24.5	
5.00	62.5	26.5		59	25	
6.00	62.8	24		53.3	26.2	
7.00	59	24.1	252	55.6	21	736
8.00	58.1	25.2	3800	53.8	23.2	7200
9.00	58.3	28.1	8740	49.5	26.9	31300
10.00	56.3	33.1	25200	40.6	31	60400
11.00	56.8	39.7	43600	37.7	33	73600
Two fans operated from 12.00 to 12.30 pm						
12.00	53.2	44.2	47000	34.8	33.9	68400
12.05	40.5	39.2	47800			
12.10	39.4	88.8	45500			
12.15	38.6	38.5	45800			
12.20	37.5	38.5	52400			
12.25	37.8	39.3	52000			
12.30	36.9	36.8	14000			
12.40	46.8	37.5	17900			
12.50	48.4	41	10970			
1.00 pm	50.4	40	12440	32.3	32.2	73800
2.00	58.6	47	43700	36.3	37	266400
3.00	59.8	40.5	33800	38.9	34.1	39500
4.00	63.6	39.6	10600	40.3	30.5	29200
5.00	66.4	35.2	5580	45	30	8420
6.00	67.9	32.8	1540	48.7	28.5	1360
7.00	61.4	31		53.5	26	
8.00	60.1	29		53.5	26	
9.00	58.8	28.9		56.9	25	
10.00	59.8	28.6		60.5	24.5	
11.00	60.7	28		57.9	24.5	

Table 7a. Variations in different parameters when one fan and pad system operated for 0 .5 h on 21-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	59.7	26		60.9	21.5	
1.00	59.5	24.8		59.8	21	
2.00	59.3	24.2		59.6	20.4	
3.00	57.3	23.5		58.2	20.3	
4.00	60.4	22.5		59.6	20	
5.00	61.1	23		59.8	19.2	
6.00	62.2	23		60.3	19.8	
7.00	59.6	24	766	56.2	21	1155
8.00	56.6	24.8	4350	54	22.2	14340
9.00	55.4	27	9610	50.1	25.4	52100
10.00	51.8	31.1	23800	43.7	31.1	66000
11.00	56.9	39.8	52500	41.5	32.8	93300
12.00	51.1	46	63200	39.7	34.2	102700
1.00 pm	53.4	46.5	73600	29.9	31.6	80500
One fan and pad system operated from 1.00 to 1.30 pm						
1.05	38	43.6	72000			
1.10	38.7	41.7	163000			
1.15	35.6	41.5	69000			
1.20	35.4	41.4	73000			
1.25	36.4	41.3	75500			
1.30	33.6	41.6	73800			
1.40	39.4	44.1	77500			
1.50	42.8	46	72500			
2.00	43.4	46.7	75500	26.4	33.2	86900
3.00	47.4	45.8	33600	40.8	35.5	79000
4.00	56	36.8	9490	38.9	30.5	49500
5.00	64.4	33.1	2940	34.6	29	36600
6.00	61.7	30.8	1099	47.8	27.1	2000
7.00	61.9	29.5		51	26.2	
8.00	62	29		56.5	24.8	
9.00	61.5	2		51.5	23.5	
10.00	62.6	27		58.4	22.5	
11.00	60.6	26.5		57.1	21.8	

Table 7b. **Variations in different parameters when one fan and pad system operated for 0 .5 h on 25-01-1997**

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	59.9	26.3		59.4	21.9	
1.00am	59.4	25.1		58.2	20.6	
2.00	59.1	24.3		57.6	20.1	
3.00	58.1	23.1		55.4	20	
4.00	60.1	22.7		54.2	19.7	
5.00	61.7	23.1		53.8	19.6	
6.00	62.1	23.5		52.9	20.1	
7.00	58.4	23.8	532	51.8	21	930
8.00	54.2	25	4970	49.9	23	9100
9.00	51.7	27.6	6880	51.8	27.2	32700
10.00	52.8	31.3	15500	40.7	30.6	53000
11.00	43.6	38.5	48000	31.1	30.6	75700
12.00	45.8	44	53500	35.7	29.6	73400
1.00 pm	36	47.5	53000	28.2	33.4	71000
One fan and pad system operated from 1.20 to 1.50 pm						
1.20	43.4	47.2	30700			
1.25	45.4	43.5	60000			
1.30	40.2	42.3	50200			
1.35	37.3	41.8	64000			
1.40	37.2	41.6	56400			
1.45	36.4	41.8	56000			
1.50	32.5	41.7	59800			
2.00	43.5	44.5	55600	27.1	32.9	68600
2.10	49.3	45.2	55400			
2.20	46	45	33000			
3.00	62.2	40.1	14500	41.5	33.1	18400
4.00	58.3	39.8	12700	44.6	32.5	31800
5.00	59.4	35	5180	50.9	30.8	8380
6.00	61.7	32.8	2980	51.8	28.1	3790
7.00	62.1	30.2		53.1	26.8	
8.00	62	29.5		56.1	24.5	
9.00	61.7	28.5		56.8	23.8	
10.00	62.8	27.3		58.1	22.6	
11.00	61.1	26.8		58.7	22.3	

Table 8a. Variations in different parameters when one fan and pad system operated for 0 .5 h on 08-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	69.1	24.9		60.2	23.5	
1.00 am	68.7	24.5		58.7	23	
2.00	69.8	24.8		59.1	23.4	
3.00	69.3	24.7		58.5	23.1	
4.00	68.9	23.9		57.6	22.8	
5.00	67.2	23.8		57.6	23	
6.00	66.8	23.7		57	23.2	
7.00	70.2	25.3	581	57.5	23.7	1465
8.00	68.8	25	3270	53.6	24.8	8250
9.00	66.5	27.4	7990	44.1	29.8	24800
10.00	59.5	34.7	27300	41.8	33.3	46800
11.00	55.6	39.4	44000	37.6	36.8	57800
12.00	54.5	43.5	49800	34.8	37.6	66400
1.00 pm	51.8	47.7	41000	37.1	37.9	65700
Fans and pad system operated for 0.5h from 1.30 to 2.00pm						
1.30	51.5	45.5	47400			
1.35	37.5	41.5	48800			
1.40	38.3	36.7	41700			
1.45	39	36	39300			
1.50	40.2	34.4	39300			
1.55	40.1	33.9	41400			
2.00	40.3	34.2	43300	37.3	34.8	58000
2.10	50.3	37.88	44400			
2.20	49.4	42.2	45200			
2.30	47	42.8	44100			
3.00	50.9	42.9	37000	35.8	38.6	45800
4.00	61.7	34.9	8700	39.7	32.3	21800
5.00	61.4	31.7	4170	46	29.3	4800
6.00	73.9	28.2	1370	53.4	27.4	940
7.00	69	27.6		53.6	26.4	
8.00	68.6	27		55.4	24.8	
9.00	67.8	26.4		55.7	24.8	
10.00	71	25.6		58.2	23.8	
11.00	68.2	25.2		59.3	24	

Table 8b. Variations in different parameters when two fan and pad system operated for 0 .5 h on 12-01-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	66	27.8		62.3	24.5	
1.00 am	62.5	27.4		58.6	24	
2.00	60.6	27.6		58.3	24	
3.00	59.3	27		54.3	24.5	
4.00	58.3	27.5		53	24.5	
5.00	58.8	26.5		54.3	24	
6.00	59.2	26		54.5	23.8	
7.00	69.3	25.2	316	62.5	24	668
8.00	68.9	26.5	4300	61.2	24.8	8630
9.00	66.4	29	9070	52.1	27.5	35800
10.00	56.8	34	30800	40.3	28.9	56800
11.00	60.2	39.9	48100	36.6	34.5	72600
12.00	56.7	41.8	57800	35.1	35.8	73500
1.00 pm	53	46	53600	34.5	35.8	786003
Fans and pad system operated from 1.30 to 2.00 pm						
1.30	50.6	46.8	53400			
1.35	38.8	38.5	49800			
1.40	38.2	39	51600			
1.45	36.2	39.5	58500			
1.50	34.8	39.2	55500			
1.55	35.9	39	52600			
2.00	34.8	38.2	50600	34	34	68800
2.10	49.6	42.5	52400			
2.20	46	43.2	46600			
2.30	46	43.8	42200			
3.00	50.4	42	8680	36.6	32	12300
4.00	64.5	37.2	8160	46.8	31	8320
5.00	62	34.9	4490	43.4	30	4960
6.00	65.6	32	988	46.1	28	1206
7.00	66.5	30.5		53	26.1	
8.00	63.3	29.8		54.3	25.9	
9.00	62	29		58.7	25	
10.00	61.9	28.5		58.2	25.5	
11.00	66.8	28		61.9	24	

Table 9a. Maintenance of temperature inside the greenhouse between 30°C and 35°C by means of mist system on 19-04-1997

	Inside							Outside		
				Mist operator						
						Fall in temperature				
Time	RH (%)	Temperature °C	Solar intensity lux	From	To	Initial	Final	RH (%)	Temperature °C	Solar intensity lux
12.00	60.7	25.3		53.7	21.9					
1.00 am	58.9	24.7		53.2	21.7					
2.00	58.3	24.3		52.7	21.3					
3.00	58.9	23.7		51.9	20.9					
4.00	59.9	23.4		53.1	20.6					
5.00	62.7	22.9		53.7	20.3					
6.00	61.5	22.5		52.8	20.1			53	22.8	
7.00	52.1	29.5	1719					51.9	27	5170
8.00	51.7	30.2	7060					50.7	28.2	24800
9.00	50.1	30	30300					48.3	30.5	49600
				9.42	9.45	35	30			
10.00	48.7	30.5	38300					47.2	31.2	86500
				10.16	10.19	35.2	29.7			
				10.33	10.36	35	30			
				10.5	10.53	35	30			
11.00	48.5	32.8	36200					46.3	36.2	52100
				11.03	11.07	35	29.3			
				11.15	11.18	34.6	30			
				11.27	11.3	35	29.8			
				11.37	11.4	35.4	30			
				11.45	11.49	35	29.6			
				11.55	11.58	35	30			
12.00	48.4	31	54800					43.1	35.4	106100
				12.03	12.06	35	30			
				12.11	12.14	35	30			
				12.2	12.23	35	30			
				12.28	12.31	35	30			
				12.36	12.39	35	30			
				12.45	12.48	35	30			
				12.52	12.55	35	30			
1.00 pm	45.3	34.2	27200					39.7	31.7	54500
				1.04	1.07	36	30			
				1.12	1.16	35.6	30			
				1.21	1.25	35.4	29.8			
				1.3	1.33	35	29.8			
				1.4	1.42	35	30			
				1.47	1.5	35	30			
				1.54	1.57	35	30			

2.00	46.7	32.2	65000					37.8	36.2	87900
				2.01	2.05	35	30			
				2.12	2.15	35	30			
				2.2	2.23	35	30			
				2.29	2.32	35	30			
				2.38	2.41	35	30			
				2.47	2.5	355	30			
3.00	42.1	35.8	52300	3	3.07	35.8	30	38.7	33.4	61500
				3.18	3.24	35	30			
				3.36	3.42	35	29.5			
4.00	42.6	34	25600					38.2	31.4	48000
				4.07	4.12	35	28.5			
5.00	50.1	34	6410					40.4	30.8	5170
6.00	54.6	32.6	3130					48.7	29.4	4880
7.00	59.2	29.2		52.6	26.3					
8.00	59.5	28.3		55.3	25.1					
9.00	61.7	27.6		53.2	24.3					
10.00	62.4	27.3		54.3	23.2					
11.00	61.3	26.3		54.6	22.3					

Table 9b. Maintenance of temperature inside the greenhouse between 30°C and 35 °C by means of mist system on 20-04-1997

	Inside							Outside		
				Mist operator						
						Fall in temperature				
Time	RH (%)	Temperature °C	Solar intensity lux	From	To	Initial	Final	RH (%)	Temperature °C	Solar intensity lux
12.00	60.9	25.7						54.6	22.1	
1.00pm	58.7	24.6						53.4	22.2	
2.00	58.4	24.3						52.8	21.3	
3.00	58.8	23.7						51.7	20.8	
4.00	59.7	23.3						53.7	20.5	
5.00	62.4	22.7						52.8	20.1	
6.00	62.7	22.8						53.4	20.5	
7.00	57.4	26.5	2170					52.3	25	3170
8.00	53.4	28	5900					51.8	26.2	10700
9.00	49.9	32.2	25300					46.7	32.9	26700
10.00	47.1	34	15300					47.2	31.3	41200
				10.30 am	10.33 am	35.2	29.8			
11.00	46.3	34.8	22100					46.3	33.6	36700
				11.01 am	11.05 am	35	30			
				11.30 am	11.33 am	35.5	29.5			
				11.45 am	11.47 am	35	29			
12.00	45.2	34.5	16100					46.3	33.6	36700
				12.13 pm	12.15pm	35	29.8			
				12.34 pm	12.37 pm	35	29			
				12.59 pm	1.05 pm	35.5	30			
1.00 pm	48.4	30	69500					38.9	36	96000
				1.10 pm	1.15 pm	35.5	30			
				1.22 pm	1.25 pm	36	30			
				1.33 pm	1.36 pm	35	29.5			
				1.43 pm	1.46 pm	35	30			
				1.55 pm	1.58 pm	35	30			
2.00 pm	47.6	32.5	31500					43.1	35.4	41200
				2.05 pm	2.09 pm	35	30			
				2.17 pm	2.20 pm	35	30			
				2.30 pm	2.35 pm	35.55	30			
				2.45 pm	2.47 pm	35	30			
				2.55 pm	2.57 pm	35	30			
3.00 pm	47.3	31.5	17400					46.3	32.2	25700
				3.20 pm	3.22 pm	35	30			
				3.34 pm	3.37 pm	35	30			
4.00 pm	43.7	34.5	24200					38.7	33.2	34200
				4.08 pm	4.11 pm	35	30			
5.00 pm	50.2	34	5200					40.5	30.8	8780
6.00 pm	54.3	32.4	21.3					48.3	29.3	47300
7.00 pm	59.7	30.2						52.5	26.4	
8.00 pm	59.1	69.3						55.6	25.3	
9.00 pm	59.4	28.2						53.4	24.3	
10.00 pm	61.9	27.3						54.1	23.6	
11.00 pm	61.7	26.4						54.3	22.1	

Table 10a. Maintenance of temperature inside the greenhouse between 30°C and 35°C by means of fan and pad system on 10-02-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	59.1	25.7		54.3	22.3	
1.00 pm	58.7	24.8		53.8	21.7	
2.00	58.3	24.3		53.8	20.1	
3.00	58.6	23.6		54	19.3	
4.00	59.9	23.2		53.8	19.1	
5.00	61.1	23.1		54	20.1	
6.00	59.7	22.6		52.7	20.2	
7.00	53.6	21.8	251	53.4	20	663
8.00	53.1	23	2810	51.6	21.2	4400
9.00	52.1	26	5620	49.6	25.2	21500
10.00	49.9	29.9	26300	49.1	33	61000
Fans and pad system operated from 10.30 to 5.00 pm						
10.30	45.1	35	55600	48.99	34	65000
11.00	49.4	32.5	50600	48.5	33.5	81000
12.00	45.2	34.8	49000	45.9	31.5	82000
1.00 pm	42.4	36.2	54800	42.4	32.5	64800
2.00	39.4	37	60100	39.4	33.5	68400
3.00	40.5	35	47000	40.5	34	61500
4.00	40.7	34	21400	40.2	32.6	38800
5.00	48.6	32.4	5700	42.7	29.3	6020
6.00	54.4	30	1890	50.2	28	2860
7.00	58	28.5		54.8	25.5	
8.00	58.1	25.1		57.3	25	
9.00	60.8	26.5		54.3	24	
10.00	65.2	26.3		55.5	23	
11.00	59.7	26.1		55	22.6	

Table 10b. Maintenance of temperature inside the greenhouse between 30°C and 35°C by means of fan and pad system on 14-02-1997

Time	Inside			Outside		
	RH(%)	Temparature °C	Solar intensity lux	RH (%)	Temperature °C	Solar intensity lux
12.00	58.3	25.3		65	22.4	
1.00 am	58.1	24.7		64.5	21.7	
2.00	57.9	24.4		63.9	21.3	
3.00	57.7	23.8		64	20.6	
4.00	58.6	23.3		63.5	19.7	
5.00	59.7	22.8		63	19.6	
6.00	58.6	23.1		62.9	20.6	
7.00	51.9	23	1246	50.1	21.5	1997
8.00	54.9	24.8	4010	53.2	23.1	6480
9.00	49.6	27.3	5560	49.5	26.3	35700
10.00	45.4	30.1	25100	45.7	31.6	61300
11.00	43.5	31.5	34900	40.5	33.8	42900
Fans and pad system operated from 11.20 to 4.30 pm						
11.20	42.1	35	59200	39.1	34	79500
12.00	34.8	34.2	51800	32.5	32.8	78000
1.00 pm	34.3	37.4	51200	30.1	32.9	70500
2.00	34.9	37.9	51000	29.4	33.5	71300
3.00	35.2	35	21400	32.1	34	55900
4.00	45.2	32	20400	49.2	31	34000
5.00	52.5	32	3710	50.7	29	8500
6.00	52	30.5	2390	49.9	28.5	3250
7.00	53.6	29.1		53.9	25.9	
8.00	56.1	28.1		55.6	24.7	
9.00	58.7	26.7		62.8	23.6	
10.00	60.9	26.1		64.7	23.1	
11.00	58.6	25.6		64.8	22.8	

Table 11 Power requirement to maintain 30 to 35 °C inside the greenhouse

Condition	Kilo watt	Time of operation (min)	Power required (kwh)	Remarks
2 fan and p	1.49	30	0.745	Feasible to maintain th temperature
1 fan and p	0.93	30	0.465	Not feasible to maintai the temperature
2 fan only	1.12	30	0.56	Not feasible to maintai the temperature
Mist syste	1.49	15	0.3725	Feasible to maintain th temperature

ENVIRONMENTAL CONTROL IN GREENHOUSES FOR HUMID TROPICS

BY

BOBBY, T.
SINIJA, V. R.
SURESH, A.

ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

BACHELOR OF TECHNOLOGY
in
AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering & Technology
KERALA AGRICULTURAL UNIVERSITY

Department of Irrigation and Drainage Engineering
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
Tavanur - 679 573
MALAPPURAM

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ABSTRACT

Greenhouses are enclosed structures in which artificial conditions favorable for the growth of crops can be created. Temperature, relative humidity, air composition and solar intensity are the important parameters that govern the growth of crops inside the greenhouse. These climatic parameters are greatly affected by climatic conditions prevailing outside the greenhouse and the methods for maintaining optimum conditions are designed according to these conditions.

The project entitled "Environmental control in green houses of humid tropics" was carried out in the greenhouse constructed by the Plasticultural Development Centre in the instructional farm of K.C.A.E.T., Tavanur. The variations in temperature relative humidity and solar intensity inside as well as outside the greenhouse with and without cooling system in operation was measured in 1 hour interval and were compared with that of outside conditions. The variations showed that the maximum temperature was seen during the period between 12.00 noon and 2.00 pm and the effect of different cooling methods during this period was noted.

The variations showed that of all the cooling methods adopted the temperature inside was reduced to the optimum level but the mist system was more efficient compared to other systems as it reduced the temperature in a short span. The reduction in relative humidity was less compared to the other system and power consumed was less. The cooling with two fans and pad was effective but power consumption was more compared to the mist system. The cooling with one fan and pad was not much effective due to reduced air exchange. The removal of air by using fans reduced the parameters to the conditions of ambient air prevailing outside the greenhouse.