OPTIMIZATION OF GREENHOUSE VENTILATION FOR HUMID TROPICS

By

JINU, A.

THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Irrigation & Drainage Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679 573, MALAPPURAM

KERALA, INDIA

2000

DECLARATION

I hereby declare that this thesis entitled **"OPTIMIZATION OF GREENHOUSE VENTILATION FOR HUMID TROPICS"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Tavanur,

Date: 22-12-2000

Jinu, A.

CERTIFICATE

Certified that this thesis entitled **"OPTIMIZATION OF GREENHOUSE VENTILATION FOR HUMID TROPICS"** is a record of research work done independently by **Sri. Jinu, 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 him.

Tavanur,

Date: 22-12-2000.

Er. Abdul Hakkim, V.M.
(Chairman, Advisory Committee)
Assistant Professor
Dept. of Irrigation and
Drainage Engineering
KCAET, Tavanur

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Sri. Jnu,A.** a candidate for the degree of Master of Technology in Agricultural Engineering majoring in Soil and Water Engineering, agree that the thesis entitled **"OPTIMIZATION OF GREENHOUSE VENTILATION FOR HUMID TROPICS"** may be submitted by **Sri. Jinu,A.** in partial fulfilment of the requirement for the degree.

Er. ABDUL HAKKIM, V.M.
(Chairman, Advisory Committee)
Assistant Professor,
Dept. of Irrigation and Drainage Engineering
KCAET, Tavanur

Dr. K. John Thomas
Dean,
KCAET, Tavanur
(Member)

Er. Kurien, E. K.
Asst. Professor
Dept. of IDE
KCAET, Tavanur
(Member)

Dr. J. Thomas
Assoc. Professor and Head,
AMPRS, Odakkali
(Member)

Dr. U. Sreelatha
Asst. Professor
Dept. of Pomology and Floriculture
College of Horticulture, Vellanikkara
(Member)

External Examiner T. P. George
Rtd. Professor of Agrl. Engineering
Thrikkakara Home, Narakathara Road, Cochin

ACKNOWLEDGEMENTS

I would like to avail this opportunity to express my deep sense of gratitude, utmost indebtedness and heartfelt thanks to **Er. Abdul Hakkim, V.M.,** Asst. Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T., Tavanur and Chairman of Advisory Committee, for his professional and unfailing guidance, constant backing, constructive and creative suggestions, didactic criticism and prolific encouragement during the course of this toil and in the preparation of this thesis. Without his untiring enthusiasm this work would not have completed this much soon.

I am immensely grateful to **Dr. K John Thomas,** Dean, KCAET, Tavanur, and Member of the Advisory Committee, for his timely guidance, co-operation and support during this course of work.

It is with extreme pleasure that I extend my courteous gratitude, exuberant thanks and a high sense of loyalty to **Dr. J. Thomas**, Associate Professor and Head, AMPRS, Odakkali and member the Advisory Committee, for his assiduous interest and extremely valuable suggestions to carry out this investigation successfully.

Heartfelt thanks are due to **Er. Kurien, E.K.**, Asst. Prof., Dept. of Irrigation and Drainage Engineering, KCAET, Tavanur and **Dr. U. Sreelatha,** Asst. Prof., Dept. of Pomology and Floriculture, College of Horticulture, Vellanikkara, members of the Advisory Committee for their suggestions and co-operation to complete this thesis work.

It gives me immense pleasure to express my profound sense of gratitude and heartfelt thanks to **Dr. K.I. Koshy**, Professor and Head, Dept. of SAC, KCAET, Tavanur for his help and enthusiastic co-operation in carrying out the statistical analysis of the data.

I sincerely thank **Dr. Jobi. V. Paul**, Assoc. Prof. and Head, Dept. of Agricultural Engineering, College of Horticulture, Vellanikkara for his valuable advise and suggestions.

My heartfelt thanks to all the staff members and labourers of AMPRS, Odakkali for their help and co-operation during this research work.

I sincerely acknowledge **Dr. V. Anilkumar**, Asst. Prof., Dept. of SAC for the co-operation and for permitting me to avail the facilities of the computer centre.

I am indebted to my friend **Mr. Sumesh Kumar,T.** for the helps rendered to me and I am short of words to express my humble thanks to him.

At this time, I express my sincere thanks to my teachers and friends for their remarkable co-operation and encouragement during this work.

The award of junior fellowship by Kerala Agricultural University is greatly acknowledged.

I express my deep sense of gratitude to my loving parents and family members for their unfailing support and inspiration all through my studies.

Above all I bow my head before the God Almighty for His blessings showered upon me.

Jinu, A.

Dedicated to
My Loving Parents

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

A	-	ampere
Agric.	-	agriculture
am	-	ante meridian
AMPRS	-	Aromatic and Medicinal Plant Research Station
ASAE	-	American Society of Agricultural Engineers
CI	-	Confidence Interval
CIAE	-	Central Institute of Agricultural Engineering
cm	-	centimetre(s)
Ed.	-	edition
eg.	-	for example
Engng.	-	engineering
et al.	-	and others
Fig.	-	figure
GI	-	galvanised iron
GL	-	ground level
h	-	hour(s)
Hort.	-	horticulture
hp	-	horse power
Hz	-	hertz
IDE	-	Irrigation and Drainage Engineering
i.e.	-	that is
Int.	-	international
J.	-	journal
KAU	-	Kerala Agricultural University
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
KW	-	kilowatt
lph	-	litre(s) per hour
lpm	-	litre(s) per minute
lps	-	litre(s) per second
m	-	metre(s)
Meteor.	-	Meteorology

Introduction

INTRODUCTION

Historically changes in agricultural productivity have been the prime driving force for economic growth, political stability and social and cultural development globally. Agriculture is the backbone of Indian economy and cultural heritage. Our experience during the last five decades has demonstrated strong correlation between agricultural growth and economic prosperity. India has agriculture based economy and when we talk about globalization of Indian economy, we must think about globalizing Indian agriculture. With independence, the production of food increased through the emergence of new land policies, efficient irrigation systems, improved seeds and use of fertilizers. Now-a-days the production of high value horticultural crops and floricultural products has a great export potential. So, development of new technologies to suit with the cultivation of these crops has a good scope.

Suitable and meaningful manipulation of the environment is very important for sustainable development of agriculture in the country. The need of the hour is to increase the productivity of crops and the quality of produce to meet the demands of ever increasing population. For a plant of given genetic make up, the factors that affect the plant growth are light, temperature, air composition and nature of the growing medium. Most of the engineering and agronomic practices modify only the nature of the growing medium. Irrigation and windbreaks have some degree of influence on the temperature conditions. There is practically no way to suitably modify or control light, temperature and air composition parameters in the open field cultivation. To tap the full potential of a crop, the crop environment needs to be suitably regulated. Therefore to increase the agricultural productivity, controlled environment agricultural practices can play a major role. In controlled environment agriculture or in protected cultivation, we are providing a barrier between the plant microclimate and the ambient climate.

Environment control structures in practice are cloches, low tunnels, mulches, growth chambers and greenhouses. In these structures, the plant growth affecting factors such as light, temperature, air composition and growing medium can be modified effectively to tap full potential of crops. By controlling the environment suitably, we can grow any plant in any place during any season. Of all the above mentioned structures, greenhouses are getting wider adaptability because the environment control can be achieved in a good manner in this type of structure. All types of plants except tall trees can be grown in greenhouses. Greenhouses can be defined as framed or inflated structures covered with transparent or translucent material, in which crops can be grown under the condition of at least partially controlled environment and which are large enough to allow a person to walk within them to carry out agricultural operations.

Greenhouse technology is the technique of providing favourable environment or growth condition to the plants. It is rather used to protect the plants from the adverse climatic conditions by providing optimum conditions of light, temperature, humidity, carbondioxide and other growth parameters to achieve maximum yield of best quality. Greenhouses are covered structures, which gives protection to the plants from wind, precipitation, excess solar radiation, extreme temperature and considerable pest and disease attack.

In most agricultural universities and research institutions of the country, greenhouse cultivation started since 1960's. The commercial use of greenhouses started in 1988, since then there is an increase in the area under greenhouse, because of the policies of Government of India. Greenhouse cultivation may be undertaken for handling tissue cultured plants or for growing high value horticultural crops such as foliage ornamental plants and cutflowers to achieve optimum levels of production. Greenhouse cultivation has greater significance when flowers or ornamental plants are grown for export. Now some of big industrialists are diversifying into greenhouse cultivation because of the export potential of high value crops. Nearly 70 percent of the greenhouses are used for growing flowers.

The main potentials of greenhouse technology in India are

1. Production of high value, low volume horticultural crops.
2. Supply of high quality fresh fruits / vegetables and flowers for metropolitan cities.
3. Production of planting materials.
4. Cultivation in problematic regions and extreme climates.

5. Export of hybrid seeds, ornamental plants and tissue culture plants.
6. In the field of biotechnology and genetic engineering.
7. Cultivation of rare and exotic medicinal, aromatic and ornamental plants.

The yield of greenhouse cultivation may be 10 to 15 times higher than that of outdoor cultivation depending on the type of greenhouse, availability of environment control facilities, cropping system, management of the greenhouse and type of the crop. The choice of crops to be raised in a greenhouse depends on the physical size of the structure and the economics of crop production. In greenhouses it is economical to grow the high value floricultural and horticultural crops like chrysanthemum, carnation, rose, orchid, anthurium, gerbera, african violet, tomato, capsicum, cucumber and some ornamental pot plants and foliage plants as the investment per unit area could be high compared to that of open field cultivation.

A modern greenhouse has three main components viz. the structure, the cladding material and the environment control system. Temperature plays an important role in the growth and development of plants. So temperature control in greenhouses is necessary for optimum growth and development of plants. Desirable temperatures can be maintained in a greenhouse with a well designed heating or cooling system. One could use hot water or steam through coils in various arrangements, forced hot air, infrared heat or electricity to increase the temperature during winter months. Various techniques viz. ventilation, roof shading, maintaining water film on the glass and evaporative cooling have been suggested for greenhouse cooling. In India cooling of greenhouses is a major concern and research is to be done to find out an effective cooling system. The different methods of evaporative cooling are fan and pad system, high pressure mist system and low pressure mist system.

Ventilation of greenhouse can be defined as the process of exchanging air inside the greenhouse with the outside air. It is required to remove surplus solar heat and transpired water vapour and to supply carbondioxide. Ventilation can be used with or without evaporative cooling, but evaporative cooling cannot be used without ventilation. The two types of ventilating systems in use are natural ventilating system and forced ventilating system. In natural ventilating system, the movement of inside air takes place due to pressure difference created by wind or temperature gradients. When high ventilation rates are required, the natural ventilation alone cannot meet the requirement and it is better to adopt forced ventilation system. Exhaust fans are used for the forced ventilation.

Natural ventilation is acceptable when screening to prevent pest entry is not a necessity and evaporative cooling is not required for temperature control. These restrictions may limit applications of natural ventilation in hot climates. However, fan ventilation uses a significant amount of electricity and can be noisy, which can make it unsuitable for some location. Natural ventilation system, if properly designed and controlled, can provide rates of air exchange comparable to that provided by mechanical ventilation systems. Natural ventilation systems, combined with shade, can provide a certain degree of environmental control in greenhouses that suffices for many crops. The major advantages of natural ventilation are its simplicity, non requirement of electricity and noise free operation.

A popular method of achieving greater cooling than that can be obtained with ventilation alone is evaporative cooling. With a well designed evaporative cooling system, air temperatures approaching the ambient wet bulb temperature can be obtained. It should be noted that even in relatively humid locations, significant benefits can be obtained with evaporative cooling. Temperatures in the middle of the day and early afternoon are significantly hotter than at dawn and as the relative humidity of the air does not usually increase very much during the day, there is a substantial wet bulb depression during the hottest part of the day even in the humid tropics.

The agroclimatic conditions of the country varies widely, the design and control of greenhouse environment varies from place to place. The climatic control methods adopted in other parts of the country cannot be adopted in Kerala because the parameters that has to be controlled in the greenhouse are region specific and crop specific. In humid tropical climate, high temperature as well as humidity are the major environmental parameters to be controlled in greenhouses. As Kerala falls under the humid tropical climatic condition, the greenhouse environment of this condition is to be studied for the adoption of this technology. Since ventilation is the cheapest method of lowering the temperature during warm periods, the effect of ventilation on different climatic parameters inside the greenhouse is to be studied. The parameters inside the greenhouse vary with different percentages of ventilation, and so, the optimal ventilation required for the specific greenhouse environment is of great importance.

The present study was undertaken at AMPRS, Odakkali and the study aims at evolving a low cost greenhouse cooling system through the natural ventilation. The main objective of the study was "optimization of greenhouse ventilation for humid tropics".

The specific objectives of the study are:

1. To study the effect of natural ventilation on greenhouse cooling.
2. To determine the optimum percentage ventilation area.
3. To study the effect of fan and pad cooling system for the environment control of greenhouse.
4. To study the effect of mist system for the environment control of greenhouse.
5. To study the effect of roof shade for the environment control of greenhouse.

Review of Literature

REVIEW OF LITERATURE

A number of studies have been conducted about the greenhouse environment in the past and the amount of literature available is exhaustive. A brief review of the studies conducted about greenhouse environmental conditions especially the changes in temperature, relative humidity, solar intensity and ventilation of the greenhouse are presented in this chapter.

Cloches, low tunnels, growth chambers, mulches and greenhouses are different methods of environmental control for plant growth. Of the various practices adopted for controlled environment agriculture, greenhouses are the most common because active environmental control can be achieved exclusively with the greenhouse.

Greenhouses are framed or inflated structures, covered with transparent or translucent material, large enough to grow crops under partially or fully controlled environmental conditions to get optimum growth and productivity. A greenhouse protects plant from wind, precipitation, excess solar radiation, temperature extremes, insects and diseases. According to (Attavar, 1997) the advantages of growing plants in a greenhouse are:

1. Productivity per unit area can be increased because the genetic potentiality can be fully exploited.
2. Intensity of cropping can be increased.
3. Any crop can be grown in any place during any season of the year depending on the demand and the market.
4. Problematic area can be brought under cultivation.
5. Excellent quality produce, free from any blemishes can be obtained.
6. Higher extent of bud or graft take and extended period of grafting can be achieved.
7. Easy protection from pests and diseases.
8. Temporary storage.
9. Controlled environment research work in horticultural crops is possible.

10. The produce can be obtained early in the season, with minimum requirement of water.

2.1 Protected Cultivation

The ever increasing population pressure and the limited land resources imply that more intensive and more productive agricultural practices have to be adopted to fulfil the growing demands of food, feed and fibre. Crop production in open fields still. remains to be contingent upon good weather condition. With the increasing human population, rising level of sophistication, increasing competition for resources and unpredictable climatic changes, the traditional open field cultivation needs to be re-assessed. To tap the full potential of a crop, the crop environment needs to be suitably regulated. Therefore to increase the agricultural productivity, controlled environment agricultural practices have to be adopted. The proposition of controlled environment agriculture envisages a barrier between the plant microclimate and the ambient climate (Chandra, 1985).

2.1.1 Forms of protected cultivation

The various forms of protected cultivation include cloches, low tunnels, growth chambers, mulches and greenhouses.

2.1.1.1 Cloches and low tunnels

Cloches and low tunnels cover an individual plant or a row of plants. These covered cultivation structures do not permit artificial heating or cooling. Therefore, cloches and low tunnels have usefulness under cold climates where the advantage of greenhouse effect is realised for keeping the young plant seedlings warm. These structures also protect the plants from such adversities such as heavy wind, intensive rain, hail and snow. The biggest advantage of cloches and low tunnels is their low initial cost. Cloches and low tunnels can have metallic or wooden framework. They are generally covered with flexible plastic films such as polyethylene or PVC of 0.05 to 0.15 cm thickness. Low tunnels are commonly semicircular in shape and not more than 1.0 m high. These tunnels and cloches may have perforations for ventilation along the sides or ridges (Bohra, 1985).

2.1.1.2 Growth chambers

These are mostly experimental environmental control chambers with the provision of precise control over the temperature, humidity, ventilation and light. They are mainly used to study the growth dynamics of a particular crop under controlled environment, so as to either arrive at optimum environmental parameters for every stage of growth or to find out the behaviour of it under the given environmental conditions. Simultaneously they are also used to study the growth of microbes and other side effects of providing the environmental control. The aim of such studies is to provide optimum environmental parameters for plant growth, which greenhouses make use of (Bohra,1985).

2.1.1.3 Mulches

Mulches are the simplest of all covered cultivation methods, in which the soil surface around the plants is covered with such materials as crop residues, leaves, manure, paper, plastic films, petroleum products and gravel. The advantages of mulching has been observed in cold climates and dry land agriculture by way of influencing infiltration, evapotranspiration, soil temperature, weed growth, soil salinity, soil erosion, soil nutrients and soil biological activities. Mulches reduce the mid-day maximum temperature under hot and dry conditions. The seasonal effect of which is that, in colder areas it increases soil temperature during winter and reduces the rate of rise in temperature during spring and early summer. Colour of plastic mulches is important in regulating soil temperature. White or reflective mulches have no effect on soil temperature where as clear plastic mulches increases soil temperature. Black plastics have been observed to have variable effects on soil temperature .The cost of mulching is quite low (Bohra, 1985).

2.1.1.4 Greenhouses

A greenhouse is an enclosure designed to help, create and maintain a suitable environment for enhancing the growth rates of botanical plants. Green houses are framed or inflated structures covered with transparent or translucent material in which crops may be grown under the conditions of at least 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 in the sense that solar radiation could pass through it, but the thermal radiation emitted by the objects in the green house could not escape. This particular effect, so called green house effect, causes rise of temperature within the greenhouse. The closed boundaries of greenhouse checks natural ventilation thus permitting retention of radiant heat within the greenhouse and also allows enrichment of carbondioxide of the greenhouse air. Further, the greenhouse water requirements are low due to increased humidity as a result of transpiration losses. A typical greenhouse generally contains in addition to the covered crop land, a work room and an environmental control room. The cost of greenhouses vary with the type of glazing material used and of environmental control practice adopted (Bohra, 1985).

2.1.1.4.1 Types of greenhouses

There are different types of green houses designed to meet specific needs (Chandra, 1985). Some of them are

(i) Lean-to greenhouse

These are usually the extensions of buildings such as residences and are erected on south facing side in northern hemisphere to interact maximum sunlight. These greenhouses may serve the adjoining buildings.

(ii) Detached or single span greenhouses

These greenhouses may be of different shapes. eg. quonset, gothic, gable and dome shaped. A single unit could cover about 200 m^2 to 500 m^2 floor area. Small greenhouse growers usually have one or more of single span greenhouses.

(iii) Ridge and furrow greenhouses

Multi – span greenhouses and gutter connected greenhouses are synonymous with this category. For large greenhouse ranges, this type of structure is economical, provided that it is to be used for crops requiring similar crop environment.

(iv) Tower greenhouses

Where land costs are very high or where the land availability is constrained, greenhouses are made taller for multi-tiered cultivation. These greenhouses are rare today.

(v) Circular greenhouses:

Circular greenhouses are attractive in appearance and have unique ventilation system. The centre dome of the roof can be opened. Spring loaded flaps are arranged all around at ground level. These are operated by simple controls inside the door.

(vi) Pit type greenhouses

These are usually employed in sloping lands and for the purpose of heat retention. They have insulated walls on the north, east and west sides. The walls are suitably designed to permit maximum reflection of the incoming radiation into the plant canopy. It is partially sunk and has the advantage of being in contact with the temperature stability of deep earth.

(vii) Air supported greenhouses

These are greenhouses without rigid frame, and 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 plastic film to keep them apart for insulation purposes. The principal advantage is its low cost.

2.2 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 a change in the climatic condition as compared to that outside by reducing radiation and air velocity, by increasing temperature and vapour pressure of the air and by making the fluctuations in carbondioxide concentrations stronger. Each of these changes has its own impact on growth, production and quality of the greenhouse crop, some of them being detrimental. These passive changes in the greenhouse weather, traditionally referred to as greenhouse climate, in combination with fluctuating outside weather

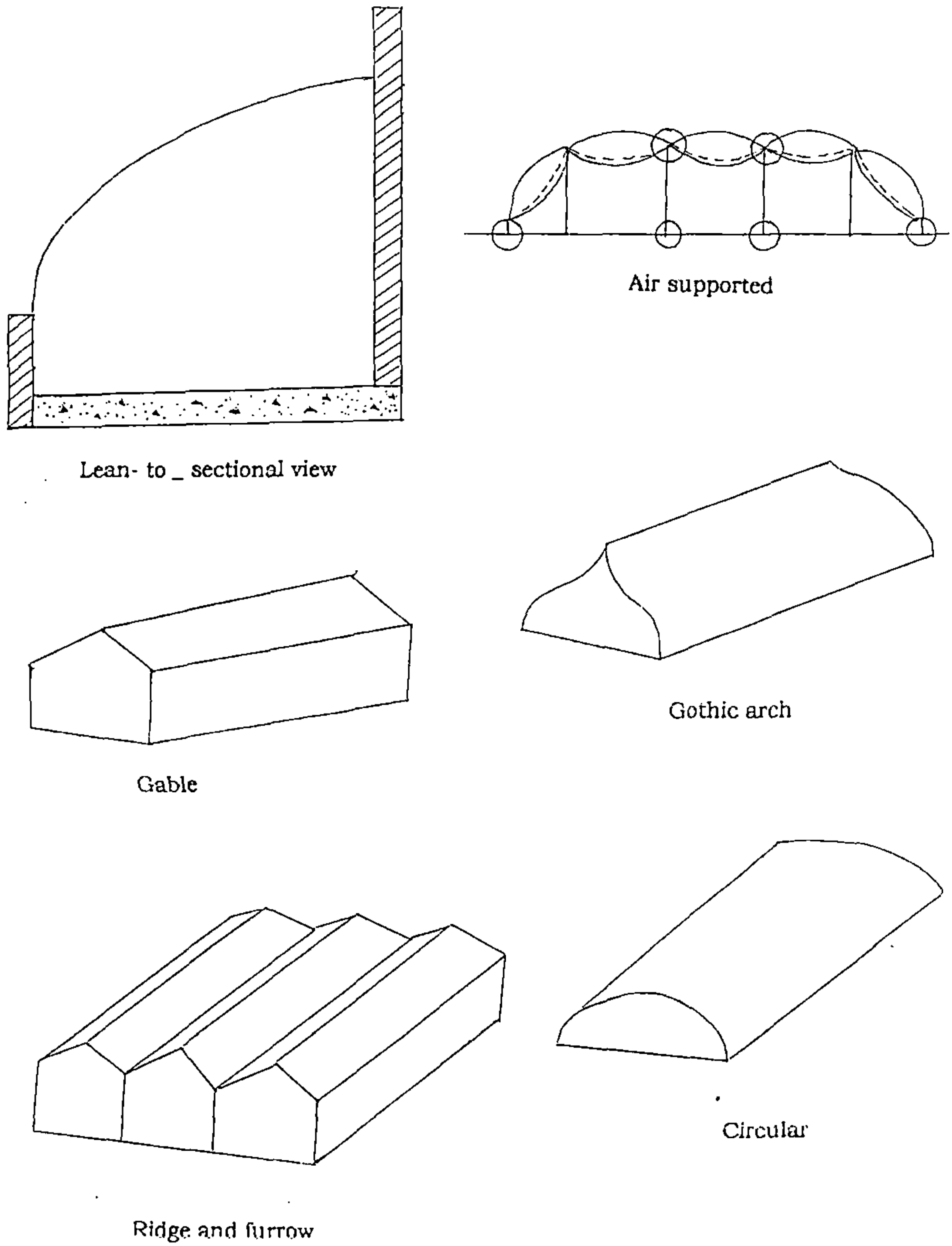

Fig. 1 Different types of greenhouses.

conditions, forces the grower to take an active role with respect to climate conditioning (Bailey, 1995).

The high productivity enables the grower to invest in climate control equipment to improve and facilitate production such as heating, carbondioxide enrichment, supplementary lighting, day length control, screening, cooling, soil cooling / heating. When the control was by wind, the main issue was to control climate extremes. With the introduction of heating and automatic ventilation, the focus shifted to a question of optimal set points for crop growth. Now-a-days green house climate is considered as an important issue in protected cultivation, because it enables the grower to control the production process, more or less independently of the outside weather conditions and as such represents an important operational management tool to optimize growth, production and quality (Bakker, 1995).

2.2.1 Light

Light may be considered as 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, there by the transpiration is affected by the light intensity. In order to achieve good growth of plants inside the greenhouse, there should be sunshine of desired quantity and intensity.

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.

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 sunlight varies from 86080 to 107600 lux on a clear day. In energy units, the requirement is 80 to 120 W/m of plant height.

Weimann (1985) in a study on light transmissivity of different covering materials for 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 greenhouse construction.

Zanen (1990) remarked that photosynthesis measured as released carbon dioxide depended on the light intensity and increased with luminosity. The increase was found in a definite range beyond which there was no effect.

In some circumstances, artificial light may be provided to supplement the deficit. Thus light in greenhouse is to be regulated so that excess light does not harm the crop. Light control in addition to other parameters can be employed for enhancing or delaying the maturity of the crops (Bakker, 1995).

The intensity, quantity as well as duration of light in a day influence many physiological processes in plants. The flowering responses of plants to light duration has a practical relevance in commercial floriculture. Flowering is influenced to a greater extent by the day length (Prasad, 1997).

Papadakis *et al.* (1998) investigated experimentally the greenhouse transmissivity to solar radiation using a greenhouse scale model of 40 cm width and 80 cm length. The solar transmissivity was measured at 48 positions on the ground surface of the scale model using silicon solar cells. The results showed that for the latitude of 37° 58' N during winter, the east west orientation was preferable to the north south one.

Thevenard *et al.* (1999) described a theoretical model for computing light penetration into a double row crop canopy. The inputs of the model were diffuse and beam irradiance above the canopy, position of the sun and description of the crop canopy in terms of plant stand dimensions and foliage characteristics. The outputs of the model were beam, diffuse and scattered irradiance at any location within a plant stand. Solar irradiance levels were monitored outside the greenhouse, inside the greenhouse above the canopy and at three heights within the canopy. Comparison between measured and predicted values showed that this model could be used to predict the average hourly light levels at any position within a double row greenhouse crop with mean bias differences less than 10 %. This model can be combined with plant physiology models for estimating canopy photosynthesis and transpiration of greenhouse crops and with greenhouse climate models for estimating canopy and leaf surface micro climate in greenhouses.

2.2.2 Temperature

Temperature control in greenhouses is necessary for optimum growth and development of plants. It influences initiation and development of reproductive organs. Temperature manipulation to induce flowering has commercial value in horticulture. Temperature affects time from sowing to flowering in three distinct ways; (1) there may be a specific cold temperature hastening of flowering known as vernalization, (2) the rate of progress towards flowering increases with increase in temperature to an optimum temperature at which flowering is most rapid and (3) at supra-optimal temperature flowering is progressively delayed as temperature gets warmer. When outdoor temperatures are too low, it is relatively easy to maintain temperature within desired limits in greenhouses. Heat can be added through the heating system or it can be removed by overhead or perforated tube ventilation. However as seasonal temperatures increase, precise control of day temperature becomes more difficult. It generally requires forced ventilation or evaporative cooling to control excess temperature. In the summer months, acceptable control of day temperature requires the application of a shading compound on the glass and the operation of an evaporative cooling system.

Kempkes (1985) carried out studies to gain an insight into the vertical temperature differences within a 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.

Rajinder (1985) reported that temperature plays an important role in the growth and development of plants. Soil temperature influenced the availability, absorption and utilization of mineral elements and water, seed germination and rooting system of a plant while transpiration rates were affected by leaf temperatures. Temperature also influenced the rates of photosynthesis, respiration and other metabolic processes which in turn affected the yield, quality of product and timing of crop maturity.

Glausauco (1992) studied 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 plants exhibited greater height.

Effect of temperature on biological processes viz. photosynthesis, transpiration, respiration, maturity and quality of products were further revealed through the studies of Prasad (1997).

2.2.3 Humidity

Winspear *et al.* (1970) experimentally shown that limiting relative humidity to 75 % compared to 90 %, reduced the incidence of Botrytis Cinera in glasshouse tomatoes.

Grange and Hand (1987) in a review paper concluded that relative humidities in the range of 60 to 90 % had little influence on the growth and development of the plants normally grown in greenhouses, which explains why there has been relatively little interest in controlling relative humidity.

Holder and Cockshull (1990) showed that calcium deficiency as occurred in the leaves of tomatoes grown at elevated humidities will occur in well-sealed energy efficient greenhouses. As a consequence leaf size was reduced, less light was intercepted and photosynthesis and fruit yield were reduced. The calcium deficiency was attributed to the reduction in temperature, which occurs when the humidity is high.

Jolliet (1994) developed 'HORTITRANS' a new model to predict humidity and transpiration as a function of the outside climate, with the particular objective of developing optimal control strategies for humidity in greenhouses. The model allows the inside vapour pressure to be directly calculated as a function of the outside conditions and the greenhouse characteristics. The model determines the water and energy to be added to or extracted from the greenhouse air, in order to achieve given humidity or transpiration set points.

Sudden changes in humidity can cause heat injury because water uptake cannot match the transpiration rate. Long term exposure to high or low humidity has beneficial as well as detrimental effects on growth and production. The adhesion of stigma in the flower may be strongly 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).

Plants grown under humid atmosphere are characterized by large and fleshy leaves, stem and flowers. Maintenance of plants under low humidity is associated with injury to margins and tips of leaves and petals, within and symptoms of senescence. The leaves and flowers appear weak and distorted. Plants which are maintained continuously under high humidity conditions may exhibit soft, mushy rotted leaf and stem tissue (Prasad, 1997).

Hand (1998) carried out investigations to find the effects of atmospheric humidity on greenhouse crops. He reported that, from crop production stand point, the test strategy is to maintain a high humidity during the day and to avoid too high humidity at night. Such a regime will maximize the quality of output and minimize the risk of plant diseases.

2.3 Greenhouse Heating

In colder climates, heat is lost through the covering materials, 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 radiation and electricity. (Masterlez, 1977).

2.4 Greenhouse Cooling

Several techniques based on convection/forced air movement with or without the evaporation of water are available for cooling of greenhouses. They are ventilation with roof and side ventilators, roof shading, water film on greenhouse glass and evaporative cooling (Rajinder, 1985).

During the majority of production cycle, greenhouse temperature is too high, both for good crop performance and for the health of greenhouse workers. Reducing temperatures is one of the main problems facing greenhouse management in mild climates. Cooling is more expensive and more difficult than heating and most greenhouses are not adequately structured for installing cooling systems. The four major factors which permit temperature reduction are ventilation or air renewal, crop evapotranspiration, reduction of solar radiation which affects plants(shading) and water evaporation inside the greenhouse through fog or mist system. These four factors are interlinked in the balance of energy equation. For air in a permanent greenhouse, the equation connecting the above four factors is

$$\text{Rint} + \text{Hci} = \text{Vent} + \text{LE} + \text{Evap}$$

Where

Rint	=	Solar energy transmitted to and absorbed in the greenhouse
Hci	=	Heat transferred by convection to the greenhouse air from the cover.
Vent	=	Energy transferred out of the greenhouse by ventilation
LE	=	Energy used in transpiration from the crop
Evap	=	Energy consumed to evaporate water from the evaporative cooling devices.

A change in any one of these factors affects all the other factors. For example, on reducing solar radiation by means of shading, transpiration usually decreases and the ventilation rate is changed by the charge in temperature (Montero and Anton, 1994).

Greenhouses can be cooled by any of the methods commonly used in commercial, industrial or residential buildings. However, large cooling loads imposed on greenhouses by the sun and the high costs of installing and operating air conditioning systems, reduce the practical options for cooling greenhouses to ventilation, evaporative cooling and shading. Ventilation may be used with or without evaporative cooling but evaporative cooling cannot be used without ventilation (Albright, 1997).

Feuerman *et al.* (1997) developed a computer simulation model to study the relationship between design parameters of a Liquid Radiation Filter Greenhouse (LRFG) and its thermal performance under different climatic conditions. For a LRFG, a Liquid Radiation Filter (LRF) circulating in double layered cladding is provided. The filter greatly reduces the heat input and transmits most of the photosynthetic radiation. Validation of the simulation was performed with data from a 330 m^2 LRF greenhouse, operating in the Negev (Israel) desert highlands. The predicted greenhouse temperatures were found to agree with measured values to within one to two degrees Celsius.

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).

2.4.1 Ventilation of greenhouses

Ventilation of greenhouses can be defined as the process of exchanging air inside the greenhouse with the outside air. It is required to remove surplus solar heat and transpired water vapour and to supply carbondioxide. Ventilation rate is defined as the volume of air exchange per unit of time per unit floor area. It is measured as cubic meters of air per second per square metre of greenhouse floor area because the heat load derived from solar radiation is directly proportional to the floor area. Ventilation rate is sometimes expressed as internal air volume change per unit of time.

According to Walker (1965) 60 air changes per hour are generally considered necessary to avoid heating above the outside air temperature. This number will not be reached until external wind speeds at 0° (normal to ridge) exceed 1 *m/s in a* greenhouse with a windward ridge vent opened to 40° and both side vents are opened. He developed an analytical procedure for the prediction of temperatures within both heated and ventilated greenhouses. Experimental tests were conducted to establish the applicability of the procedure for the prediction of greenhouse temperatures. The comparison of the predicted and observed temperature showed a reasonable consistency between the two values.

Okada and Takakūra (1973) showed that wind speed and temperature difference between the inside and outside of the greenhouse were the two main factors, which influenced the rate of air exchange.

Kozai and Sase (1978) developed a simulation model for glasshouses upto four spans. Their results showed that for outside wind velocities less than 2 m/s, the number of air changes was mainly dependent upon the inside to outside temperature difference. Above 2 m/s, the number of air changes was approximately proportional to wind speed and the number of spans. The method used could not be applied to varying wind speed and natural convection conditions.

Mihara and Hayashi (1978) presented the design standards for both the fog and fan cooling system and a de-humidifying ventilation system. The ventilation rates and supplementary evaporation rates for the fog and fan system and ventilation rates in greenhouses were determined by enthalpy calculation based on outdoor climatic conditions, inside net radiation and ventilation rates.

Kozai *et al.* (1980) computed pressure coefficients for various ventilators as functions of ventilator angle and wind direction for single and double span models in a wind tunnel. These coefficients are a measure of resistance of the opening to airflow, and are used to compute the number of air changes per hour, which is the common method of expressing ventilation rate. Pressure coefficients of side ventilators were dependent only on wind direction and not on opening angle. Coefficients also changed with manipulation of the various ventilators.

Bakker (1984) studied the climatic effects of sudden increase of ventilator aperture from 0 to 60% on greenhouse cucumber. Greenhouse temperature and specific humidity decreased after the ventilators were opened, while water vapour transport by ventilation was increased from 1 to 28 $g/m^2/min$ and transpiration increased from 3 to $12g/m^2/min$. The results showed that there is a close relation between water vapour transport and transpiration.

Nederhoff *et al.* (1984) described a method to determine the ventilation rate in commercial greenhouses. The method is based on the use of carbondioxide as tracer gas. A series of measurements were performed in glass houses without a crop by changing wind velocity and window operation. From the data a relationship was established for describing the ventilation rate as a function of wind velocity and window aperture.

According to Smith (1988), ventilator area (for calculating area as percentage of total floor area) should be about 16%.

Okushima *et al.* (1989) developed a support system for natural ventilation design of greenhouses, based on computational aerodynamics. This system can predict the distribution of airflow, temperature, humidity and gas concentration under various conditions of greenhouse structure including the configuration and arrangements of ventilator openings, plants and meteorological conditions.

Arbel *et al.* (1990) studied the effect of natural ventilation in desert climate. Greenhouse was provided with 15% ventilation area (percentage of the floor area). Comparison of temperature and humidity from the greenhouse showed that there are small differences in temperature, while relative humidity in the greenhouse was closer to the required value of humidity.

Feuilloley *et al.* (1990) determined the static ventilation efficiency of the three opening systems in tunnel greenhouses. The three different opening systems were (1) traditional opening - the films are kept apart by crates at each side of the tunnel, (2) opening length wise at the top and (3) opening length wise at the top associated with 2 side openings at the bottom of the tunnel. They estimated the ventilation efficiency by the difference between inside and outside temperatures, and the efficiency of air replacement per hour (R), Ventilation rate was measured by decay rate method. Tests were undertaken in the greenhouse under no crop condition and under simulated vegetated condition by providing plastic wind breaks. The vegetation decreases the air removal rate by about 50%. The height of the crop has a greater effect on the natural ventilation rate. Either with or without vegetation, the best ventilation system is one, which has top and bottom opening and bottom opening area greater than the top opening. The optimal total opening area for the system is 32% (15% for top and 17% for bottom). The percentage opening area is calculated based on the percentage of floor area.

Harbaoni *et al.* (1990) studied the effect of different percentage of ventilation in Tunisia. They tried 35%, 41% and 45% ventilation area. The three systems produced similar improvements, i.e. a decrease of the maximum air temperature by 4°C and 1°C respectively at 20 cm and 100 cm above the ground and a decrease of 1°C to 15°C of the soil temperature measured at 7 cm depth.

Verheye and Verlodt (1990) compared three different static ventilation systems of greenhouse with a classic lateral aeration by means of wooden pegs for spacing away the touching polythene sheets. The best system is one, which has 30% ventilation area (percentage of floor area).

Wells and Amons (1994) developed a method for designing low pressure perforated polyethylene ducts for air distribution in closed greenhouses. The method was based on a well-validated implicit mathematical model of duct performance, ie. jet discharge coefficient of a duct based on duct parameters. Ventilation ducts designed according to this procedure should provide adequate and uniform air circulation to ensure that all plants within a greenhouse receive similar conditions of air temperature, humidity and carbondioxide concentration.

Boulard and Baille (1995) derived a method to find out the ventilation rate from already existing models using wind and stack effects as driving forces. The model fitted to experimental data of air exchange. The results showed that in the experimental conditions characterized by roof vents, all ventilators facing the same direction, wind is the main driving force of ventilation and the air exchange rate seems mainly dependent on the wind turbulence.

Kittas *et al.* (1996) studied the influence of wind speed on ventilation rates in a plastic tunnel with continuous side ventilators. Air exchange rate was measured using nitrous oxide as tracer. The air exchange rate is dependent on the wind velocity and total ventilator area, and can be expressed as a function of a global wind coefficient having properties similar to the turbulent wind coefficient.

Papadakis *et al.* (1996) carried out natural ventilation measurements in a plastic greenhouse with continuous roof and side openings. The result showed that air exchange rate depends on wind velocity and total ventilator opening area but not on the wind direction. Wind induced ventilation become dominant when wind speed exceed 1.8m/s. Roof ventilators alone and roof and side ventilators configuration are always more efficient than side ventilators alone.

Boulard *et al.* (1997) examined the ventilation performance of six different greenhouses equipped with either roof or side vents or both. Altogether 16 different ventilation configurations were analyzed. The surface area of the vent opening and wind speed together explain the largest part of the variance of air exchange rate measurements. The presence of crop decreases the ventilation efficiency, and the air exchange rate has a linear dependence on wind velocity.

Boulard *et al.* (1998) characterized the airflow and temperature patterns induced by natural convection in a half scale mono-span greenhouse model simulating the absorption of solar radiation at the floor surface. Values for the ventilation rates were deduced by expressing the thermal balance of the greenhouse and were compared with those deduced by Bernoulli's theorem. More generally, the measured flow patterns were compared with those reported in the literature for ventilation and heat transfer in closed greenhouses. The similitude of the inside pattern observed in each case suggested that both the exchange between inside and outside the greenhouse and between the warm soil and the roof can be considered as the driving forces influencing the flow.

Kacira *et al.* (1998) developed a computational fluid dynamics program, Fluent V4 to predict natural ventilation rates and airflow patterns of a multi-span sawtooth greenhouse for various roof and side vent openings and outside wind speeds. Predicted rates were found to be well above and well below a standard volumetric air exchange rate of 1 volume per minute.

Mignel et al. (1998) conducted an experimental and theoretical study of air exchange through porous screens and window openings and the driving potential was studied based on an approach derived from fluid mechanics. The predictions of airflow versus wind pressure were made and the temperature differences agree reasonably well with experimental data, differences between them being less than 20% in general.

Baptista et al. (1999) measured leakage and ventilation rates in a four span glasshouse by using tracer gas technique. The influence of wind speed, wind direction and temperature difference between inside and outside the green house were analyzed for each ventilator position. Temperature difference affected by ventilation rates at low wind speeds. A dimensionless function was calculated to express the ventilation flux per unit ventilator area and unit wind speed as a function of the angle of the ventilator opening.

Oca *et al.* (1999) developed a laboratory scale model for the physical simulation of natural ventilation by thermal effects in greenhouses. The method is a useful tool for the visualization of the ventilation flow for the comparison of the ventilation efficiency of different greenhouse geometries and for the validation of numerical models of greenhouse ventilation.

Wang and Deltour (1999) investigated experimentally the lee side ventilation induced air movement in a 1728 m^2 multi span greenhouse. The airflow pattern in the horizontal plane of a greenhouse was analysed qualitatively under different external wind conditions. Results showed that horizontal air 'velocities at different locations were proportional to the external wind speed and the opening angle.

2.4.1.1 Natural ventilating system

In this system, the movement of inside air takes place due to pressure difference created by wind or temperature gradients. To take advantage of wind created pressure difference, vent openings on both sides and ridge of the greenhouses are recommended. Greenhouses with only side vents, depend upon wind pressure to force air exchange, are usually ineffective when wind direction is not favourable. The total vent area can be 15-25% of the floor area (Pandey, 1985).

In many areas and for many crops adequate cooling can be obtained with ventilation alone. In many cases, natural ventilation alone can be relied upon to provide sufficient cooling. Natural ventilation with side and ridge openings is most effective on smaller single span greenhouses. Ridge vents can be adequate for cooling multispan glasshouses in colder climates (Mears, 1991)

Natural ventilation may be solely due to thermal buoyancy or wind or due to combination of both. Although high humidity makes air more buoyant, its influence is minor compared to temperature (Albright, 1997).

2.4.1.2 Forced ventilation system

When high ventilation rates are required, then the natural ventilation system has limitations and the air exchange from greenhouse to outside is required to be done through forced ventilation system. Forced ventilation denotes two options. The most obvious is the use of ventilation fans for air exchange. The second and less common use is for internal air mixing to improve air temperature uniformity and to keep the carbon dioxide concentration within dense plant canopies up to the ambient level.

In warmer climates fan ventilation will be required and the very popular polyethylene greenhouses are generally ventilated with fan systems. With exhaust fans of sufficient capacity, air temperature can be lowered up to 3°C to 6°C and a larger reduction in temperature is affected by using some evaporative cooling system. The air flow pattern and temperature distribution with forced ventilation may not be uniform, unless the opening through which air enters the greenhouse is relatively large and is distributed across the entire length of the wall on which it is located (Pandy, 1985)

Adequate airflow is the first requirement for any cooling system designed for the majority of Indian conditions. It is a good practice to arrange the fan systems to operate in two to four stages so that air flow can be matched to the cooling requirement at any given time. With a properly designed ventilation system, temperatures within a fully cropped greenhouse will not exceed more than three to five degrees hotter than outside ambient (Mears, 1991)

Mechanical ventilation for air exchange includes more than two fans. Fan placement, staging, inlet placement and control are critical to create an optimal system. Variable speed fans can be used, but are less energy efficient than single speed fans and less effective in coping with the effects of strong winds. The distance between groups of fans can be as great as 50 m in a long greenhouse and the two stages are arranged so that approximately the same number of fans are active in each group to balance ventilation air exchange throughout the greenhouse (Albright, 1997)

2.4.2 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 wet bulb depression that occurs with a given set of climate 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 wet bulb temperature of the outside air. The results showed that in a greenhouse planted with freely transpiring plants, the air temperature could be reduced by 10 to 15 percent, inspite of a high level of solar radiation.

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

The two evaporative cooling systems presently in use are, fan and pad system and mist system. In large greenhouses, high pressure mist system is used. Fan and pad system is adaptable to both large and small greenhouses. In fan and pad system of greenhouse cooling, low velocity, high discharge fans draw air through fibrous pads mounted on the opposite side or end wall of the greenhouse (Pandey, 1985)

Evaporative cooling systems are most effective in areas where a consistently low·humidity exists. Generally the lowest humidity occurs during the hottest part of the day, when the greatest degree of cooling required and evaporative cooling is more effective. During night, relative humidity increases and temperature decreases. The efficiency of evaporative cooling is at its lowest during the night. Exhaust fans or overhead ventilators are sufficient to control green house temperatures after sunset (Rajinder, 1985).

Abdulla (1986) conducted experiments on the performance of a fan and pad cooled greenhouse in Saudi Arabia. Environmental conditions were monitored at 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 6 m floor dimension was installed with a fan and pad system of evaporative cooling. Measurements of temperature, humidity and solar radiation inside and outside the greenhouse and water consumption were made to study the resulting greenhouse thermal environment. The observed greenhouse temperatures were found to be within 2°C of those predicted by a simple thermal analysis.

Bailey (1990) developed a simulation model to predict the temperature and vapour pressure deficits obtained in a greenhouse with fan and pad cooling system. The temperature gradient inside the greenhouse between cooling pad and air exhaust 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, 7.5 m apart, otherwise warm areas may develop.

With a well-designed evaporative cooling system, air temperature approaching the ambient wet bulb temperature can be obtained. Even in relatively humid locations significant benefits can be obtained with evaporative cooling. Temperatures in the middle of the day and early afternoon are significantly hotter than at dawn and as the specific humidity of the air does not usually increase very much during the day, there is a substantial wet bulb depression during the hottest part of the day even in the humid tropics (Mears, 1991).

Govindan *et al.* (1993) constructed a low cost greenhouse at the instructional farm of KCAET, Tavanur. Fan and pad evaporative cooling system was 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 5 mm of standard water gauge.

Ajayambika (1995) developed and tested a low cost greenhouse at the instructional farm of KCAET, Tavanur. The size of the greenhouse was 12 x 3 m and the sturcture was gable shaped. A fan with maximum airflow rate of 10450 m^3/h and a pad size of 3000 x 1200 mm were 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 percent of the solar radiation incident on it. The average efficiency of the pad was 65 percent.

Bobby *et al.* (1997) studied the variation of greenhouse microclimate with or without using the cooling system in a greenhouse located at the instructional farm of KCAET, Tavanur. They reported that the maximum variations in the microclimate parameters were noted between 12 noon and 2 pm. They used fan and pad system and mist system. The study revealed that mist system is better compared to the fan and pad cooling system, because the energy required to get the same degree of cooling is less in the case of mist system compared to fan and pad cooling system.

2.4.2.1 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 brought in through the pads. The area of pads provided has a greater effect of cooling. The air exchange rate from a greenhouse is measured in cubic metres of air per hour. Normally a rate of 144 $m^3/h/m^2$ area is sufficient for a greenhouse located at an elevation of less than 300 m above mean sea level 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 increases with increase in elevation of the greenhouse site, as air density decreases with increasing elevation. Thus a larger volume of air has to be drawn through the greenhouse at higher elevations, than at a low elevation to effect equivalent cooling. The heat of air inside the greenhouse also increases with the intensity of incident solar radiation and so it affects the rate of air removal from greenhouse. Intensity of 53800 lux is accepted as a desirable level for crops in general. A 4°C increase in air temperature between the fan and the pad can be tolerated across the greenhouse. The pad and the fan should be placed on opposite walls. The distance between the pad and the fan is an important consideration in determining which walls to use. A distance of 30 to 60 m is best. When the distance is reduced below 30 m, the cross sectional velocity becomes lower and the air often develops a clammy feeling (Masterlez, 1977).

In fan and pad system, fans drain air through wet fiber pads mounted on the opposite side or end walls of the greenhouse. Temperature differences ranging from 3 to 12°C can be achieved by this system over uncooled greenhouse sections and depends on radiant flux density, relative humidity and amount of shading compound applied. Both horizontal and vertical pads are used. Various materials viz. gravel, pine bank straw, bulrap, aspen wood fibre, honeycomb paper, coir fibre etc. can be used for making the pad. Most greenhouses will require about 1m pad height for every 20 m of pad to fan distance. Pad design system should be provided with at least 6 lpm of water per linear metre of the pad system length. To avoid excessive greenhouse humidity, a humidstat set to operate at 80 to 85% relative humidity can be installed to over ride the thermostat and turn off the water supply of the pad (Rajinder, 1985).

2.4.2.2 Fog cooling system

The fog evaporative cooling system uses high pressure pumping apparatus to produce extremely fine mist, allowing essentially a fog that tends to remain in the air. Evaporative cooling occurs above the crop with minimal wetting to foliage. A heavy fog also reduces solar intensity. Such a system is expensive, requiring heavy pumps, pipings, special nozzles and very clean water and it has a high electrical consumption. A fine mist fills the greenhouse atmosphere by cooling the air as it evaporates. Although most of the mist evaporates before reaching the plant level, some of the water settles on the foliage where it reduces leaf temperatures. Temperature difference, of 5°C to 14°C can be obtained between high pressure mist and fan cooled greenhouses. It is more effective during the warmest part of the day (Rajinder, 1985).

One type of fogging system utilizes a special nozzle in which high pressure air and water are mixed to produce extremely fine fog. Other popular systems rely on high pressure water sprayed out through very fine holes to achieve small drop sizes. Good water quality and careful filtration are required to keep fog systems operating at full effectiveness and good system maintenance is essential (Mears, 1991).

The main advantages of fog system compared to fan and pad system are: uniformity of conditions throughout the greenhouses, the need for forced air ventilation is completely eliminated, cooling is more effective and it can be adapted to very simply structured greenhouse. The disadvantages of fog systems are: the high installation cost, the need to use excellent quality water and the rust problems in the greenhouse structure and equipment (Montero and Anton, 1994).

2.4.2.3 Low pressure mist system

Misting with water pressure less than 7 kg/m^2 can reduce air temperature 5°C cooler in a greenhouse compared to natural ventilation. The water droplets from a low pressure misting system are quite large and do not evaporate quickly.

Leaching of nutrients from the foliage and the soil is a serious drawback of using this technique.

2.4.3 Roof shading

The amount of solar radiant energy entering the greenhouse can be reduced by applying opaque materials directly to the cover or by placing wood or aluminium lather over the cover. Commercial shading compounds or mixtures prepared with paint pigments are preferred for this purpose. White compounds are preferred, for they reflect a maximum amount of sunlight, i.e. about 83%. Shading compounds are less effective than shade covers. Shading compounds reflects most of the radiant energy, but some of it is absorbed and transmitted to the inside by conduction, but for the case of lath shades, air circulates between laths and glass and hence it provides more cooling. Another method of shading is to install curtains of various cloth materials on the greenhouse. Cloth shades are effective and it can lower leaf temperature by 6°C (Rajinder, 1985).

Vladimirova *et al.* (1996) evaluated the effect of four shade levels (47%, 63%, 80% and 91%) on air temperature, using twenty four arch-shaped, open-ended shade structures oriented with their longitudinal axis north-south. Each model structure was 0.8 m wide, 1.85 m long and 0.8 m high. Data from twenty consecutive days in August, 1994 were analyzed. The highest air temperature was measured under 80% shade. Analysis of the data showed that average air temperatures differed by 1.4°C or less for all shade levels.

Shading material can also be attached to the green house and removed when no longer needed. One material that works well is saran cloth, which can be purchased, in large sheets and in various densities to give varying degrees of shade (Albright, 1997).

2.4.4 Evapotranspiration

Solar radiation entering the greenhouse is partitioned between sensible heat transferred to the air and latent heat through the evaporation of water. The greenhouse climate and the air exchange rates required to control the high temperature, depend on the proportions of solar energy which are dissipated as sensible and latent heats. During transpiration, lot of solar radiant energy is utilized. The plant evapotranspiration which increases with increase in solar radiation will increase air temperature inside the greenhouse, if it is not utilized. So a developed crop can use more than half of the solar energy it receives in transpiring water, which proves that transpiration is one of the most important sources of cooling (Montero and Anton, 1994).

Materials and Methods

MATERIALS AND METHODS

The materials used and methodology adopted for conducting the study are described in this chapter.

3.1 Experimental Details

3.1.1 Location and study period

The study was undertaken in the greenhouse at AMPRS, Odakkali. It is situated at 10° 5' 40" to 10° 6' North latitude and 76° 32' 52" to 76° 32' 55" East longitude and at an elevation of 60 m above mean sea level. The study was undertaken during the period, March to May, 2000.

3.1.2 Orientation

The greenhouse was oriented in the east-west direction. An east-west oriented greenhouse provides maximum solar radiation compared to others.

3.1.3 Shape

The greenhouse has a gable roof shaped structure with floor dimensions of 18.2 m x 5.4 m. The specification of the greenhouse are given in Appendix I. Fig. 2 shows the plan and elevation of the greenhouse. A view of the greenhouse is given in plate I.

3.1.4 Structure

The greenhouse is supported on cement plastered brick masonry wall of 45 cm height and 13 cm thick (one brick thickness) on four sides, with an opening of 1.0 m X 2.15 m for the door. The gutter provided at the pad end wall drains the water falling from cooling pad into the storage tank provided near the back side of the green house. The masonry wall supports the door, cooling pad, fans and the structure of the green house. The structure is made of GI pipes of 5 cm diameter spaced at 3 m apart. Roof truss is made of GI pipes of 5 cm diameter spaced at 3 m apart and are interconnected by using angle iron pieces of 30 X 30 X 3 mm. Angle

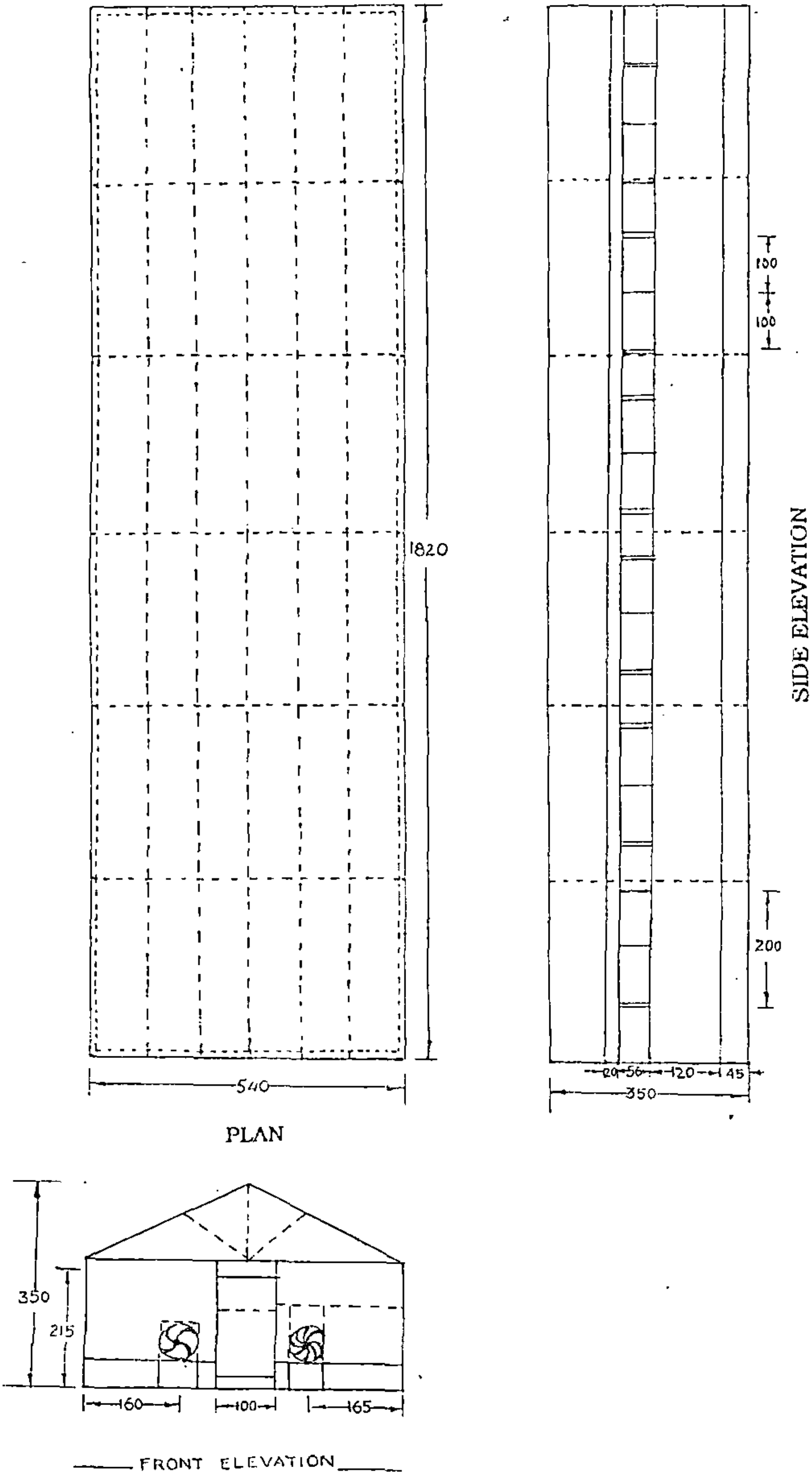

Fig. 2 Plan and elevation of the greenhouse.

Plate I A view of the experimental greenhouse.

Plate II A view of ventilator in open position.

iron (50 X 50 X 5 mm) structures are provided to hold the exhaust fan as well as the cooling pad. The glazing material used is ultraviolet stabilized polythene sheets.

3.1.5 Cooling system

The cooling system consists of the following.

3.1.5.1 Ventilators

The greenhouse was provided with 12 side ventilators of 2 m X 0.56 m size on the two longitudinal sides at a height of 1.65 m from the ground. A view of the ventilator in opened position is given in plate II.

3.1.5.2 Cooling pad

The cooling pad provided at the rear end of the greenhouse is made of coir mat having 150 mm thickness compressed between two wire meshes of 1 inch size. The pad is wetted using water pumped from the storage tank. Water is dripped on the pad through tap type drippers placed over the cooling pad. The water draining from the cooling pad flows into the tank through the gutter. Specification of the cooling pad is given in Appendix II. The total discharge on the cooling pad was calculated by measuring the discharge from one drip emitter and multiplying with the total number of drip emitters. The calculation is shown in Appendix III. Plate III and IV show the pad end view of the greenhouse and the cooling pad with drippers respectively.

3.1.5.3 Mist system

The greenhouse was provided with three lines of mist units at a spacing of 1.5 m. The spacing between the lines was also maintained as 1.5 m. A view of the mist system in operating condition is shown in plate V. There were 12 number of mist units in each line, counting to a total of 36 mist units in the greenhouse. The water supply for operating the mist system was delivered by the pump. The total discharge from the mist system was calculated by measuring the discharge from one mist outlet and multiplying with the number of mist units. The calculation is shown in Appendix IV.

Plate III Pad end view of the greenhouse.

Plate IV Cooling pad with drippers.

Plate V Mist system under operation.

Plate VI Cropped environment in the greenhouse.

3.1.5.4 Water supply system

A storage tank of 1500 litre capacity was provided at the rear side of the greenhouse. Water from the storage tank was pumped using a 0.5 hp pump and the water was filtered by passing through a screenfilter. The outlet from the filter was divided into two sections, one for wetting the cooling pad, and the other for the mist system. Gate valves were provided to control the flow through each mist line. Mist system and cooling pad can be operated separately with the help of valves provided at both sections. Specification of the pump is given in Appendix V.

3.1.5.5 Fans

Two fans were provided on either side of the door at a distance of 1.3 m from the sides and at a height of 45 cm from the ground surface. The capacities of the fans were not the same. The specifications of the fans are given in Appendix VI.

3.2 Cropped Environment

Cropped environment was maintained inside the greenhouse by placing mango plants grown in polythene bags. Plate VI shows a view of the crops inside the green house.

3.3 Measurement of Climatic Parameters

The different parameters measured for the study are temperature, relative humidity and solar intensity. The instruments used and the methods adopted for the measurements are explained below.

3.3.1 Temperature

Temperatures both inside and outside the greenhouse were measured using ordinary mercury thermometers. The temperature measurements in degree Celsius were taken at every one hour interval.

Wet and dry bulb thermometers were provided, both inside and outside the greenhouse to measure the wet bulb and dry bulb temperatures. Maximum-minimum thermometers were provided, both inside and outside the greenhouse to find the daily maximum and minimum temperatures. The thermometers were installed at the centre of the greenhouse at a height of 90 cm from the ground level.

For measuring the temperature distribution inside the greenhouse, thermometers were installed at different positions. To find the longitudinal temperature distribution, thermometers were installed at 3 m interval through the centre line of the greenhouse in the longitudinal direction. To find the temperature distribution across the greenhouse, thermometers were installed at 1.5 m interval through the centre line across the greenhouse. To measure the vertical temperature distribution, thermometers were installed at 90 cm vertical interval through the centre line of the greenhouse.

3.3.2 Relative humidity

Relative humidity in percentage was measured by using 80 mm dial hygrometer. Relative humidity both inside and outside the greenhouse was also estimated using the wet and dry bulb temperatures measured. One hygrometer was installed inside the greenhouse at the centre and another at outside. Relative humidity was measured at every one hour interval.

3.3.3 Light intensity

Light intensity was measured using a digital luxmeter. The intensity of light was measured at every one hour interval keeping the instrument inside the greenhouse at the centre and at outside the greenhouse.

3.4 Calculation of Percentage Ventilation Area

Ventilation area calculated as the percentage of total floor area of the greenhouse was used for the study. The details of the calculation of percentage ventilation area are given in appendix VII.

3.5 Experimental Condition Inside the Greenhouse

The variations of climatic parameters inside the greenhouse at static condition and during the operations of different cooling methods were measured.

3.5.1 Static condition

Static condition is the condition with no ventilation and without the use of any of the cooling methods. The variation of temperature, relative humidity and solar intensity both inside and outside the greenhouse were noted round the clock at every one hour interval.

3.5.2 Cooling methods

The variations of different climatic parameters, while operating different cooling methods were noted with mango plants kept inside the greenhouse.

3.5.2.1 Greenhouse cooling by providing different percentages of natural ventilation

The variation of temperature, relative humidity and intensity of solar radiation were noted at every one hour interval, both inside and outside the greenhouse under different percentages of ventilation for 24 hours continuously (7.30 am to 7.30 am). Greenhouse was provided with 12 ventilators. For the experiment 6 ventilation conditions were used. They were 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8 percentages of ventilation.

2.3% of ventilation was provided by opening two ventilators at the pad end (one on each side and opposite to each other). 4.6% of ventilation was provided by opening two more ventilators, one on either side from the fan end. Ventilations of 6.9%, 9.2%, 11.5% and 13.8% were provided in the same manner by opening 6, 8, 10 and 12 ventilators respectively.

Temperature at different layers inside the greenhouse was measured using thermometers installed in the greenhouse. Measurements were taken at every one hour interval.

3.5.2.2 Evaporative cooling using fan and pad system

The effect of fan and pad system was studied by operating the system for every alternate 30 minutes interval. Thus half an hour working time and half an hour rest time was provided during every hour. The experiment was started at 10.00 am and continued upto 5.00 pm. The temperature, relative humidity and solar intensity readings were taken at every 30 minutes interval from 10.00 am to 5.00 pm. Thus the changes in temperature and relative humidity due to the operation of the system and the changes of these parameters, 30 minutes after switching off the system were obtained. The fan and pad system was operated without ventilation.

3.5.2.3 Evaporative cooling using mist system

The greenhouse temperature can be brought to a lower level by using mist system. Mist system was operated for 10 minutes during every half an hour and 20 minutes off time was provided. This process was repeated. The experiment was started at 10.00 am and continued up to 5.00 pm. Inside and outside solar intensity and outside temperature and relative humidity were measured at every 30 minutes interval. Inside temperature and relative humidity were measured just before starting the mist system and just after switching off the mist system. The readings were taken with the assumption that within 10 minutes, much changes will not occur in the climate outside the greenhouse. All the mist units were operated during the working period of mist system and both fans were also operated along with the mist system. To find the effect of ventilation during misting, mist system was operated with different percentages of ventilation.

3.5.2.4 Shading

To get more cooling inside the green house, one shade net of 75 % shade was provided over the top of the greenhouse. The climatic parameters inside the shaded greenhouse under different experimental conditions were studied. All the ventilators of the shaded greenhouse were closed, and the fan and pad and mist systems were not operated. Variation of temperature, relative humidity and intensity of solar radiation both inside and outside the greenhouse were noted at every one hour interval from 7.30 am to 6.30 pm.

3.5.2.4.1 Evaporative cooling by fan and pad system inside a shaded greenhouse

All the ventilators of the greenhouse were closed and the experiment was started at 10.00 am. Fan and pad system was operated for 30 minutes and then was kept off for the next 30 minutes. This procedure was repeated. The experiment was continued upto 5.00 pm. The parameters inside and outside the greenhouse were measured at every 30 minutes interval, just before starting the fan and pad system and just after switching off the fan and pad system.

3.5.2.4.2 Evaporative cooling using mist system inside a shaded greenhouse

Mist units were operated inside the shaded greenhouse for 5 minutes and were kept off for the next 25 minutes. Thus 5 minutes working time and 25 minutes rest time was provided during every 30 minutes. This procedure was repeated. Operation of the mist system was started at 10.00 am and continued upto 5.00 pm. The combination of 5 minutes on time and 25 minutes off time was chosen by trial error. Several combinations were tested and the optimum was chosen. All the three climatic parameters both inside and outside the greenhouse were measured at every 30 minutes interval. In addition, inside temperature and humidity were noted just after stopping the mist system to find the effect of mist system. This was done by the assumption that within 5 minutes much variation will not occur in the outside climate. Fans were also operated along with the mist system.

To find the effect of ventilation on greenhouse cooling under shaded condition, tests were conducted with 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8% of ventilation.

3.5.2.4.3 Cooling inside the greenhouse provided with two shade net layers

The greenhouse was covered with 2 shade nets of 75% shade, one outside and the other inside. Evaporative cooling using mist system was provided inside the greenhouse with 13.8% of ventilation. Operation of the mist system was as in the case of that with one shade cover. i.e. 5 minutes on time and 25 minutes off time during every 30 minutes. All the three climatic parameters both inside and outside the greenhouse were noted at every 30 minutes interval. In addition, the inside temperature and relative humidity were measured just after stopping the mist system. Fans were also operated along with the mist system.

3.6 Soil Temperature

Soil temperature inside the greenhouse under shaded condition was measured at different depths of 5cm, 10cm and 20cm from the ground surface. Soil thermometers were used for the measurement. Measurements were done at every one hour interval.

3.7 Data Analysis

The collected data were analyzed using statistical methods and graphs. Statistical analyses was done using one sample t-test and paired sample t-test (Edward, 1990) for the data collected.

3.7.1 Effect of different percentages of natural ventilation on greenhouse cooling

Variation of climatic parameters inside and outside the greenhouse were described by plotting time along the X-axis, solar intensity along the Y-axis and temperature and relative humidity along the secondary Y-axis.

Inside to outside temperature difference was obtained by subtracting outside temperature from the inside temperature. Inside to outside temperature difference were calculated for the data from 7.30 am and 6.30 pm at hourly intervals for different percentages of natural ventilation.

Graphs were plotted for the period from 9.30 am to 5.30 pm with percentage ventilation along the X-axis, intensity of solar radiation along the Y-axis and the temperature and relative humidity along the secondary Y-axis.

3.7.2 Optimum percentage of natural ventilation

Optimum percentage of natural ventilation was determined from the graphs plotted for different climatic parameters against percentage ventilation. The percentage ventilation, which gives the maximum cooling, was taken as the optimum percentage of natural ventilation.

Another method tried was, by using statistical analysis. 95% confidence interval for the mean of the inside to outside temperature difference values were found out. The percentage ventilation, which gives minimum mean value, was taken as the optimum percentage of natural ventilation.

Paired sample t-test was conducted to check whether there is any significant difference between the values.

3.7.3 Effect of fan and pad system on greenhouse cooling

Graphs were plotted with time along the x-axis, intensity of solar radiation along the Y-axis and temperature and relative humidity along the secondary Y-axis to describe the effect of fan and pad system on greenhouse cooling.

Inside to outside temperature difference was calculated by subtracting outside temperature from inside temperature. Temperature differences at 30 minutes interval for different percentages of ventilation were obtained by interpolating the values calculated for one hour interval. Statistical analyses for the data was done using one sample t-test and paired sample t-test.

3.7.4 Effect of mist system on greenhouse cooling

Degree of cooling was calculated by subtracting the inside temperature at the end of operation of mist system, from the outside temperature at the start of mist system and fans for different percentages of ventilation tested. This calculation was done by making the assumption that, within the small operating period of mist system, much temperature difference will not occur at the outside. Statistical analyses for the degree of cooling at each percentage of ventilation was done. One sample t-test was used to check the mean value. Basic statistical parameters were also found out. Paired sample t-test was done to find whether there is any significant difference between different percentages of ventilation. The percentage ventilation which gave maximum cooling was taken as the optimum percentage of ventilation. Mean value for degree of cooling was higher at maximum cooling.

The same procedure was repeated for the data obtained with mist system under shaded condition.

3.7.5 Effect of shade net on greenhouse cooling

To analyze the variation of parameters under shaded condition, graphs were plotted with time along the X-axis and inside and outside climatic parameters along the Y-axis.

Effect of shade was described by using data from conditions viz.,

1. no ventilation, with and without shade
2. fan and pad system without ventilation, with and without shade
3. mist system with and without shade .

Separate graphs were plotted for temperature, relative humidity and light intensity both inside and outside the greenhouse at no ventilation condition with and without shade cover. Graphs were plotted with time from 7.30 am to 6.30 pm along the X-axis and the different climatic parameters on Y-axis. Statistical analyses of the inside to outside temperature difference was also done.

95% confidence intervals for different percentages of ventilation under shaded and unshaded conditions were determined. The better cooling is for the case with the least values for the upper and lower limits of the confidence interval.

3.7.6 Effect of two shade net layers on greenhouse cooling

Degree of cooling while operating mist system under two shade covers was found out. 95% confidence interval for its mean value was determined. This interval was compared with that obtained for the mist system operated without shade cover and with single shade cover. Paired sample t-test was done to check for any significant difference between these three sets of readings. One sample t-test was done to determine the accepted mean value for 5% level of significance.

Results and Discussion

RESULTS AND DISCUSSION

The greenhouse technology is becoming popular in our country as a solution to number of specific situations related to increased production and productivity of crops. Some of these situations are cultivation in inclement agro climatic conditions, off season cultivation of horticultural crops, nursery raising and plant propagation, export oriented cultivation of horticultural crops and intensive cultivation of medicinal, aromatic and non-conventional plants. The knowledge of the greenhouse microclimate and the variation of different climatic parameters inside the greenhouse under various conditions are essential for the most beneficial cultivation of crops inside the greenhouse. The extent of variation possible and the methods of varying these parameters can contribute to the choice of crop varieties.

The environmental control in greenhouse depends on climatic region and the crops to be cultivated. Natural ventilation is the cheapest method of greenhouse cooling in warm periods. The results of the study conducted to analyze the extent of greenhouse cooling under different percentages of natural ventilation, the effects of fan and pad system, shading and mist system on green house climate are described in this chapter.

4.1 Static Condition (No Ventilation Condition)

The variations of temperature, relative humidity and light intensity inside as well as outside the greenhouse without ventilation are shown in Fig. 3. The values of these three parameters are also given in Appendix VIII. The results show that temperature increases with increase in light intensity. Inside temperature reaches its maximum value at 2.30 pm and then decreases. Relative humidity decreases as the light intensity increases. The lowest value of relative humidity was obtained at 1.30 pm. At 12.30 pm there was a decrease in temperature and an increase in humidity, which was a variation from the normal trend of the curve. This may be due to the sharp decrease of the light intensity due to clouds. This shows that the intensity of light has a great influence on the temperature and relative humidity inside the greenhouse. The maximum temperature noted inside the greenhouse was 55°C at 2.30 pm and minimum temperature was

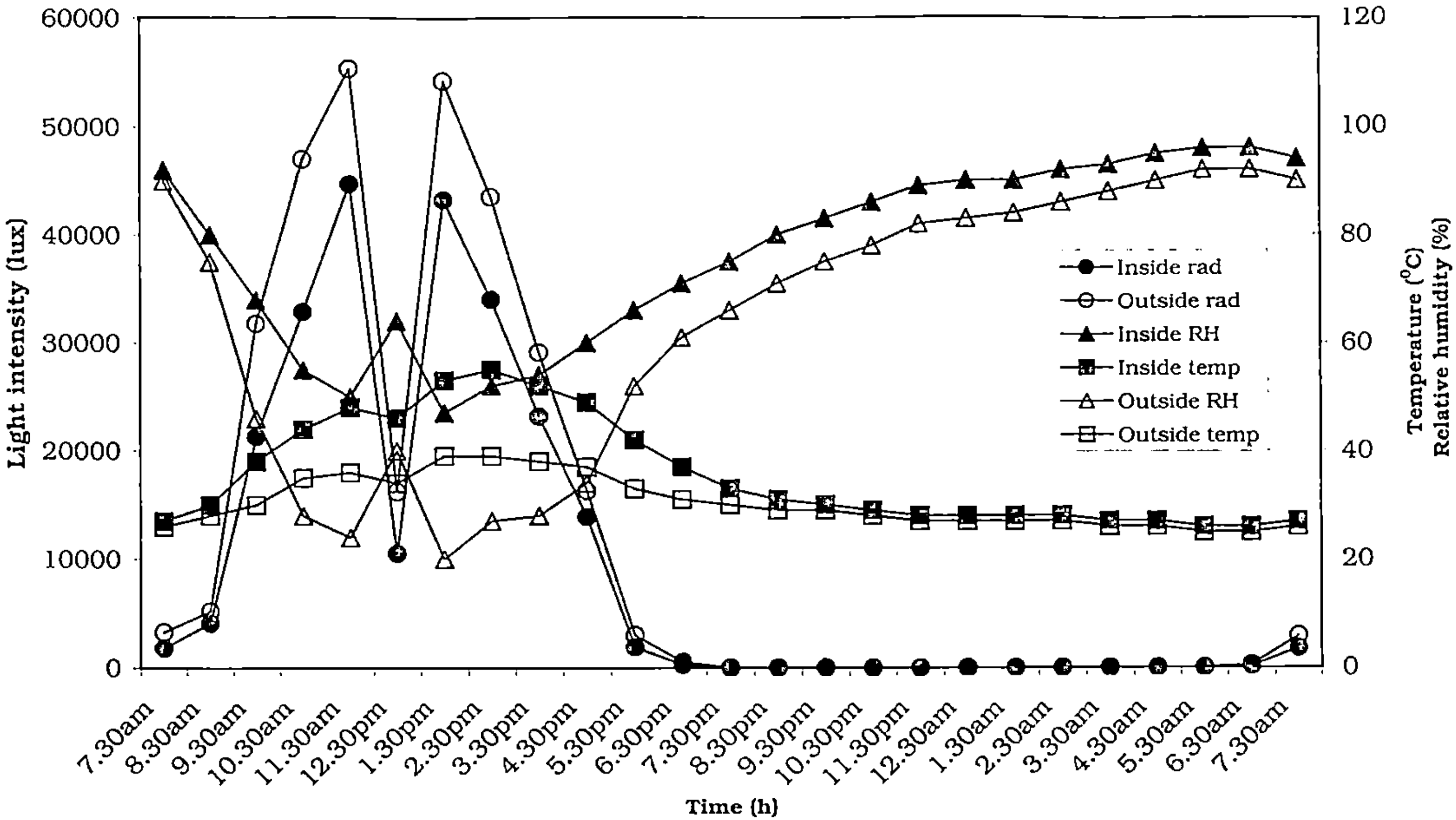

Fig. 3 Variation of parameters inside and outside the greenhouse without ventilation (unshaded condition, without fan and pad and mist systems).

26°C at 5:30 am and 6.30 am. The relative humidity reduced to a lowest value of 42% at 1.30 pm and reached a maximum value of 96% at 5.30 am and 6.30 am. The figure shows that temperature varies directly with the light intensity and relative humidity varies inversely with the intensity of light. The variation of intensity of light inside the greenhouse was in the same manner as the outside light intensity, but there is a reduction of intensity value due to the interference of the cladding material. The difference between inside to outside temperature was very high in this case. Mean of the temperature difference was 9.58 and the 95% confidence interval for the mean values was 6.6 to 12.5.

4.2 Effect of Different Percentages of Natural Ventilation on Greenhouse Microclimate

4.2.1 Temperature variation inside the greenhouse at different percentages of ventilation

The variation of temperature inside the greenhouse at different percentages of natural ventilation without fan and pad and mist systems are shown in Fig.4 and the values are given in table 1. At 2.3% ventilation, maximum temperature inside the greenhouse was 47°C and minimum temperature was 26°C. The maximum outside temperature was 39°C and minimum outside temperature was 25°C. Compared to the highest value of temperature inside the greenhouse without ventilation, there is a decrease of 8°C for 2.3% ventilation condition. The inside to outside temperature difference is less in this case compared to the no ventilation condition. The mean of the temperature difference from 7.30 am to 6.30 pm was 4.583 and 95% confidence interval for the mean was 3.1 to 6.1.

At 4.6% ventilation, maximum temperatures inside and outside the greenhouse were 46°C and 39°C respectively and the minimum temperatures were 26°C and 25°C respectively. The maximum inside temperature at this condition was 9°C less compared to no ventilation condition and 1°C less compared to 2.3% ventilation condition. The inside to outside temperature difference at daytime is less in this case compared to previous cases. The mean of the inside to outside temperature difference

Table 1. Variation of temperature (^0C) inside and outside the greenhouse at different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Time	Percentage ventilation													
	0		2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
7.30am	27	26	27	26	27	26	27	26	27	26	27	26	26	25
8.30am	30	28	30	28	30	28	30	28	29	28	29	28	29	28
9.30am	38	30	36	32	36	32	35	32	34	31	32	30	33	32
10.30am	44	35	39	35	38	34	39	36	37	34	36	33	36	34
11.30am	48	36	42	36	40	36	40	37	39	36	38	35	38	36
12.30pm	46	34	45	38	44	38	43	38	43	39	41	37	41	38
1.30pm	53	39	46	39	46	39	44	39	44	39	42	38	42	39
2.30pm	55	39	47	39	46	39	45	39	43	38	43	38	43	40
3.30pm	52	38	46	39	44	38	43	37	42	37	42	37	42	39
4.30pm	49	37	41	36	41	36	40	36	40	37	40	37	39	37
5.30pm	42	33	35	33	35	33	34	32	34	32	34	33	33	32
6.30pm	37	31	32	30	32	30	32	31	32	31	32	31	31	30
7.30pm	33	30	31	29	31	29	31	30	31	30	30	29	30	29
8.30pm	31	29	30	29	30	29	31	30	30	29	29	28	30	29
9.30pm	30	29	30	28	30	28	30	29	29	28	28	27	29	27
10.30pm	29	28	30	28	29	28	30	29	29	28	27	25	28	27
11.30pm	28	27	29	27	29	28	29	28	28	27	27	25	27	26
12.30am	28	27	29	27	28	27	29	28	28	27	27	25	27	26
1.30am	28	27	28	27	28	27	28	27	27	26	26	25	27	26
2.30am	28	27	28	26	27	26	28	27	27	26	26	25	26	25
3.30am	27	26	27	26	27	26	27	26	27	26	26	24	26	25
4.30am	27	26	27	26	26	25	27	26	26	25	25	24	26	25
5.30am	26	25	26	25	26	25	26	25	26	25	25	24	25	24
6.30am	26	25	26	25	26	25	26	25	26	25	25	24	25	24
7.30am	27	26	27	26	27	26	27	26	27	26	26	25	26	25

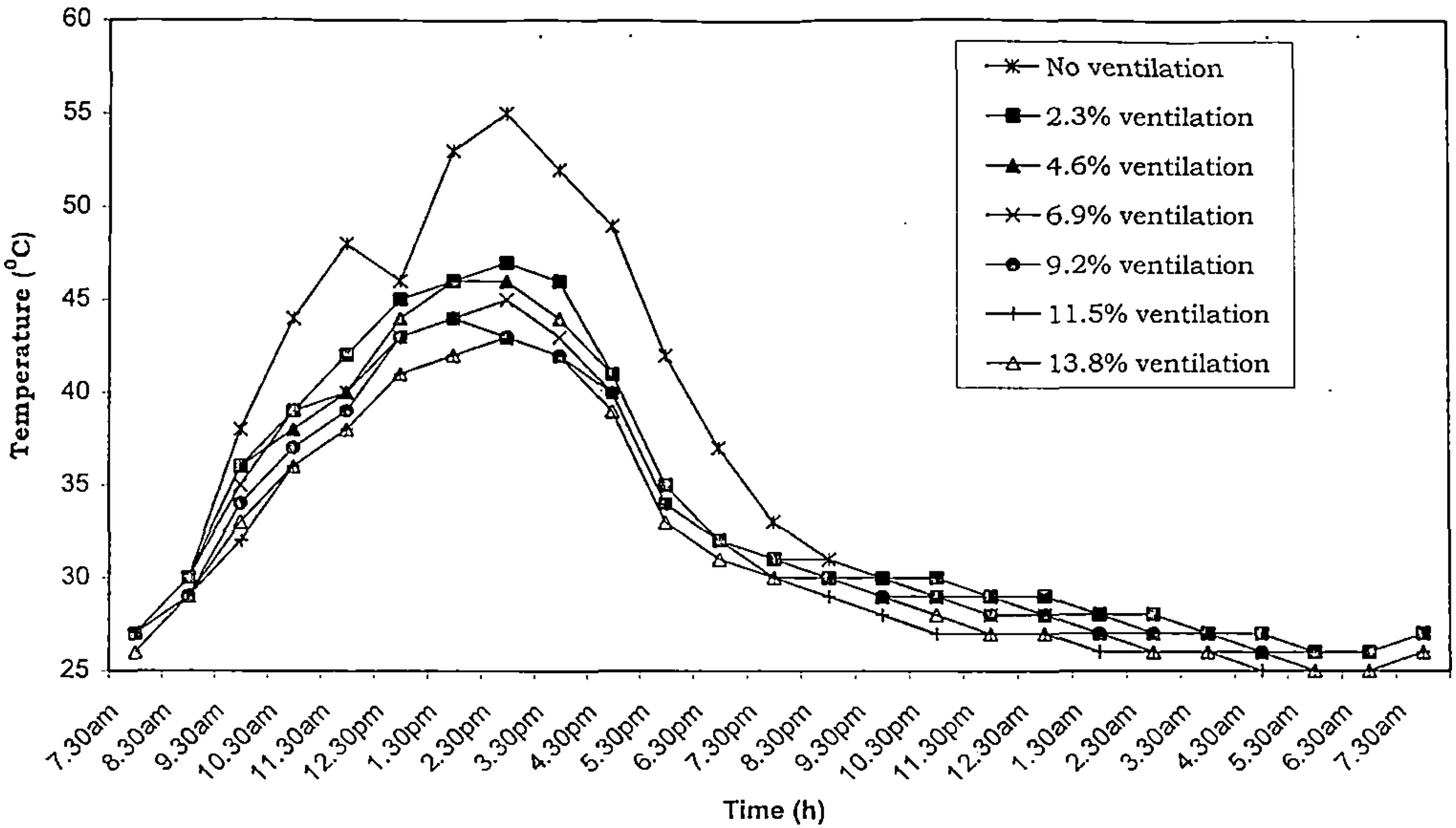

Fig. 4 Variation of temeprature inside the greenhouse at different percentages of ventilation without fan and pad and mist systems (unshaded condition).

from 7.30 am to 5.30 pm was 4.167 and 95% confidence interval for the mean was 2.9 to 5.4.

At 6.9% ventilation, maximum temperature inside the greenhouse was 45°C and minimum temperature was 26°C. The maximum and minimum outside temperatures were 39°C and 25°C respectively. The highest temperature inside the greenhouse at this condition was 10°C less compared to no ventilation condition, 2°C less compared to 2.3% ventilation condition and 1°C less compared to 4.6% ventilation condition. The inside to outside temperature difference is less in this case compared to previous cases. The mean of the inside to outside temperature difference from 7.30 am to 6.30 pm was 3.4 and 95% confidence interval for the mean was 2.3 to 4.5.

At 9.2% ventilation, maximum temperatures inside and outside the greenhouse were 44°C and 39°C respectively and the minimum temperatures were 26°C and 25°C respectively. The maximum inside temperature at this condition was 11°C less compared to no ventilation condition, 3°C less compared to 2.3% ventilation condition, 2°C less compared to 4.6% ventilation, and 1°C less compared to 6.9% ventilation condition. The inside to outside temperature difference is less in this case compared to previous cases. The mean of the inside to outside temperature difference from 7.30 am to 6.30 pm was 3.0 and 95% confidence interval for the mean was 2.1 to 3.9.

At 11.5% ventilation, the maximum temperatures inside and outside the greenhouse were 43°C and 38°C respectively and the minimum temperatures were 27°C and 25°C respectively. The maximum outside temperature is 1°C less compared to previous cases. This was due to the effect of less radiation intensity. The maximum temperature inside the greenhouse was 12, 4, 3, 2, and 1°C less compared to 0, 2.3 ,4.6, 6.9 and 9.2 percentages of ventilation respectively. The inside to outside temperature difference is less in this case compared to previous cases. The mean of the inside to outside temperature difference from 7.30 am to 6.30 pm was 2.75 and 95% confidence interval for the mean was 1.8 to 3.7.

At 13.8% ventilation, maximum temperatures inside and outside the greenhouse were 43°C and 40°C respectively and the minimum temperatures were 25°C and 24°C respectively. The maximum temperature inside the greenhouse was 12, 4, 3, 2 and 1°C less compared to 0, 2.3, 4.6, 6.9 and 9.2 percentages of ventilation respectively. Even though the maximum temperatures at 11.5% and 13.8% ventilation were same, better cooling was obtained at 13.8% ventilation because the maximum outside temperature at this condition was 2°C higher as compared to 11.5% ventilation. The inside to outside temperature difference is less compared to previous cases. The mean of the inside to outside temperature difference from 7.30 am to 6.30 pm was 1.92 and 95% confidence interval for the mean was 1.4 to 2.4.

4.2.1.1 Temperature variation at different layers within the greenhouse under different percentages of ventilation

The temperature variations at different layers within the greenhouse under different percentages of ventilation are given in tables 2 to 7. From the tables it can be seen that there is no much variation in temperature at different layers within the greenhouse under different percentages of ventilation. In all the cases, the temperature at the middle layer is almost equal to the average value of the temperatures at different layers inside the greenhouse. From the data it can be seen that irrespective of the percentage of natural ventilation, the temperature inside the greenhouse is almost uniformly distributed inside the greenhouse. Hence for the remaining part of the study, inside temperature reading was taken only at the middle layer of the greenhouse.

4.2.2 *Variation of relative humidity inside the greenhouse at different percentages of ventilation*

The variations of relative humidity inside the greenhouse at different percentages of natural ventilation without fan and pad and mist systems are shown in Fig. 5 and the values are given in table 8. At 2.3% ventilation, the lowest values of relative humidity inside and outside the greenhouse were 41% and 20% respectively and the highest values were 94% and 92% respectively. The maximum relative humidity inside and outside the greenhouse at 4.6% ventilation were 94% and 92%

Table 2. Temperature variation (^{0}C) at different layers inside the greenhouse with 2.3% ventilation (unshaded condition, without fan and pad and mist systems).

	Lengthwise distance from from the pad end					Widthwise distance from left to right			Vertical distance from bottom to top		
Time	*3m*	*6m*	*9m*	*12m*	*15m*	*1.2m*	*2.7m*	*4.2m*	90cm	180cm	270cm
9.30am	35	36	36	36	37	35	36	37	36	36	37
10.30am	38	39	39	39	40	38	39	40	39	40	42
11.30am	41	42	42	42	43	43	42	43	42	43	45
12.30pm	45	45	45	45	45	45	45	45	45	45	47
1.30pm	*46*	*46*	*46*	*46*	*46*	46	46	46	46	46	47
2.30pm	47	47	47	47	47	47	47	47	47	48	44
3.30pm	45	46	46	46	47	46	46	46	46	46	48
4.30pm	40	41	41	41	42	42	41	40	41	41	42
5.30pm	34	35	35	35	36	35	35	35	35	35	36

Table 3. Temperature variation (^{0}C) at different layers inside the greenhouse with 4.6% ventilation (unshaded condition, without fan and pad and mist systems).

	Lengthwise distance from from the pad end					Widthwise distance from left to right			Vertical distance from bottom to top		
Time	3m	6m	9m	12m	15m	1.2m	2.7m	4.2m	90cm	180cm	270cm
9.30am	35	36	36	36	37	35	36	37	36	37	38
10.30am	37	37	38	39	39	38	38	38	38	39	40
11.30am	39	39	40	41	41	40	40	40	40	41	42
12.30pm	43	43	44	45	45	44	44	44	44	44	45
1.30pm	45	45	46	47	47	46	46	46	46	46	47
2.30pm	45	45	46	47	47	46	46	46	46	46	47
3.30pm	43	43	44	45	45	44	44	44	44	45	45
4.30pm	40	40	41	42	42	41	41	40	41	41	42
5.30pm	35	35	35	35	36	35	35	35	35	35	35

Table 4. Temperature variation (^{0}C) at different layers inside the greenhouse with 6.9% ventilation (unshaded condition, without fan and pad and mist systems).

	Lengthwise distance from from the pad end					Widthwise distance from left to right			Vertical distance from bottom to top		
Time	3m	6m	9m	12m	15m	1.2m	2.7m	4.2m	90cm	180cm	270cm
9.30am	35	35	35	36	36	34	35	35	35	36	37
10.30am	37	37	38	39	39	38	38	39	38	39	40
11.30am	38	38	39	40	40	39	39	39	39	40	40
12.30pm	42	42	43	44	45	43	43	43	43	43	44
1.30pm	42	43	44	45	46	44	44	44	44	44	45
2.30pm	44	45	45	46	46	45	45	45	45	45	46
3.30pm	42	42	43	44	44	42	43	42	43	44	44
4.30pm	40	40	40	41	41	40	40	39	40	40	41
5.30pm	34	34	34	34	35	34	34	34	34	34	34

Table 5. Temperature variation (^0C) at different layers inside the greenhouse with 9.2% ventilation (unshaded condition, without fan and pad and mist systems).

Time	Lengthwise distance from from the pad end					Widthwise distance from left to right			Vertical distance from bottom to top		
	3m	6m	9m	12m	15m	1.2m	2.7m	4.2m	90cm	180cm	270cm
9.30am	34	35	35	36	36	34	35	35	35	35	35
10.30am	38	38	38	39	39	37	38	39	38	39	39
11.30am	38	39	39	39	40	39	39	39	39	39	40
12.30pm	42	42	43	44	44	42	43	43	43	43	44
1.30pm	43	44	44	44	45	44	44	43	44	44	45
2.30pm	43	43	43	43	44	43	43	43	43	43	44
3.30pm	42	42	42	42	43	42	42	42	42	42	43
4.30pm	40	40	40	40	40	40	40	40	40	40	40
5.30pm	34	34	34	34	34	34	34	34	34	34	34

Table 6. Temperature variation (^0C) at different layers inside the greenhouse with 11.5% ventilation (unshaded condition, without fan and pad and mist systems).

Time	Lengthwise distance from from the pad end					Widthwise distance from left to right			Vertical distance from bottom to top		
	3m	6m	9m	12m	15m	1.2m	2.7m	4.2m	90cm	180cm	270cm
9.30am	33	33	33	34	34	33	33	34	33	33	34
10.30am	37	37	37	38	38	36	37	36	37	37	37
11.30am	38	38	38	38	39	38	38	37	38	38	39
12.30pm	41	41	41	41	42	41	41	41	41	41	42
1.30pm	42	42	42	42	43	42	42	42	42	42	43
2.30pm	43	43	43	43	44	43	43	43	43	43	44
3.30pm	42	42	42	42	43	43	42	42	42	42	42
4.30pm	40	40	40	40	41	40	40	40	40	40	40
5.30pm	34	34	34	34	34	34	34	33	34	34	34

Table 7. Temperature variation (^0C) at different layers inside the greenhouse with 13.8% ventilation (unshaded condition, without fan and pad and mist systems).

Time	Lengthwise distance from from the pad end					Widthwise distance from left to right			Vertical distance from bottom to top		
	3m	6m	9m	12m	15m	1.2m	2.7m	4.2m	90cm	180cm	270cm
9.30am	33	33	33	33	34	33	33	33	33	34	34
10.30am	38	38	38	38	39	37	38	39	38	38	39
11.30am	38	38	38	38	38	37	38	39	38	39	40
12.30pm	42	42	42	42	42	42	42	42	42	42	43
1.30pm	42	42	42	42	42	42	42	42	42	42	43
2.30pm	43	43	43	43	43	43	43	43	43	43	44
3.30pm	42	42	42	42	42	42	42	42	42	43	44
4.30pm	39	39	39	39	39	39	39	39	39	39	40
5.30pm	33	33	33	33	33	33	33	33	33	33	33

Table 8. Variation of relative humidity (%) inside and outside the greenhouse at different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Time	Percentage ventilation													
	0		2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
7.30am	92	90	94	90	92	90	90	88	92	90	91	89	90	88
8.30am	80	75	75	71	84	81	69	67	71	69	79	77	72	70
9.30am	68	46	54	41	52	42	50	44	49	46	50	48	48	46
10.30am	55	28	52	28	48	27	46	29	44	29	44	31	41	30
11.30am	50	24	46	24	45	23	43	21	41	24	40	25	37	25
12.30pm	64	40	45	24	42	22	41	22	40	22	40	22	38	22
1.30pm	47	20	41	20	40	21	39	20	37	21	36	22	34	21
2.30pm	52	27	42	27	41	28	40	26	38	30	36	30	30	24
3.30pm	54	28	44	28	42	27	42	26	42	32	38	32	30	24
4.30pm	60	34	50	35	49	35	47	36	46	36	43	37	39	33
5.30pm	66	52	60	51	58	50	60	52	58	51	60	54	55	51
6.30pm	71	61	68	62	68	62	67	62	63	58	64	60	62	59
7.30pm	75	66	70	65	70	65	71	66	68	64	68	65	66	64
8.30pm	80	71	72	67	73	68	72	68	71	67	71	68	70	68
9.30pm	83	75	74	69	75	70	74	70	74	70	74	71	76	74
10.30pm	86	78	77	72	77	72	80	76	75	72	76	74	80	78
11.30pm	89	82	79	75	80	76	81	78	77	74	78	76	83	82
12.30am	90	83	82	78	84	80	85	82	79	76	82	80	86	85
1.30am	90	84	84	80	85	82	87	84	82	80	84	82	89	88
2.30am	92	86	86	82	87	84	91	88	86	84	85	84	91	90
3.30am	93	88	87	84	91	88	92	90	89	88	89	88	92	92
4.30am	95	90	91	88	92	90	94	92	92	91	91	90	93	93
5.30am	96	92	94	92	93	92	94	93	92	92	92	92	93	93
6.30am	96	92	94	92	93	92	94	93	92	92	92	92	93	93
7.30am	94	90	92	90	90	88	92	90	91	89	90	88	90	89

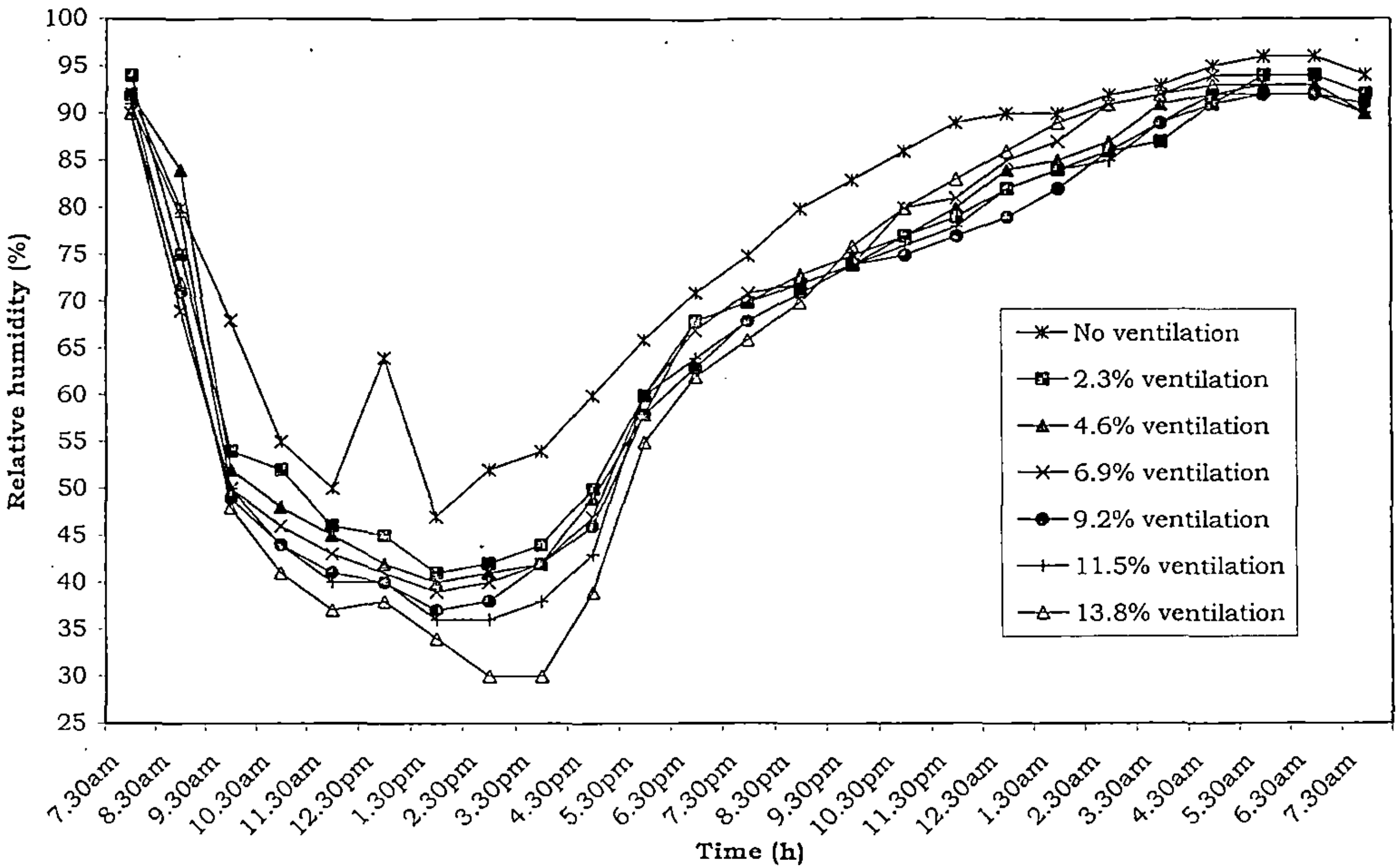

Fig. 5 Variation of relative humidity inside the greenhouse at different percentages of ventilation without fan and pad and mist systems (unshaded condition).

respectively and the minimum values were 40% and 21% respectively. At 6.9% ventilation, the maximum values of relative humidity inside and outside the greenhouse were 94% and 93% respectively and the minimum values were 39% and 20% respectively. At 9.2% ventilation, the lowest relative humidity values inside and outside the greenhouse were 37% and 21% respectively and the highest values were 93% and 92% respectively. At 11.5% ventilation, the lowest value of relative humidity inside and outside the greenhouse were 36% and 22% respectively and the highest value both inside and outside the greenhouse was 92%. At 13.8% ventilation, the minimum values of relative humidity inside and outside the greenhouse were 32% and 20% respectively and the maximum value was 93% both inside and outside the greenhouse.

Comparison of relative humidity values at different percentages of natural ventilation show that, the variation at night is almost same for all the cases and at daytime there is noticeable difference among the values. From the data it can be seen that the relative humidity inside the greenhouse decreases with increase in percentage of natural ventilation.

4.2.3 Variation of light intensity inside the greenhouse at different percentages of ventilation

The variations of light intensity inside the greenhouse at different percentages of natural ventilation without fan and pad and mist systems are shown in Fig. 6 and the values are given in table 9. From the data, it can be seen that the light intensity inside the greenhouse varies with the outside light intensity. The percentage of natural ventilation has no significant effect on the light intensity inside the greenhouse.

4.2.4 Effect of time and different percentages of ventilation on greenhouse microclimate

The variation of climatic parameters inside and outside the greenhouse with different percentages of ventilation at 9.30 am, 10.30 am, 11.30 am, 12.30 pm, 1.30 pm, 2.30 pm, 3.30 pm, 4.30 pm and 5.30 pm are shown in Figures 7 to 15 and the values are given in Appendix IX. From the graphs, it can be seen that the inside

Table 9. Variation of light intensity (lux) inside and outside the greenhouse at different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Time	Percentage ventilation													
	0		2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
7.30am	1815	3280	1778	2900	1167	1945	1048	1748	965	1612	1137	1895	1220	1746
8.30am	4110	5230	5850	6520	5528	6670	5290	6700	4380	5410	4230	5480	4950	6260
9.30am	21300	31800	24000	36500	23600	34900	19800	30700	22800	34800	11500	19180	25600	37200
10.30am	32900	47000	30600	44700	32100	45900	31500	45100	32200	46100	29800	42600	35600	49800
11.30am	44700	55300	46100	57600	43300	54200	42800	53500	43700	54600	43200	54000	48500	59800
12.30pm	10520	16200	49200	58200	46500	54700	47500	55400	49100	57800	46300	54200	51200	61000
1.30pm	43200	54200	45700	55100	43100	54200	36400	45400	41200	51500	39800	51100	44700	54600
2.30pm	34000	43500	33200	42400	37300	46700	37100	46500	29500	38800	27900	36500	40600	51000
3.30pm	23200	29100	25700	32000	26100	32400	27200	34500	25200	31400	8620	12500	28600	35500
4.30pm	13900	16300	8180	11920	12700	19800	13200	21500	8670	11570	10610	13400	10960	13630
5.30pm	1893	3010	3000	4600	1620	2670	1343	2552	4720	6800	4910	7250	3050	4850
6.30pm	270	525	108	203	147	273	64	118	43	84	257	461	140	245
7.30pm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.30pm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.30pm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.30pm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.30pm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.30am	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.30am	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.30am	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.30am	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.30am	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.30am	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.30am	157	286	171	312	39	76	79	135	108	198	129	225	124	215
7.30am	1778	2900	1428	1945	1352	1748	965	1612	1137	1895	1220	1746	965	1615

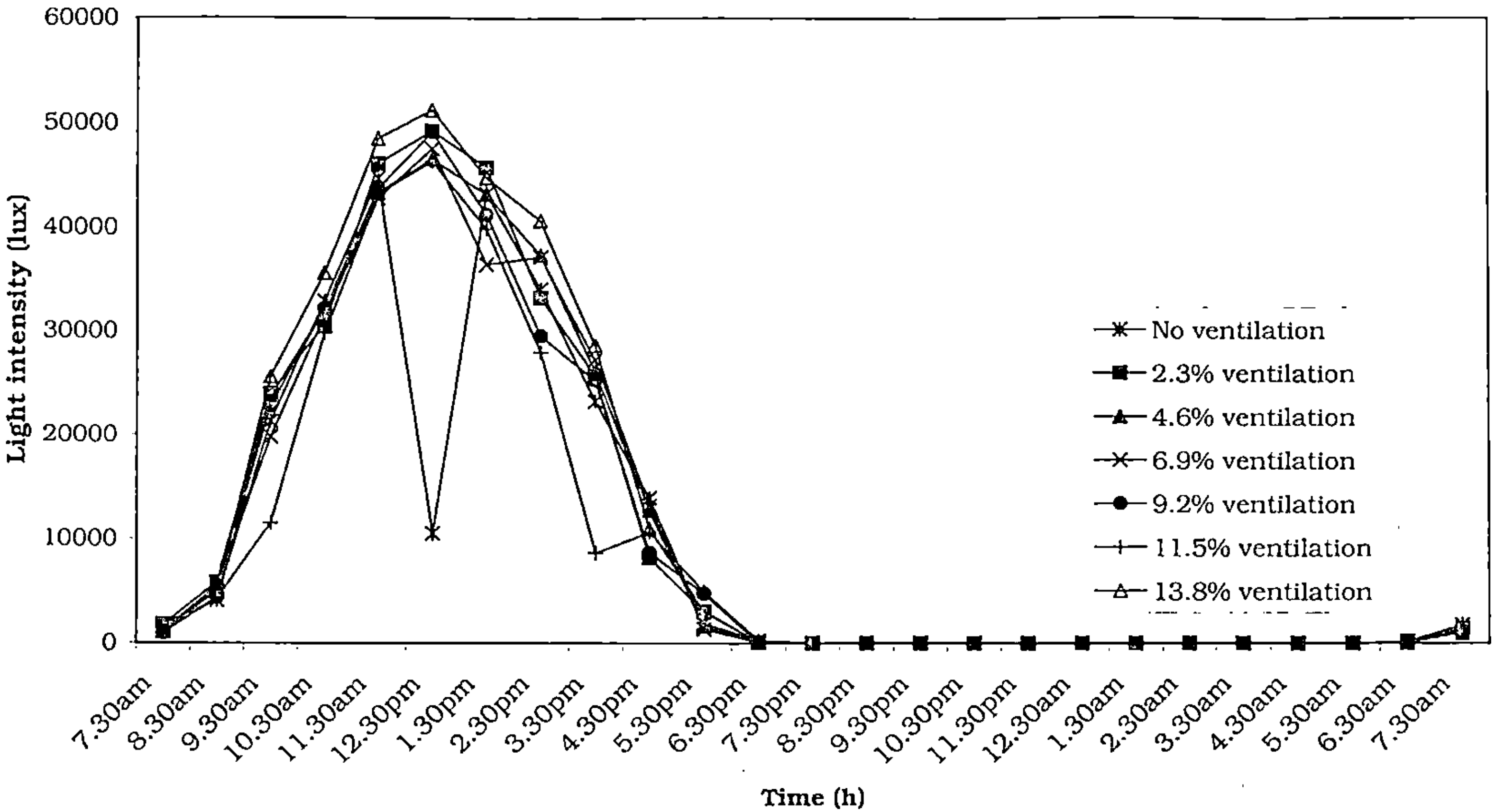

Fig. 6 Variation of light intensity inside the greenhouse at different percentages of ventilation without fan and pad and mist systems (unshaded condition).

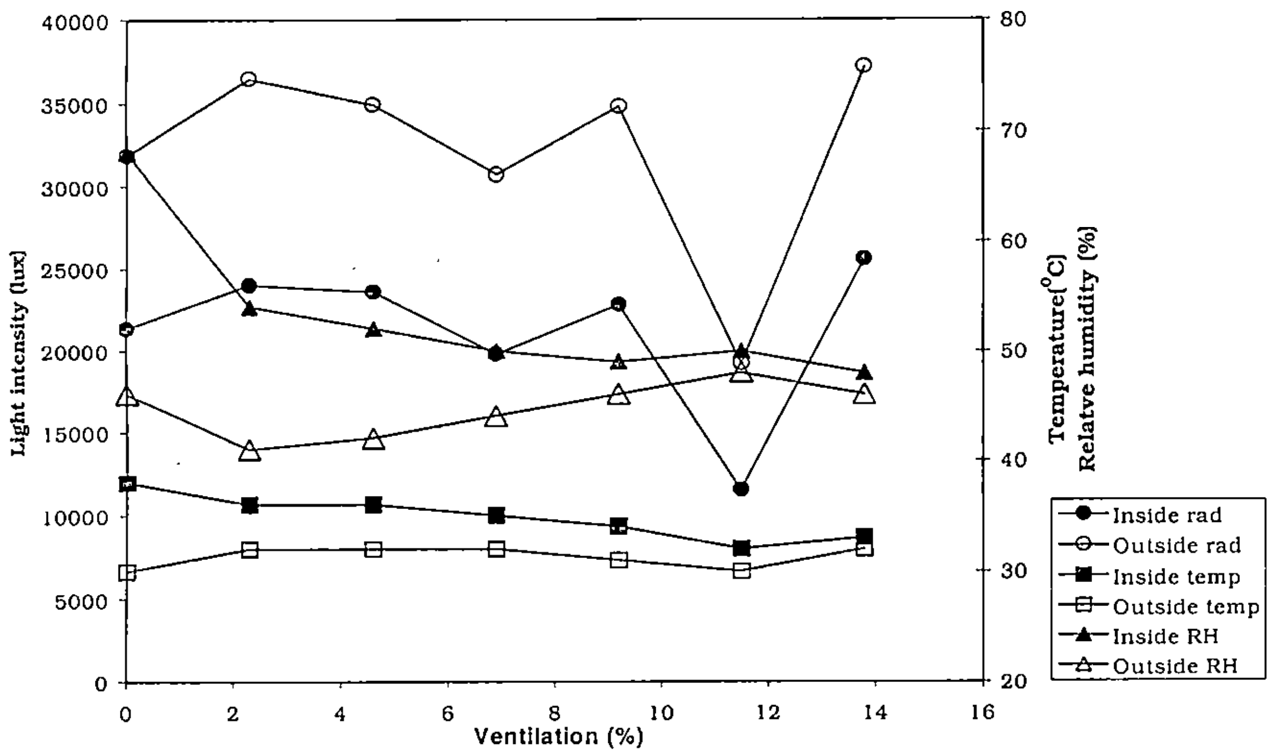

Fig. 7 Variation of parameters inside and outside the greenhouse at 9.30am under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

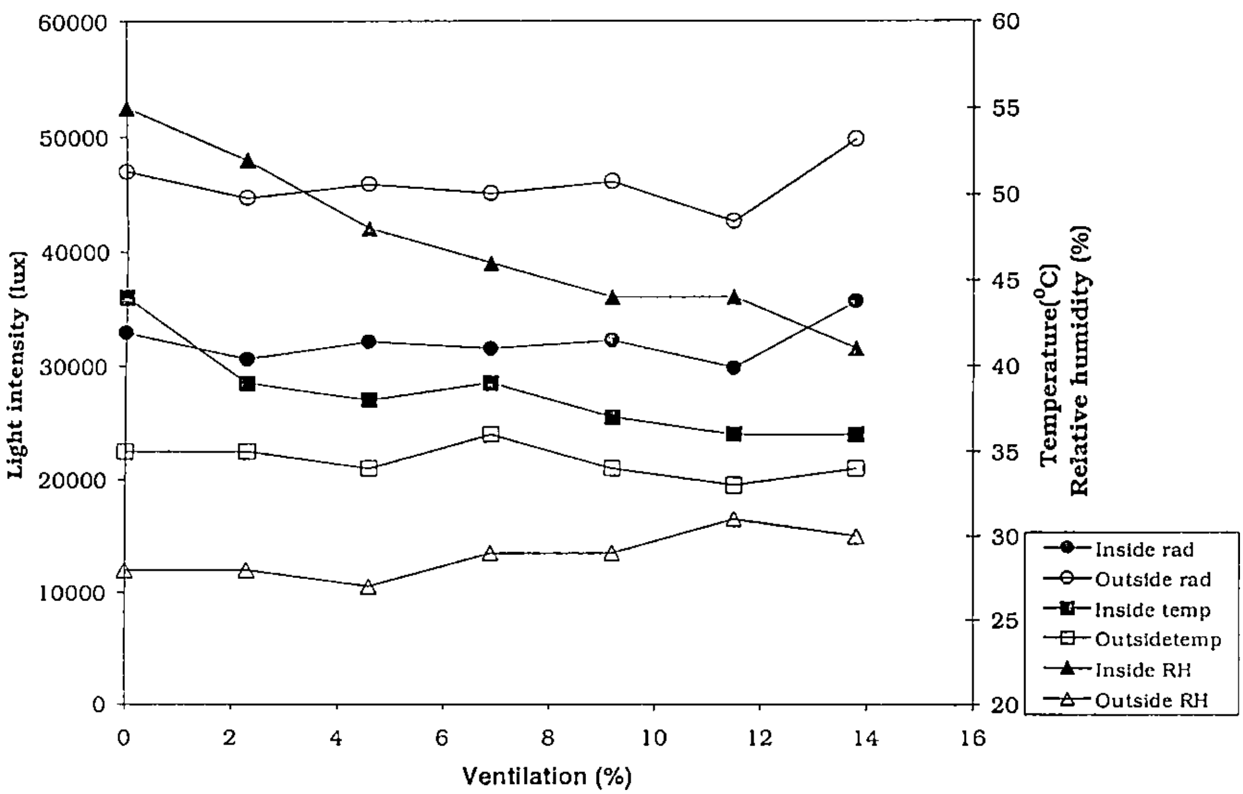

Fig. 8 Variation of parameters inside and outside the greenhouse at 10.30am under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

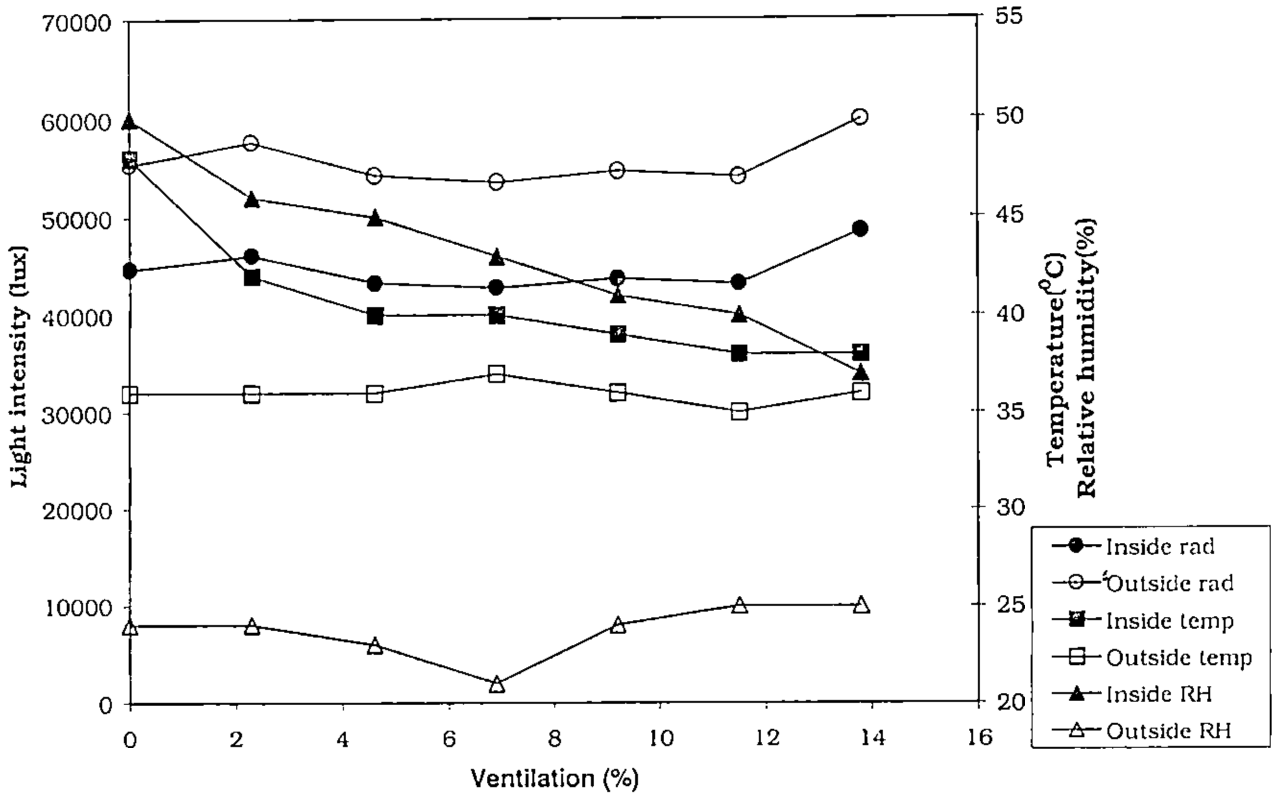

Fig.9 Variation of parameters inside and outside the greenhouse at 11.30 am under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

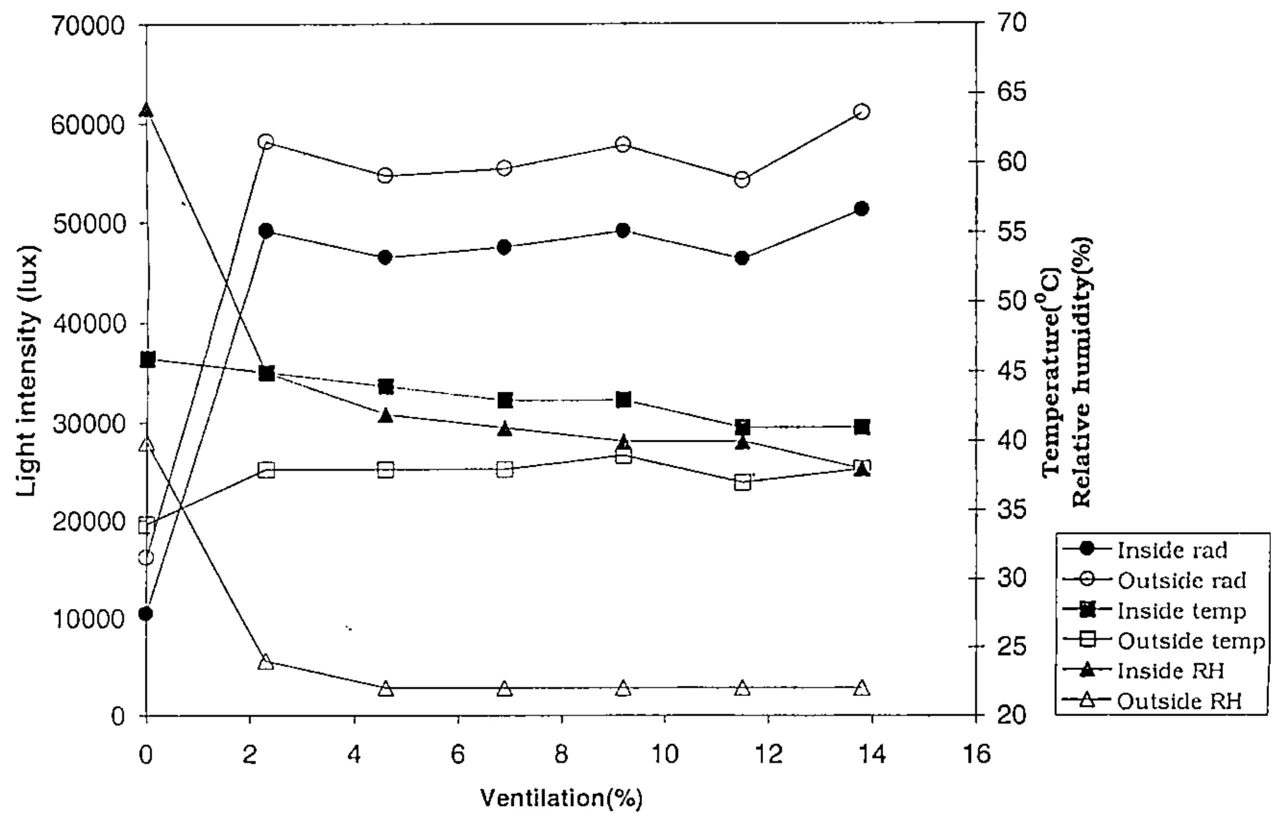

Fig. 10 Variation of parameters inside and outside the greenhouse at 12.30pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

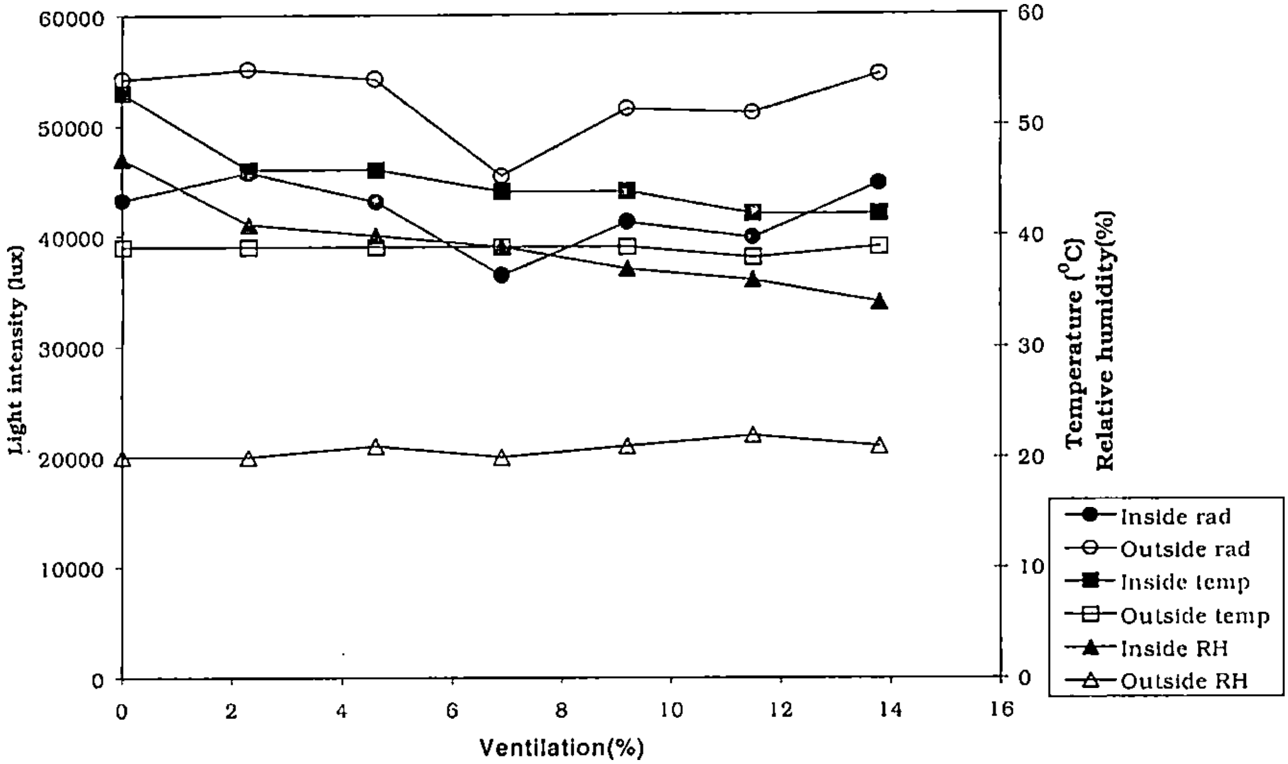

Fig. 11 Variation of parameters inside and outside the greenhouse at 1.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

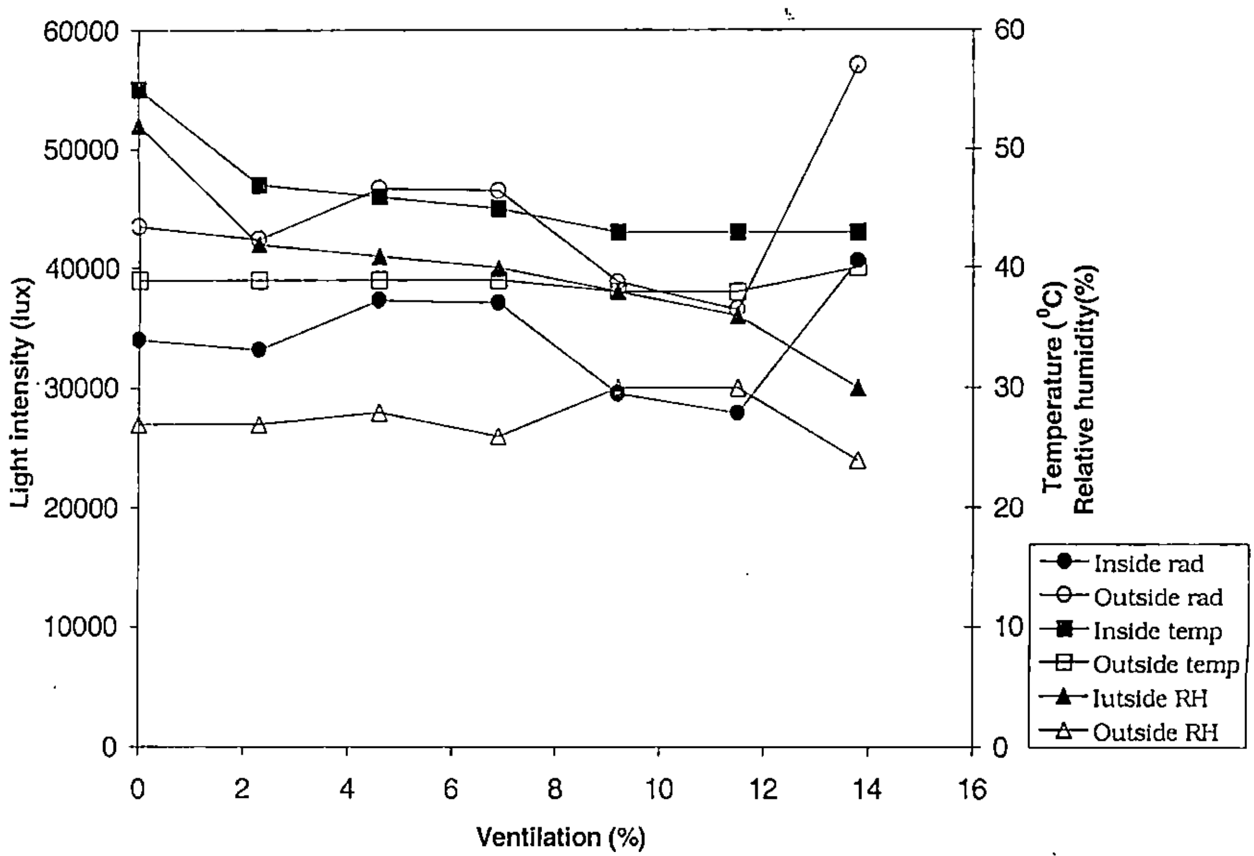

Fig. 12 Variation of parameters inside and outside the greenhouse at 2.30pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

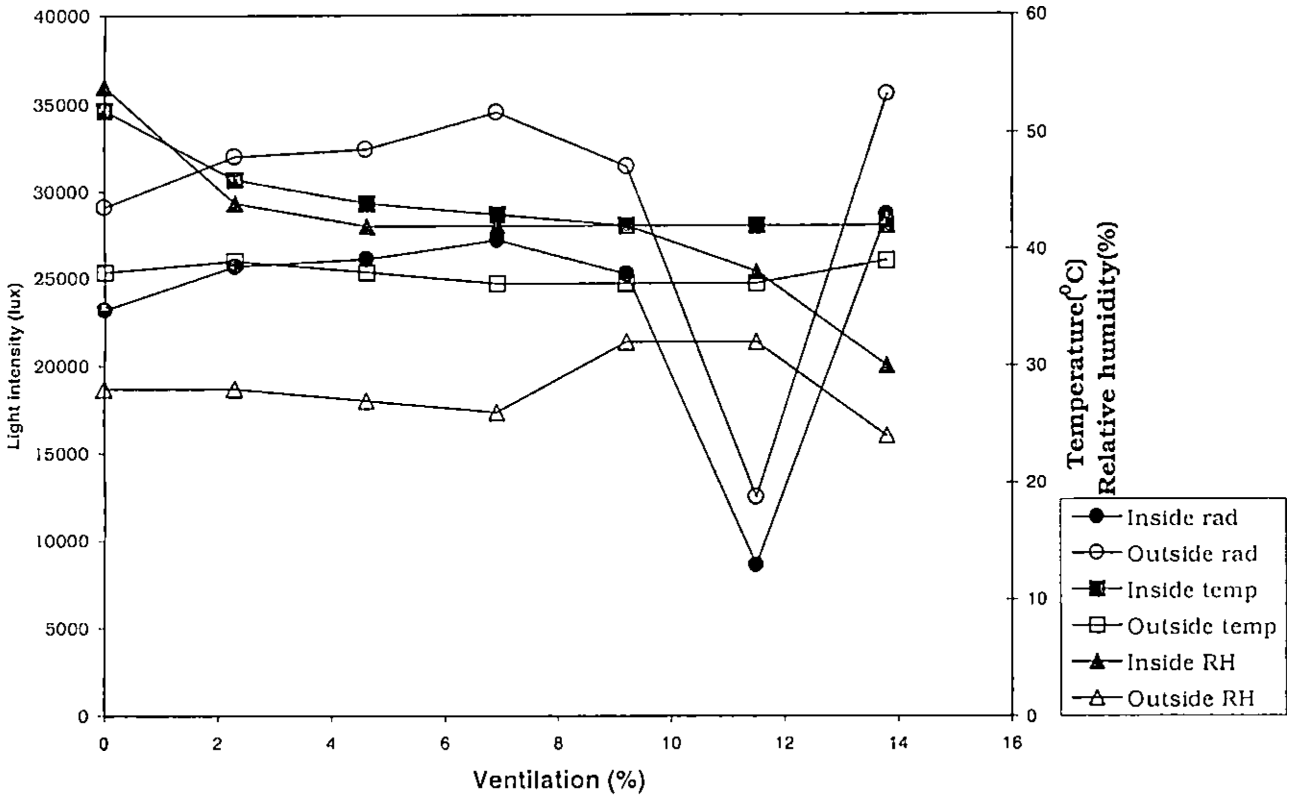

Fig. 13 Variation of parameters inside and outside the greenhouse at 3.30pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

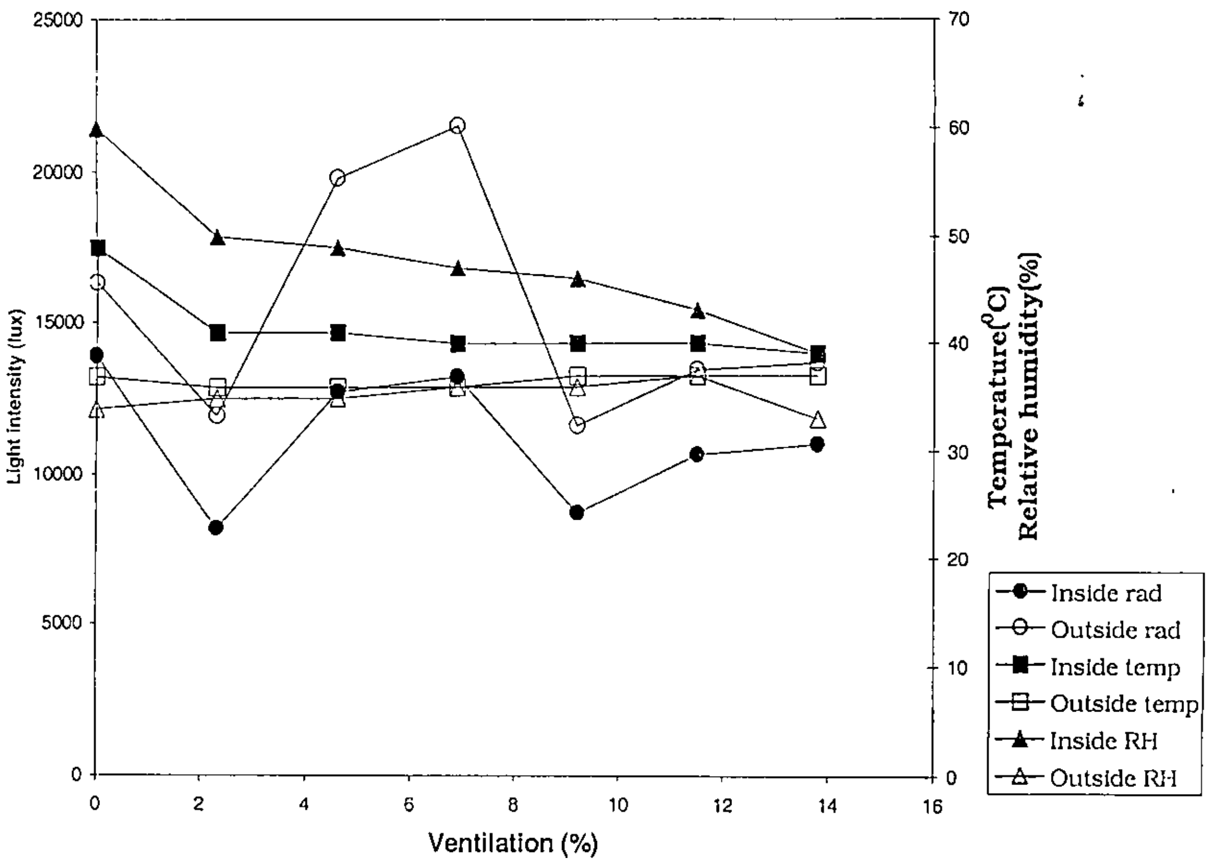

Fig. 14 Variation of parameters inside and outside the greenhouse at 4.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

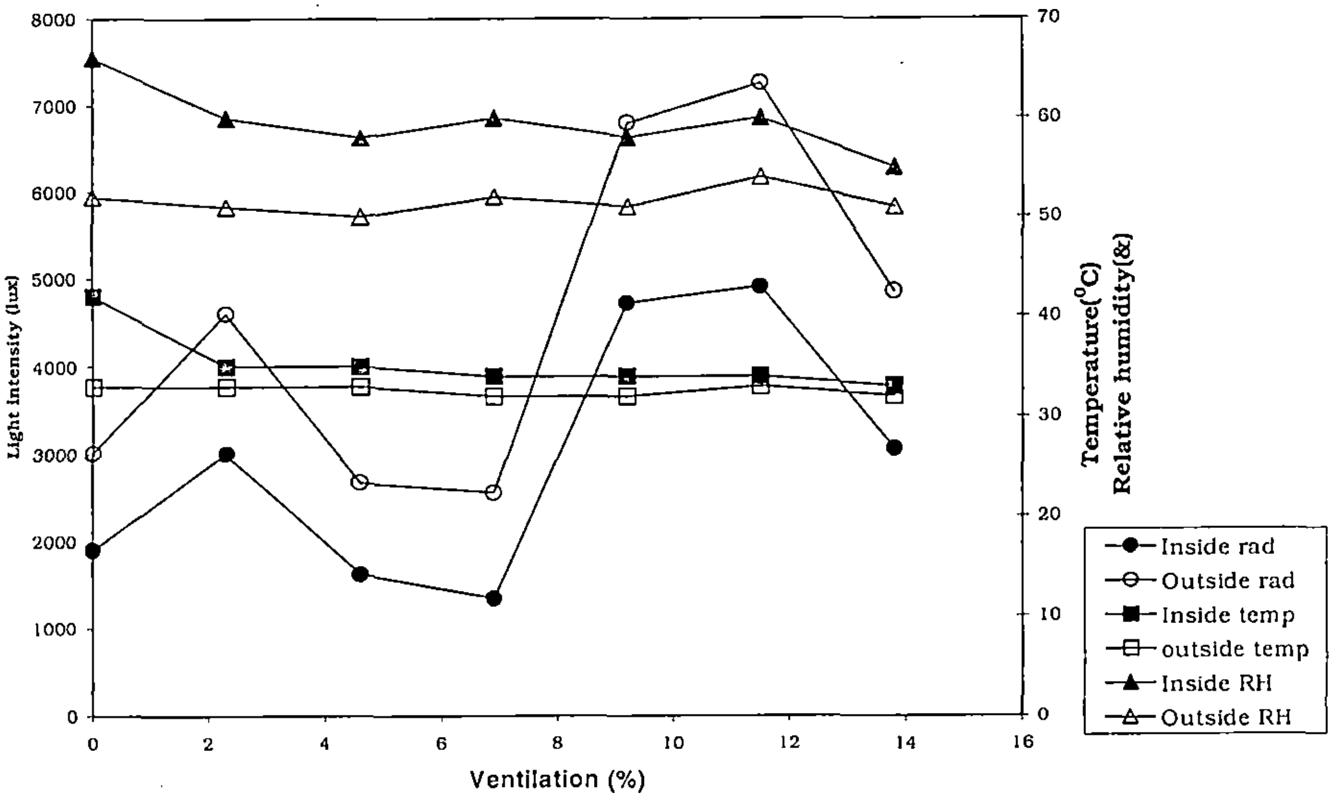

Fig. 15 Variation of parameters inside and outside the greenhouse at 5.30pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

temperature and relative humidity are dependent on the outside climate and the percentage ventilation. Variation of intensity of solar radiation inside the greenhouse is dependent only on the outside solar radiation. The data show that ventilation has no significant effect on the variation of intensity of solar radiation.

Inside temperature decreases with increase in percentage of ventilation. The inside temperature is very high for no ventilation condition in all the cases. Even when the outside temperature is less compared to that for different percentages of ventilation, temperature inside the greenhouse was maximum at no ventilation condition. From the graphs, it is clear that the inside to outside temperature difference is minimum at 13.8% ventilation and maximum at 0% ventilation. The inside to outside temperature difference decreases with increase in percentage of ventilation. This shows that the greenhouse cooling increases with increase in percentage of ventilation.

The relative humidity inside the greenhouse decreases with increase in percentage of ventilation. The maximum relative humidity inside the greenhouse was observed at no ventilation condition. The inside relative humidity also depends on the intensity of solar radiation. As the intensity of solar radiation increases the relative humidity decreases and vice versa. The inside to outside humidity difference is maximum at no ventilation condition and minimum at 13.8% ventilation condition.

4.2.5 Optimum percentage of ventilation

Figures 3 to 15 explain the effect of different percentages of ventilation on the greenhouse microclimate. The variation of temperature, relative humidity and light intensity at different time for different percentages of ventilation are given in tables 1, 2 and 3 respectively. The relative humidity and temperature decrease with increase in percentage of ventilation. Ventilation has no significant effect on the light intensity. During nighttime, the climatic parameters inside and outside the green house showed no much difference. But during daytime, the inside to outside temperature difference is noticeable. The difference between inside and outside temperatures of the greenhouse from 7.30 am to 6.30 pm are given in table 10. These values decrease as the ventilation increases. This means that,

Table 10. Inside to outside temperature difference from 7.30 am to 6.30 pm for different percentages of ventilation

Time	Percentage ventilation						
	0	2.3	4.6	6.9	9.2	11.5	13.8
7.30am	1	1	1	1	1	1	1
8.30am	2	2	2	2	1	1	1
9.30am	8	4	4	3	3	2	1
10.30am	9	4	4	3	3	3	2
11.30am	12	6	4	3	3	3	2
12.30pm	12	7	6	5	4	4	3
1.30pm	14	7	7	5	5	4	3
2.30pm	16	8	7	6	5	5	3
3.30pm	14	7	6	6	5	5	3
4.30pm	12	5	5	4	3	3	2
5.30pm	9	2	2	2	2	1	1
6.30pm	6	2	2	1	1	1	1

Table 11. Results of statistical analyses for the inside to outside temperature difference from 7.30 am to 6.30 pm for different percentages of ventilation.

	Percentage ventilation						
	0	2.3	4.6	6.9	9.2	11.5	13.8
No. of cases	12	12	12	12	12	12	12
Minimum	1	1	1	1	1	1	1
Maximum	16	8	7	6	5	5	3
Sum	115	55	50	41	36	33	23
Mean	9.58	4.583	4.167	3.417	3	2.75	1.917
Std. deviation	4.52	2:326	1.993	1.706	1.472	1.479	0.862
95% CI upper	12.5	6.1	5.4	4.5	3.9	3.7	2.4
95% CI lower	6.6	3.1	2.9	2.3	2.1	1.8	1.4

cooling is obtained at higher value of ventilation. The results of the statistical analyses of the temperature difference values are given in table 11. The maximum temperature difference was at 0% ventilation and minimum was at 13.8% ventilation. The maximum value of temperature difference decreases as the ventilation increases. The sum and mean of the temperature difference values also decrease as the ventilation increases. 95% confidence interval for all the cases are also given in Table 11. The upper and lower limits for the confidence interval is least at 13.8% ventilation.

The temperatures inside the greenhouse was always higher than the outside temperature, when natural ventilation alone was provided as the cooling method. Even at 13.8% natural ventilation, the temperature inside the greenhouse rises upto 43°C. But, compared to other percentages of ventilation, better cooling was obtained at 13.8% ventilation. No additional energy is required for natural ventilation. So economically, natural ventilation can be considered as a cost effective method for greenhouse cooling. The present study recommends 13.8% of the floor area of the greenhouse as the optimum side ventilation for better greenhouse environment.

4.3 Effect of Fan and Pad System on Greenhouse Cooling

Variation of climatic parameters inside and outside the greenhouse when fan and pad system was operated are shown in Fig.16. The values of the climatic parametrs are given in Appendix X. The fan and pad system was operated for every alternate 30 minutes from 10.00 am. This process was continued upto 4.00 pm. After 30 minutes operation of fan and pad system, the inside temperature reduces and afterwards it increases. The maximum temperatures inside and outside the greenhouse were 46°C and 37°C respectively. Fig.16 shows that there is intermittent cooling inside the greenhouse. At no ventilation condition alone, the maximum temperature inside the greenhouse was 55°C. There was a reduction of 9°C in the maximum temperature by using the fan and pad system, compared to no ventilation without fan and pad system. Relative humidity inside the greenhouse decreased when fan and pad system was operated and increased when they put off. This is clearly indicated by Fig. 16.

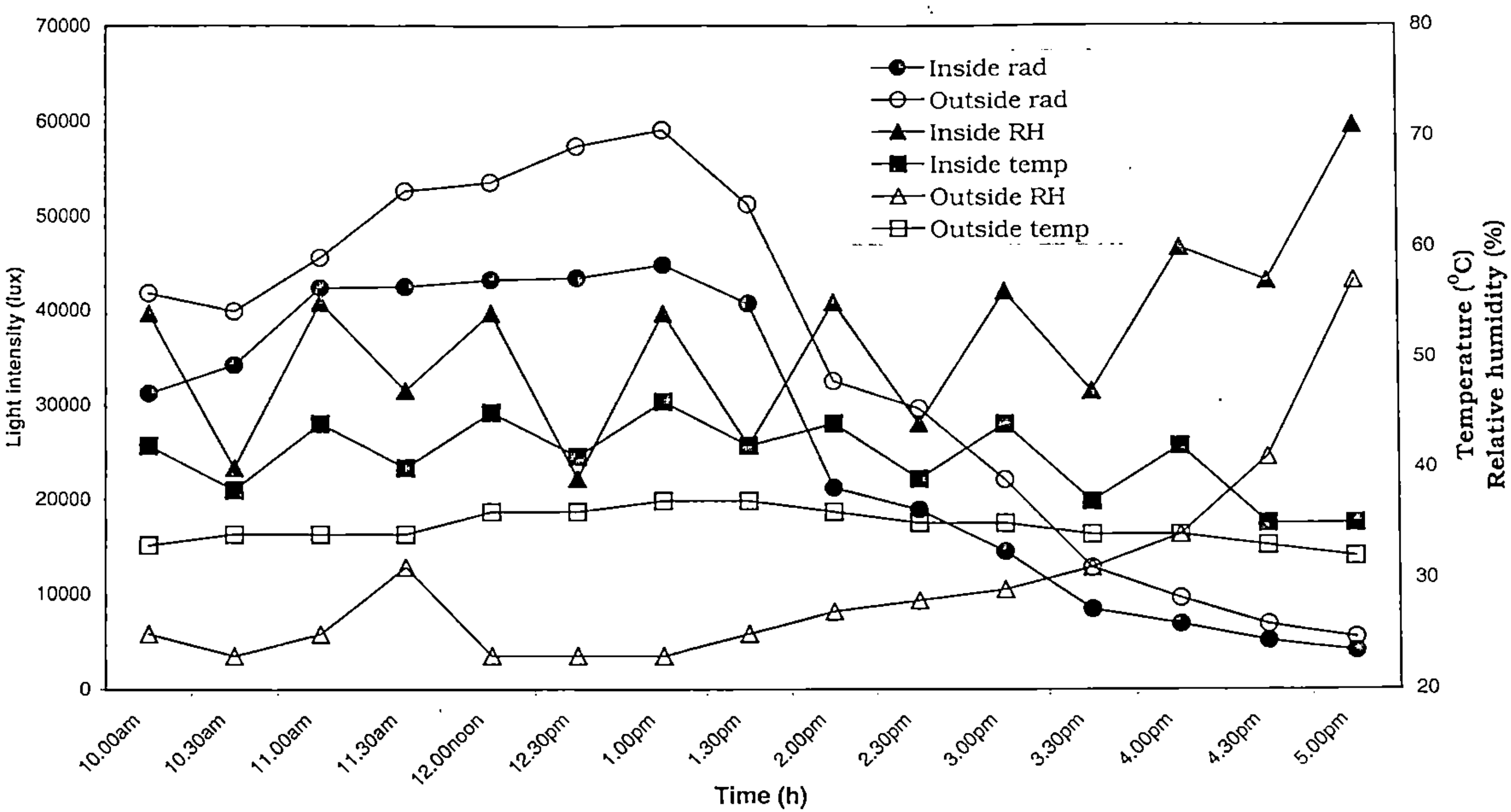

Fig. 16 Variation of parameters inside and outside the greenhouse without ventilation (unshaded condition, with fan and pad system and without mist system).

From Fig. 16, it is clear that fan and pad system alone cannot lower the temperature below the ambient temperature. The inside temperature, even while operating the fan and pad system was higher than the outside temperature. So fan and pad system alone cannot provide enough cooling inside the greenhouse. The mean value of inside to outside temperature difference from 10.00 am to 5.00 pm for half an hour intermittent operation of fan and pad system is 6.27.

The inside to outside temperature difference at 0, 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8 percentages of ventilation conditions without fan and pad system and at no ventilation condition with fan and pad system are given in table 12. It is evident from the table that, the temperature difference values at no ventilation condition with fan and pad system are lower compared to that at no ventilation condition without fan and pad system. But there was no significant difference between this values and the temperature difference values at 2.3 and 4.6% ventilation condition without fan and pad system.

The 30 minutes interval temperature difference values for 0, 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8 percentages of ventilation were obtained by interpolating the one hour interval temperature difference values from 9.30 am to 5.30 pm. The results of the statistical analyses of these values are given in table 13. The sum of the temperature difference values for fan and pad system was 94, which was lesser than that for no ventilation condition, but was greater than that for all other percentages of ventilation. The 95% confidence interval for the mean temperature difference values with fan and pad cooling system was 4.765 to 7.768, which was lesser than that without ventilation and fan and pad system, for which the interval was 11.049 to 13.618. But the confidence interval for fan and pad system is higher than that for any other percentage of natural ventilation. The paired sample t-test for all the combinations of the above cases showed that there is no significant difference between 2.3% ventilation condition and fan and pad system and 4.6% ventilation condition and fan and pad cooling system. Table 13 shows that 13.8% ventilation can give better cooling, compared to fan and pad cooling system, for which the 95% confidence interval for the mean value of temperature difference is 1.933 to 2.734. At 6.9, 9.2 and 11.5 percentages of ventilation the temperature difference values are significantly higher.

Table 12. Inside to outside temperature difference from 10.00 am to 5.00 pm for different percentages of ventilation without fan and pad system and with fan and pad system at no ventilation.

Time	Percentage ventilation							With fan and pad system
	0	2.3	4.6	6.9	9.2	11.5	13.8	
10.00am	8	4	4	3	3	2	1	9
10.30am	9	4	4	3	3	3	2	4
11.00am	10	5	4	3	3	3	2	10
11.30am	12	6	4	3	3	3	2	6
12.00noon	12	7	5	4	4	3	2	9
12.30pm	12	7	6	5	4	4	3	5
1.00pm	13	7	7	5	4	4	3	9
1.30pm	14	7	7	5	5	4	3	5
2.00pm	15	8	7	6	5	5	3	8
2.30pm	16	8	7	6	5	5	3	4
3.00pm	15	8	7	6	5	5	3	9
3.30pm	14	7	6	6	5	5	3	3
4.00pm	13	6	5	5	4	4	2	8
4.30pm	12	5	5	4	3	3	2	2
5.00pm	10	3	3	3	2	2	1	3

Table 13. Results of the statistical analyses for the inside to outside temperature difference (from 10.00 am to 5.00 pm).

Parameters	Percentage ventilation							With fan and pad system
	0	2.3	4.6	6.9	9.2	11.5	13.8	
(No. of cases)	15	15	15	15	15	15	15	15
Minimum	8	3	3	3	2	2	1	2
Maximum	16	8	7	6	5	5	3	10
Sum	185	92	81	67	58	55	35	94
Mean	12.333	6.133	5.400	4.467	3.867	3.667	2.333	6.267
(Std. deviation)	2.241	1.543	1.357	1.204	0.957	1.011	0.699	2.620
(95% CI upper)	13.618	7.018	6.178	5.157	4.415	4.246	2.734	7.768
(95% CI lower)	11.049	5.249	4.622	3.777	3.318	3.087	1.933	4.765

4.4. Effect of Mist System on Greenhouse Cooling

The mist system along with exhaust fans was operated at different percentages of ventilation to reduce the temperature inside the greenhouse. The results showed that mist system reduces the temperature inside the greenhouse considerably within a short period. Mist system was operated for 10 minutes and then was kept off for 20 minutes. This process was repeated. While using ventilation or fan and pad system for greenhouse cooling, even though there was some degree of cooling, the inside temperature was always higher than the outside temperature. But while using the mist system for greenhouse cooling, the greenhouse temperature can be reduced considerably below atmospheric temperature. Average greenhouse temperature can be reduced to about 5°C lesser than the outside temperature by using mist system. After switching off the mist system, the inside temperature increases and 20 minutes after switching off the mist system, the greenhouse temperature was almost equal or little higher than the outside temperature. Mist system increases the greenhouse humidity to almost 80%.

4.4.1 Effect of mist system on temperature at different percentages of ventilation

The variation of temperature inside and outside the greenhouse with fan and mist system at different percentages of ventilation are given in table 14. Degree of cooling values for different percentages of ventilation were calculated by taking the difference of outside temperature at the start of operation of mist system and the inside temperature soon after the mist system is stopped. This is done by the assumption that within 10 minutes, much variation will not occur in the outside temperature. At 2.3% ventilation, mean value of degree of cooling for all the 14 cases was 4.286. The one sample t-test for the degree of cooling values showed that mean value of 5 could be accepted. 95% confidence interval for the mean was 2.976 to 5.595. Paired sample t-test for the degree of cooling values showed that there is significant difference between 2.3% ventilation and all other percentages of ventilation tested. At 2.3% ventilation, mist system reduced the greenhouse temperature to 32°C.

Table 14. Variation of temperature (^{0}C) inside and outside the greenhouse at different percentages of ventilation (unshaded condition, with fan and mist system).

Time	Percentage ventilation											
	2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	36	31	36	32	36	32	34	31	33	31	34	32
10.10am	31		32		32		31		31		32	
10.30am	33	32	34	32	37	34	34	32	35	34	35	34
10.40am	32		32		32		31		32		32	
11.00am	33	34	33	33	38	36	33	33	36	34	37	36
11.10am	31		32		33		32		32		33	
11.30am	34	35	34	34	38	36	33	33	37	35	37	36
11.40am	32		32		33		32		32		33	
12.00noo	39	37	36	35	39	37	34	35	37	36	39	37
12.10pm	32		32		33		32		33		34	
12.30pm	38	37	38	37	36	35	38	37	38	37	38	37
12.40pm	32		32		32		33		33		34	
1.00pm	39	38	39	38	39	37	38	38	38	38	39	38
1.10pm	32		32		33		34		34		35	
1.30pm	39	39	39	39	40	38	39	39	39	37	39	38
1.40pm	33		33		34		35		34		35	
2.00pm	39	39	39	39	37	35	39	39	38	38	38	38
2.10pm	32		33		32		35		34		35	
2.30pm	39	39	39	39	40	38	39	39	39	39	40	38
2.40pm	32		33		34		35		35		34	
3.00pm	39	38	39	37	39	37	38	38	38	37	39	37
3.10pm	32		32		33		34		34		34	
3.30pm	37	37	37	35	38	36	37	37	36	36	39	39
3.40pm	32		32		33		33		33		34	
4.00pm	36	36	37	36	38	35	36	36	35	35	36	36
4.10pm	32		32		32		32		32		33	
4.30pm	35	35	36	35	36	34	35	35	34	34	35	35
4.40pm	32		32		32		32		32		32	
5.00pm	34	34	35	33	34	33	34	34	34	34	34	34

Mist system reduced the greenhouse temperature to 32°C or 33°C depending on the ambient condition at 4.6% ventilation. Mean value of the degree of cooling was 3.571 and the one sample t-test for it showed that a mean value of 4 can be accepted. 95% confidence interval for the mean was 2.296 to 4.847. Paired sample t-test showed that there is no significant difference between 4.6% and 6.9, 9.2, 11.5 or 13.8% ventilation.

At 6.9% ventilation, mist system reduced the greenhouse temperature to 32, 33 or 34°C depending on the outside temperature. Mean value of the degree of cooling for all the 14 cases was 3 and the one sample t-test for it showed that a mean value 3 can be accepted. 95% confidence interval for the mean was 2.359 to 3.641. Paired sample t-test for the degree of cooling values showed that there is no significant difference between 6.9% and 4.6, 9.2, 11.5 or 13.8% ventilation.

Mean value of the degree of cooling at 9.2% ventilation was 2.929 and one sample t-test for it showed that mean value of 3 can be accepted. 95% confidence interval for the mean was 2.067 to 3.790. Mist system reduced the inside temperature to 31, 32, 33, 34 or 35°C depending upon the outside cilmate. The paired sample t-test showed that there is no significant difference between 9.2% and 4.6, 6.9, 11.5 or 13.8% ventilation.

At 11.5% ventilation, mean value of the degree of cooling for all the 14 cases was 2.857 and one sample t-test for it showed that mean value of 3 can be accepted. 95% confidence interval for the mean was 2.222 to 3.492. Mist system reduced the greenhouse temperature to 31, 32, 33, 34 or 35°C depending upon the outside climate. The paired sample t-test showed that there is no significant difference between 11.5% and 4.6, 6.9, 9.2 or 13.8% ventilation.

Mist system reduced the greenhouse temperature to 32, 33, 34 or 35°C depending upon the outside climate at 13.8% ventilation. Mean value of the degree of cooling for all the 14 cases was 2.929 and one sample t-test for it showed that mean value of 3 can be accepted. 95% confidence interval for the mean was 2.310 to 3.547. The paired sample t-test showed that there is no significant difference between 13.8% and 4.6, 6.9, 9.2 or 11.5% ventilation.

4.4.2 Effect of mist system on relative humidity at different percentages of ventilation

The variation of relative humidity inside and outside the greenhouse with fan and mist system at different percentages of ventilation are given in table 15. Relative humidity increased to 80% or more while operating the fan and mist system inside a greenhouse at any percentage of ventilation. 20 minutes after stopping the mist system, relative humidity decreased by 20%.

4.4.3 Effect of mist system on light intensity at different percentages of ventilation

The variation of light intensity inside and outside the greenhouse with fan and mist system at different percentages of ventilation are given in table16. This is almost same as that without mist system.

4.4.4 Optimum greenhouse ventilation with mist system for greenhouse cooling

Table 17 shows the degree of cooling while operating the mist system along with fans at different percentages of ventilation and table 18 shows the results of statistical analyses for these values. Tables 14 and 17 show that the maximum cooling was obtained at 2.3% of ventilation while using mist system. The upper and lower limits of confidence interval were higher for this condition. The optimum temperature inside the greenhouse depends on the crops to be cultivated. The greenhouse temperature can be lowered to 32°C at 2.3 percentage of ventilation. A crop, for which the optimum temperature is 32°C, this condition is optimum. The temperature inside the greenhouse could be lowered to 33°C with 4.6% ventilation. At 6.9, 9.2, 11.5 and 13.8 percentages of ventilation, most of the time the inside temperature was lowered to 34°C. So for crops, which require an optimum temperature of 33°C, 4.6% ventilation can be adopted and for 34°C temperature 6.9, 9.2, 11.5 or 13.8 % ventilation can be adopted.

While using mist system at different percentages of ventilation, as the ventilation increases, the degree of cooling decreases. This may be due to the greater

Table 15. Variation of relative humidity (%) inside and outside the greenhouse at different percentages of ventilation (unshaded condition, with fan and mist system).

	Percentage ventilation											
	2.3		4.6		6.9		9.2		11.5		13.8	
Time	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	62	36	58	38	60	35	55	38	64	37	62	45
10.10am	80		82		88		80		76		75	
10.30am	61	35	62	36	60	28	61	40	60	27	60	27
10.40am	80		80		90		82		79		77	
11.00am	65	32	68	35	56	30	69	47	61	24	58	24
11.10am	81		81		90		80		80		78	
11.30am	62	28	65	31	62	29	75	42	65	25	64	23
11.40am	82		82		89		78		80		80	
12.00noo	53	24	62	28	56	28	60	31	64	24	53	24
12.10pm	81		80		85		86		80		80	
12.30pm	55	26	58	26	60	32	60	28	60	28	62	33
12.40pm	80		80		86		85		76		82	
1.00pm	62	30	55	27	60	29	62	34	48	30	64	31
1.10pm	81		78		84		84		85		83	
1.30pm	58	32	56	25	72	24	58	32	54	27	65	26
1.40pm	84		81		85		82		75		80	
2.00pm	60	31	61	22	72	34	56	34	51	25	51	25
2.10pm	85		84		88		80		82		79	
2.30pm	58	32	54	28	57	31	54	31	53	28	52	30
2.40pm	80		78		82		80		84		81	
3.00pm	65	36	64	36	60	34	60	36	60	39	51	30
3.10pm	81		85		85		80		85		84	
3.30pm	66	38	61	38	60	34	64	38	64	41	55	32
3.40pm	84		83		85		82		85		85	
4.00pm	65	40	58	35	72	38	62	40	66	46	68	45
4.10pm	81		82		88		84		86		84	
4.30pm	68	41	55	43	80	42	71	41	71	52	70	48
4.40pm	84		80		90		84		85		85	
5.00pm	70	42	58	57	73	52	70	42	73	54	70	52

Table 16. Variation of light intensity (lux) inside and outside the greenhouse at different percentages of ventilation (unshaded condition, with fan and mist system).

Time	Percentage ventilation											
	2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	27200	34200	26400	33400	21200	36400	10350	11050	28300	39400	17200	38400
10.30am	29400	36500	28600	35100	26800	45600	26800	32500	37500	45100	37600	45200
11.00am	37500	48600	32200	42400	34500	47500	44000	54600	34400	43400	39600	49500
11.30am	41300	52500	42100	55600	43500	53600	42200	57100	43200	56400	44000	55500
12.00noon	48500	61200	48500	62100	47400	59800	42500	61600	44200	61200	49200	60500
12.30pm	43400	57600	48700	61800	45700	53200	49600	62000	49600	62000	46100	53400
1.00pm	42500	54100	43100	56200	46300	57800	43400	54200	45600	56700	44700	54300
1.30pm	42100	53400	42500	55600	43600	52200	45100	56400	44500	53800	44200	52200
2.00pm	42400	52100	38100	47800	38500	48400	43200	53100	41500	50500	41500	50500
2.30pm	34600	47800	32900	40700	29900	34700	43400	51200	36200	48400	34500	40100
3.00pm	33400	45200	23700	32900	21300	32800	36200	45200	24100	32200	31200	37100
3.30pm	32100	42500	16800	27100	18400	27500	34200	43400	19800	29200	22700	36900
4.00pm	27600	38500	28200	39400	19500	26400	28400	38600	16500	24100	18900	27300
4.30pm	21200	33500	10800	14300	9280	13800	22100	33400	12400	21200	16200	25200
5.00pm	13500	21500	5660	8320	8420	10800	13400	21500	10100	19400	10900	19200

Table 17. Degree of cooling values while operating the mist system along with fans at different percentages of ventilation (unshaded condition).

Time	Percentage ventilation					
	2.3	4.6	6.9	9.2	11.5	13.8
10.00am	0	0	0	0	0	0
10.30am	0	0	2	1	2	2
11.00am	3	1	3	1	2	3
11.30am	3	2	3	1	3	3
12.00noon	5	3	4	3	3	3
12.30pm	5	5	3	4	4	3
1.00pm	6	6	4	4	4	3
1.30pm	6	6	4	4	3	3
2.00pm	7	6	3	4	4	3
2.30pm	7	6	4	4	4	4
3.00p,	6	5	4	4	3	3
3.30pm	5	3	3	4	3	5
4.00pm	4	4	3	4	3	3
4.30pm	3	3	2	3	2	3

Table 18. Results of statistical analyses of the degree of cooling while operating the mist system along with fans at different percentages of ventilation (unshaded condition).

	Percentage ventilation					
	2.3	4.6	6.9	9.2	11.5	13.8
No. of cases	14	14	14	14	14	14
Minimum	0	0	0	0	0	0
Maximum	7	6	4	4	4	5
Sum	60	50	42	41	40	41
Mean	4.286	3.571	3.000	2.929	2.857	2.929
Std. Deviation	2.185	2.129	1.069	1.438	1.059	1.033
95% CI upper	5.595	4.847	3.641	3.790	3.492	3.547
95% CI lower	2.976	2.296	2.359	2.067	2.222	2.310

air entry into the greenhouse. As larger amount of hot ambient air enters the greenhouse, the degree of cooling decreases. But at no ventilation condition, the relative humidity increases upto 100% and this can be avoided by providing some percentage of ventilation. So 2.3 percentage of ventilation is optimum while mist system is used for greenhouse cooling.

4.5 Effect of Mist System on Greenhouse Cooling with One Shade Net Layer

Mist system operated in a greenhouse without shade cover could not lower the temperature below 32°C, even at the optimum percentage of ventilation. Therefore greenhouse was covered with a 75% shade net and mist system was operated intermittently from 10.00 am to 5.00 pm along with exhaust fans at different percentages of ventilation. The results showed that, this can reduce the temperature to 29°C or 32°C depending upon the outside temperature and ventilation. Mist system was operated for 5 minutes and then was kept off for the next 25 minutes. This process was repeated. Control by mist system in a shaded greenhouse gives better cooling compared to others. Greenhouse temperature can be reduced to 7°C lesser than the outside temperature on an average. Twenty five minutes after switching off the mist system, the greenhouse temperature was equal or one or two degree less than the outside temperature. While operating the mist system, the humidity was increased to 80% or more. The light intensity inside the greenhouse was very less for this case. Only 20 to 25% of the light could come through the shade-covered greenhouse.

4.5.1 Effect of mist system on temperature in a shade covered greenhouse at different percentages of ventilation

The variation of temperature inside and outside the greenhouse covered with a 75% shade net while operating the fan and mist system are given in table 19. Degree of cooling values for all the cases of ventilation were calculated by taking the difference of outside temperature at the starting of mist system and inside temperature just after stopping the mist system. This is done by the assumption that within 5 minutes, no temperature variation occurs at the outside. At 2.3% ventilation, mean value of the degree of cooling for all the 14 cases was 6.786 and one sample t-test for

Table 19. Variation of temperature (^0C) inside and outside the greenhouse at different percentages of ventilation (shaded condition, with fan and mist system).

Time	Percentages of ventilation											
	2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
10.00a	33	33	33	32	33	33	33	33	33	33	34	34
10.05a	29		29		29		29		30		30	
10.30a	34	36	34	34	34	36	33	33	34	37	34	34
10.35a	29		29		29		29		31		30	
11.00a	33	34	35	36	35	36	34	36	35	36	34	35
11.05a	29		29		29		31		31		31	
11.30a	33	36	37	38	34	36	32	33	35	37	35	35
11.35a	29		30		29		29		31		31	
12.00no	34	35	37	36	36	38	38	38	34	35	35	36
12.05p	29		30		30		31		31		31	
12.30p	34	37	35	35	34	34	36	37	35	37	37	38
12.35p	29		30		30		31		31		32	
1.00pm	35	38	35	38	35	35	37	39	37	38	36	38
1.05pm	29		30		30		31		31		32	
1.30pm	35	38	37	35	35	35	36	36	35	36	36	39
1.35pm	29		30		30		31		31		32	
2.00pm	34	37	37	37	34	34	36	38	37	39	37	39
2.05pm	29		30		30		31		32		32	
2.30pm	35	37	36	38	35	35	35	36	38	39	37	40
2.35pm	29		30		30		31		32		32	
3.00pm	34	34	36	37	36	35	36	38	38	38	37	40
3.05pm	29		30		30		31		32		32	
3.30pm	33	36	35	37	36	37	37	38	37	37	37	39
3.35pm	29		30		30		31		31		32	
4.00pm	35	36	35	34	35	36	36	38	36	38	36	39
4.05pm	29		29		30		31		31		32	
4.30pm	33	34	33	34	35	35	36	36	36	36	35	35
4.35pm	29		29		29		31		31		31	
5.00pm	31	33	32	33	30	28	35	35	35	35	35	35

it showed that a mean value of 7 can be accepted. 95% confidence interval for the mean was 5.875 to 7.697. The mist system reduced the greenhouse temperature to 29°C. Paired sample t-test for the degree of cooling obtained during different percentages of ventilation showed that there is significant difference between the mean values of 2.3% and 11.5 or 13.8% of ventilation.

Mean value of degree of cooling at 4.6% ventilation was 6.143 and one sample t-test for it showed that a mean value of 7 can be accepted. 95% confidence interval for the mean was 5.270 to 7.016. Mist system reduced the greenhouse temperature to 29°C or 30°C depending upon the outside climate. Paired sample t-test for the degree of cooling values showed that there is no significant difference between 4.6% and other percentages of ventilation.

At 6.9% ventilation, mean value of degree of cooling was 5.714 and one sample t-test for it showed that a mean value of 6 can be accepted. 95% confidence interval for the mean was 4.949 to 6.480. The mist system reduced the temperature to 29°C or 30°C depending upon the outside climate. Paired sample t-test for the degree of cooling values showed that there is no significant difference between 6.9% and other percentages of ventilation.

At 9.2% ventilation, mean value of degree of cooling was 5.786 and one sample t-test for it showed that a mean value of 6 can be accepted. 95% confidence interval for the mean was 4.995 to 6.576. Mist system reduced the greenhouse temperature to 29°C or 31°C depending upon the outside climate. Paired sample t-test showed that there is no significant difference between 9.2% and other percentages of ventilation.

At 11.5% ventilation, mean value of degree of cooling was 5.714 and one sample t-test for it showed that a mean value of 6 can be accepted. 95% confidence interval for the mean was 5.019 to 6.410. The mist system reduced the greenhouse temperature to 30, 31 or 32°C depending upon the outside climate. Paired sample t-test showed that there is significant difference between 11.5% and 2.3% ventilation.

Mean value of degree of cooling at 13.8% ventilation was 5.786 and one sample t-test for it showed that a mean value of 6 can be accepted. 95% confidence interval for the mean was 4.875 to 6.697. The mist system reduced the greenhouse temperature to 30, 31 or 32°C depending upon the outside climate. Paired sample t-test showed that there is significant difference between 13.8% and 2.3% ventilation.

4.5.2 Effect of mist system on relative humidity in a shade covered greenhouse at different percentages of ventilation

The variation of relative humidity inside and outside the greenhouse covered with a 75% shade net while operating the fan and mist system are given in table 20. Inside relative humidity increased to 80% or more while operating the mist system. Twenty five minutes after stopping the mist system relative humidity inside the greenhouse was decreased by 10 to 20%. Percentage ventilation has no much effect on the relative humidity while operating the mist system.

4.5.3 Effect of mist system on light intensity in a shade covered greenhouse at different percentages of ventilation

The variation of light intensity inside and outside the greenhouse covered with a 75% shade net while operating the fan and mist system are given in table 21. Intermittent increase and decrease of the light intensity occurred due to effect of clouds. As outside light intensity decreased, corresponding decrease in inside light intensity was observed. Inside intensity of light was about 20 to 25 % of that outside.

4.5.4 Optimum ventilation for shade covered greenhouse while using mist system

The degree of cooling obtained while operating the mist system along with fans, at different percentages of ventilation in a greenhouse covered with a 75% shade net is given in table 22 and the results of the statistical analyses of these values are given in table 23. From tables 19 and 22 it can be seen that maximum cooling was obtained at 2.3% of ventilation, while using the mist system. The upper and lower limits of the confidence interval were higher at this percentage of ventilation. At 2.3%

Table 20. Variation of relative humidity (%) inside and outside the greenhouse at different percentages of ventilation (shaded condition, with fan and mist system).

Time	Percentages of ventilation											
	2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
10.00a	62	51	60	52	63	50	62	53	61	58	58	54
10.05a	82		80		80		80		80		76	
10.30a	65	42	68	44	65	43	68	51	65	44	65	54
10.35a	86		80		83		80		80		82	
11.00a	72	43	65	36	65	38	70	40	68	43	64	52
11.05a	90		86		78		80		83		83	
11.30a	72	42	60	35	76	50	76	54	70	46	65	51
11.35a	89		80		85		86		80		80	
12.00no	65	42	60	38	65	40	48	41	65	54	65	51
12.05p	85		80		78		78		85		80	
12.30p	66	41	73	45	75	56	65	38	70	57	65	41
12.35p	88		88		88		80		83		80	
1.00pm	60	38	65	32	70	53	60	34	65	42	60	45
1.05pm	90		90		80		82		78		80	
1.30pm	61	35	53	36	65	44	70	42	65	50	68	41
1.35pm	90		75		80		82		78		80	
2.00pm	78	41	68	36	75	54	70	43	62	39	63	38
2.05pm	92		80		85		80		73		80	
2.30pm	65	45	70	42	70	48	70	54	60	36	60	38
2.35pm	85		85		80		83		80		80	
3.00pm	70	45	75	41	70	48	70	41	62	34	58	38
3.05pm	85		85		80		83		80		80	
3.30pm	66	40	73	42	70	42	65	40	63	49	60	42
3.35pm	80		85		80		80		82		85	
4.00pm	64	38	71	43	70	45	68	42	65	42	65	45
4.05pm	85		83		85		83		80		85	
4.30pm	75	46	73	55	80	50	73	50	69	50	65	56
4.35pm	84		85		90		80		82		85	
5.00pm	85	58	76	60	80	68	75	58	72	58	73	62

Table 21. Variations of light intensity (lux) inside and outside the greenhouse at different percentages of ventilation (shaded condition, with fan and mist system).

Time	Percentages of ventilation											
	2.3		4.6		6.9		9.2		11.5		13.8	
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	11200	45900	12100	46100	9300	42500	6200	44700	11600	49800	8200	48800
10.30am	12600	53800	12300	52900	12500	51300	3200	13800	12400	52100	12600	51700
11.00am	4100	12600	13100	53900	12900	56300	15400	53100	2060	7120	12700	53200
11.30am	12500	54200	14700	62300	12600	54800	1810	7730	12400	53600	15100	55900
12.00noon	7600	32500	15600	58300	13100	58500	14700	59500	2210	13400	12800	52100
1.00pm	14500	54600	14900	62100	3120	9830	14000	54700	13100	51700	10900	51200
1.30pm	14300	54200	4600	11200	3310	14500	3050	13910	4500	21500	9800	52700
2.00pm	4900	23500	11300	50200	1780	6830	10100	53100	13700	55100	14700	54800
2.30pm	5600	24200	10400	45600	3520	15670	10500	44500	11200	53100	12600	53200
3.00pm	3100	13900	9500	42900	3560	15800	9200	42800	9800	49200	10800	51200
3.30pm	5500	22600	5700	31400	5200	35700	7100	33400	9700	48500	7900	45600
4.00pm	8500	37500	4500	22100	4600	28300	5900	29700	5800	31600	6300	39300
4.30pm	2450	19800	2800	15700	3420	29500	3700	21300	4400	27100	2680	19600
5.00pm	1750	8760	1790	7510	457	1850	2500	18200	3600	19700	3400	18500

Table 22. Degree of cooling values while operating the mist system along with fans at different percentages of ventilation (shaded condition).

Time	Percentage ventilation					
	2.3	4.6	6.9	9.2	11.5	13.8
10.00am	4	3	4	4	3	4
10.30am	7	5	7	4	6	4
11.00am	5	7	7	5	5	4
11.30am	7	8	7	4	6	4
12.00noon	6	6	8	7	4	5
12.30pm	8	5	4	6	6	6
1.00pm	9	8	5	8	7	6
1.30pm	9	5	5	5	5	7
2.00pm	8	7	4	7	7	7
2.30pm	8	8	5	5	7	8
3.00p,	5	7	5	7	6	8
3.30pm	7	7	7	7	6	7
4.00pm	7	5	6	7	7	7
4.30pm	5	5	6	5	5	4

Table 23. Results of statistical analyses of the degree of cooling obtained while operating the mist system along with fans at different percentages of ventilation (shaded condition).

Parameters	Percentage ventilation					
	2.3	4.6	6.9	9.2	11.5	13.8
No. of cases	14	14	14	14	14	14
Minimum	4	3	4	4	3	4
Maximum	9	8	8	8	7	8
Sum	95	86	80	81	80	81
Mean	6.786	6.143	5.714	5.786	5.714	5.786
Std. Deviation	1.520	1.457	1.278	1.319	1.161	1.520
95% CI upper	7.697	7.016	6.480	6.576	6.410	6.697
95% CI lower	5.875	5.270	4.947	4.995	5.019	4.875

of ventilation, mist system reduces the greenhouse temperature to 29°C. A crop for which the optimum temperature is 29°C, 2.3% ventilation is optimum for a shade covered greenhouse. At 4.6 or 6.9% ventilation, mist system reduces the greenhouse temperature to 30°C, 9.2% ventilation reduces the greenhouse temperature to 31°C and 11.5 or 13.8 % ventilation reduces temperature to 32°C. Crops, for which optimum temperatures are 30, 31 and 32°C, 4.6 or 6.9, 9.2 and 11.5 or 13.8 percentage of ventilation respectively are optimum.

Under this condition, as the percentage ventilation increases, the degree of cooling decreases. This is due to the greater hot air entry into the greenhouse. For no ventilation condition, the relative humidity increases upto 100% and hence it is better to provide some percentage of ventilation. So 2.3% ventilation is optimum for a shade covered greenhouse provided with mist system.

4.6 Effect of Fan and Pad System in a Greenhouse without Ventilation and Covered with a Shade Net

Figure 17 shows the variation of climatic parameters inside and outside the greenhouse without ventilation and covered with a shade net, while operating fan and pad system for cooling. This variation is also given in Appendix XI. Fan and pad system was operated intermittently for 30 minutes. The experiment was started at 10.00 am and continued upto 5.00 pm. While operating the fan and pad system, the greenhouse temperature could be reduced equal to or one degree lesser than the outside temperature. During the operation of fan and pad system, temperature and humidity decreases. Relative humidity inside the greenhouse was reduced by 10% with the fan and pad system. Intensity of light inside the greenhouse was 20 to 25% of the outside radiation. Mean of the inside to outside temperature difference was 0.333 and the 95% confidence interval was –0.207 to 0.874. One sample t-test showed that, a mean value of zero for inside to outside temperature difference can be accepted. This condition gives better cooling compared to that with fan and pad system operated in a greenhouse without shade cover, for which the 95% confidence interval was 4.765 to 7.768.

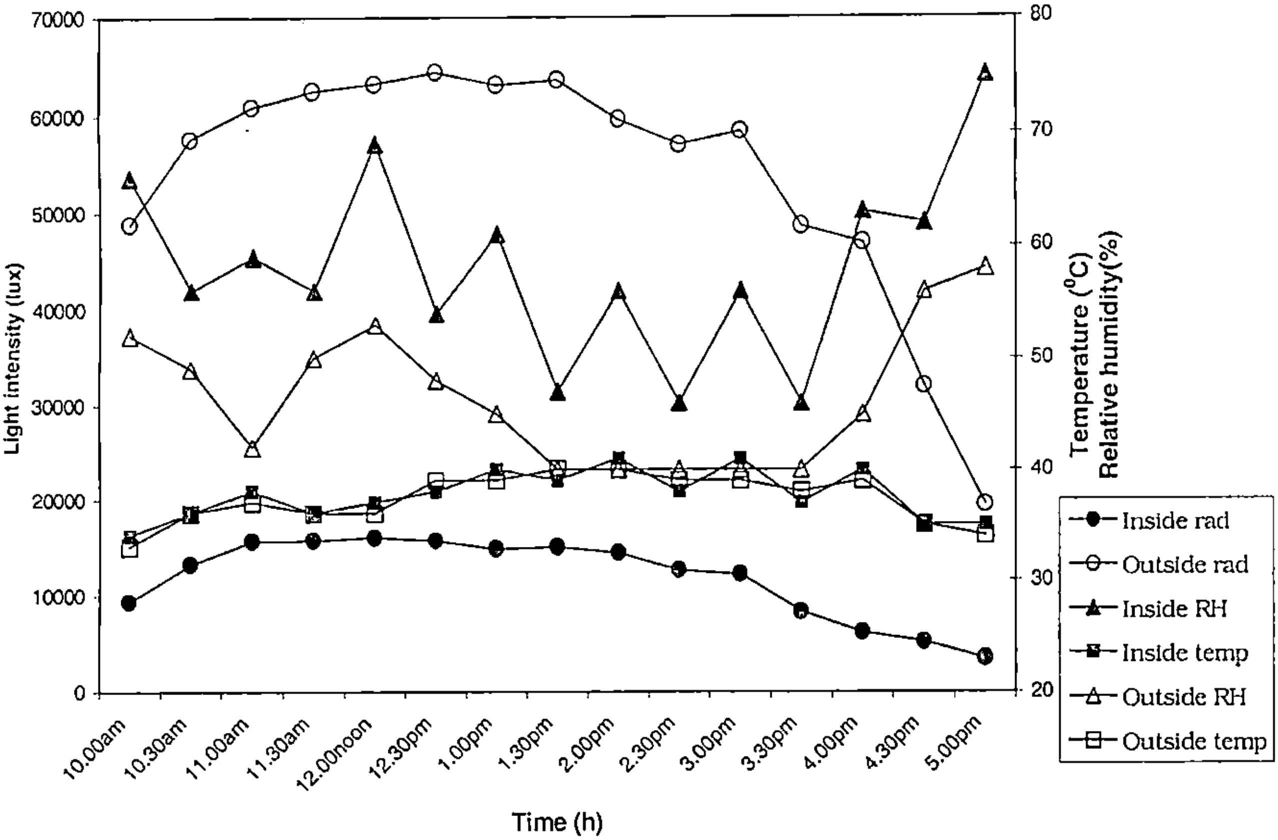

Fig. 17 Variation of parameters inside and outside the greenhouse without ventilation (shaded condition, with fan and pad system and without mist system).

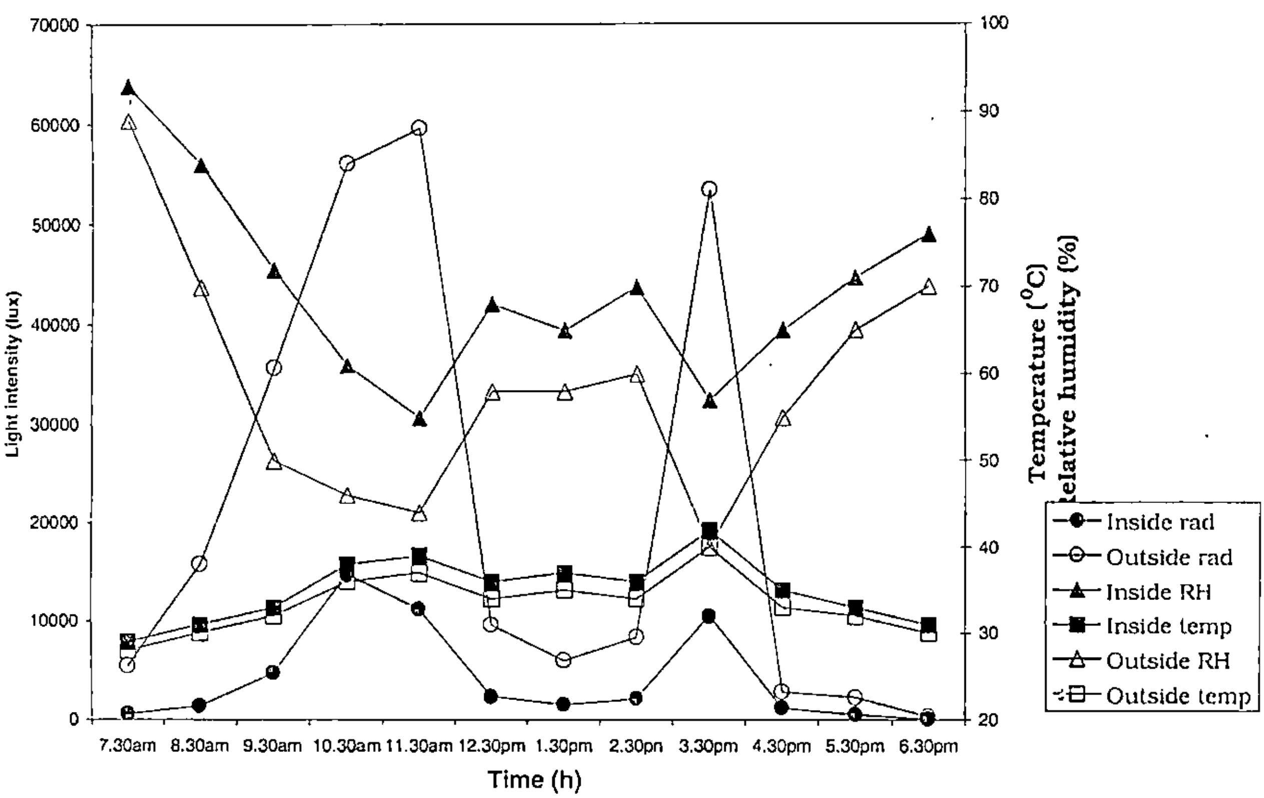

Fig. 18 Variation of parameters inside and outside the greenhouse without ventilation (shaded condition, without fan and pad and mist systems).

4.7 Effect of Shade Cover on Greenhouse Cooling

Figure 18 shows the variation of climatic parameters inside and outside the greenhouse without ventilation and covered with a 75% shade net. The values are given in Appendix XII. The maximum temperature inside the greenhouse was 42°C and that outside was 40°C. When the outside temperature was 33°C or more, inside temperature was 2 degree higher than the outside temperature and for other values, it was one degree higher than the outside temperature. Mean value of inside to outside temperature difference during daytime from 7.30 am to 6.30 pm was 1.583 and the 95% confidence interval for the mean was 1.256 to 1.911. It is much lesser compared to that for unshaded greenhouse, for which the interval was 6.6 to 12.5. This shows that shade cover gives better cooling inside the greenhouse.

Figures 19, 20 and 21 respectively show the variations of temperature, relative humidity and light intensity for a greenhouse with and without shade cover. Fig. 19 clearly explains that, temperature can be considerably reduced by providing shade net over a greenhouse. Fig. 20 shows that inside relative humidity for a shaded greenhouse was higher than that for the unshaded one. But the outside humidity was also higher for this particular case. Fig. 21 shows that the light intensity of solar radiation inside a shaded greenhouse was very much lesser, as compared to that for the unshaded greenhouse. For a shaded greenhouse, during peak hours the inside light intensity was about 20 to 25% of the outside light intensity, while for an unshaded greenhouse, it was about 70 to 90%.

Figures 22, 23 and 24 show the variations of temperature, relative humidity and light intensity respectively within a shaded and unshaded greenhouse. These figures show that there is better cooling within a greenhouse covered with shade cover. Mean value of inside to outside temperature difference was 0.333 and 6.267 respectively for a shaded and unshaded greenhouse, and the 95% confidence interval was -0.207 to 0.874 and 4.765 to 7.768 respectively. This also explains that better cooling is achieved within a shaded greenhouse.

It is evident from tables 14, 17, 19 and 22 that, mist system operated at any percentage of ventilation within a shaded greenhouse gives more cooling than the

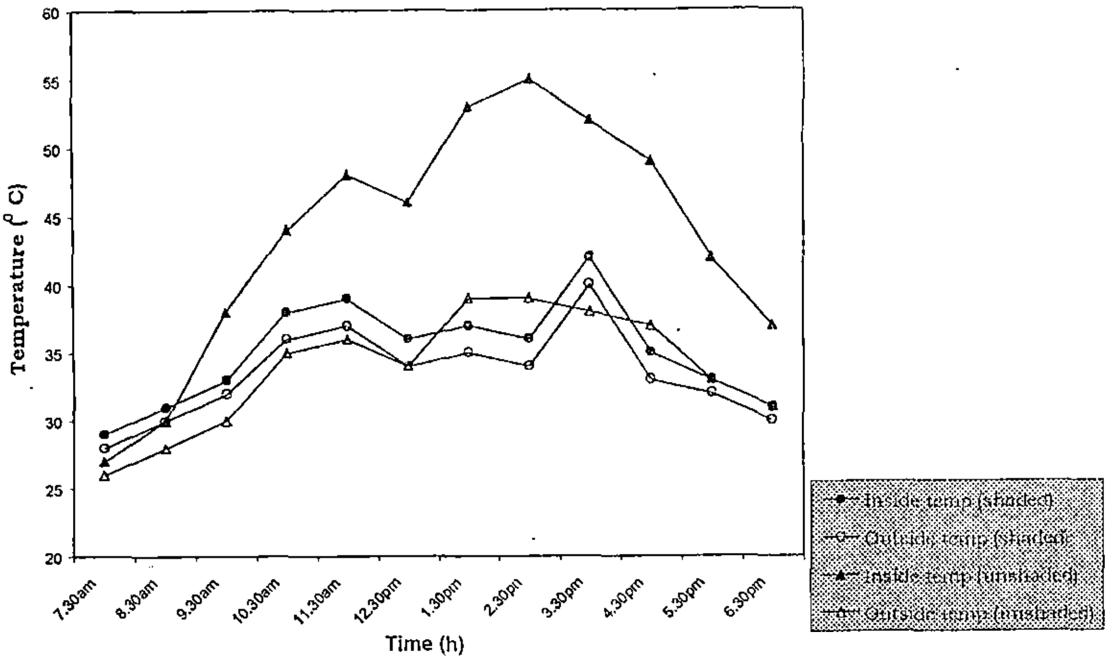

Fig. 19 Variation of temperature inside and outside the greenhouse with and without shade cover during day time (without ventilation, without fan and pad and mist systems).

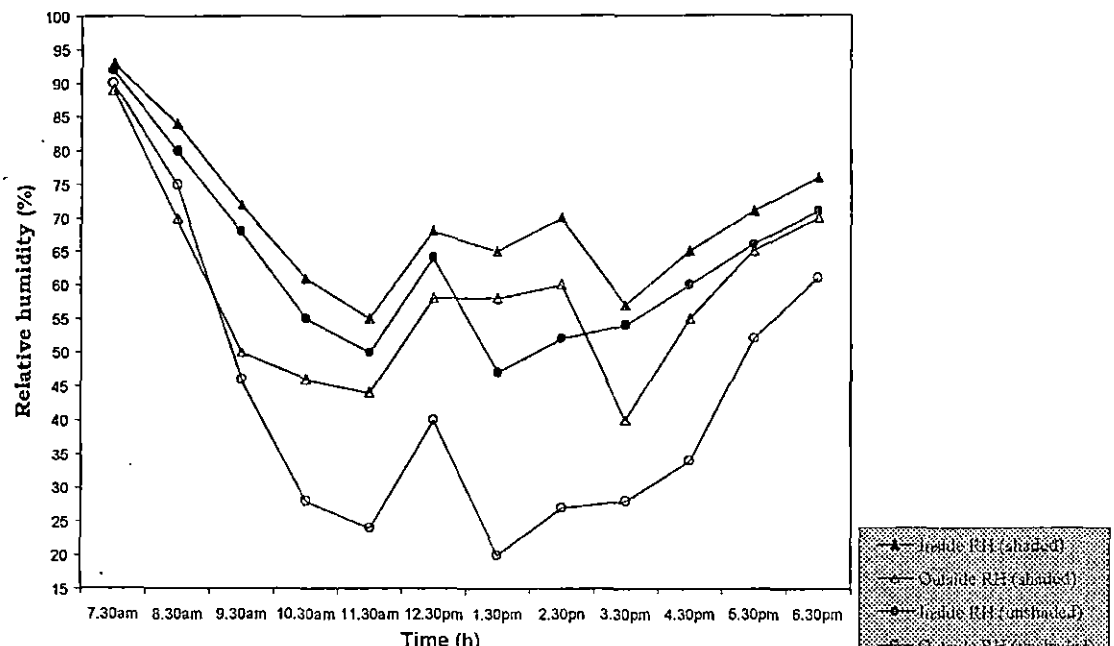

Fig. 20 Variation of relative humidity inside and outside the greenhouse with and wthout shade cover (without ventilation, without fan and pad and mist systems).

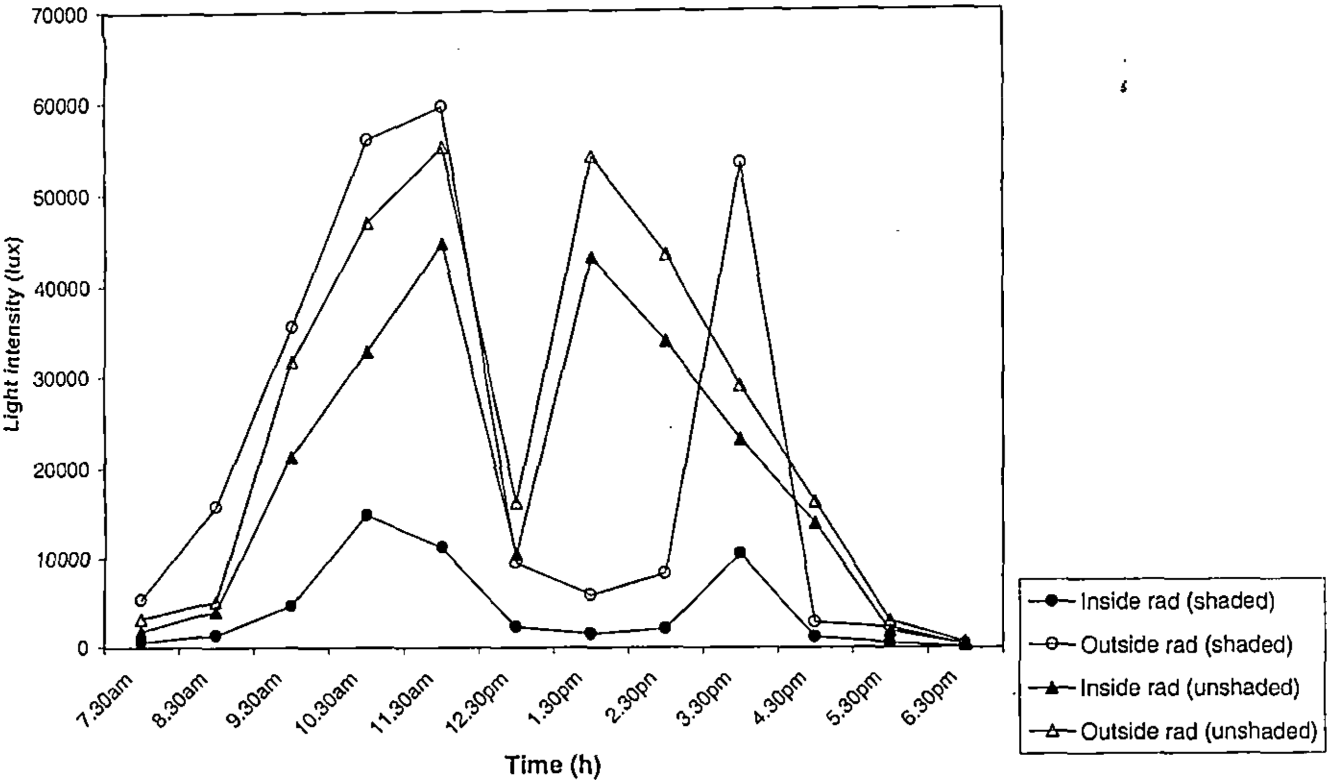

Fig. 21 Variation of light intensity inside and outside the greenhouse with and without shade cover (without ventilation, without fan and pad and mist systems).

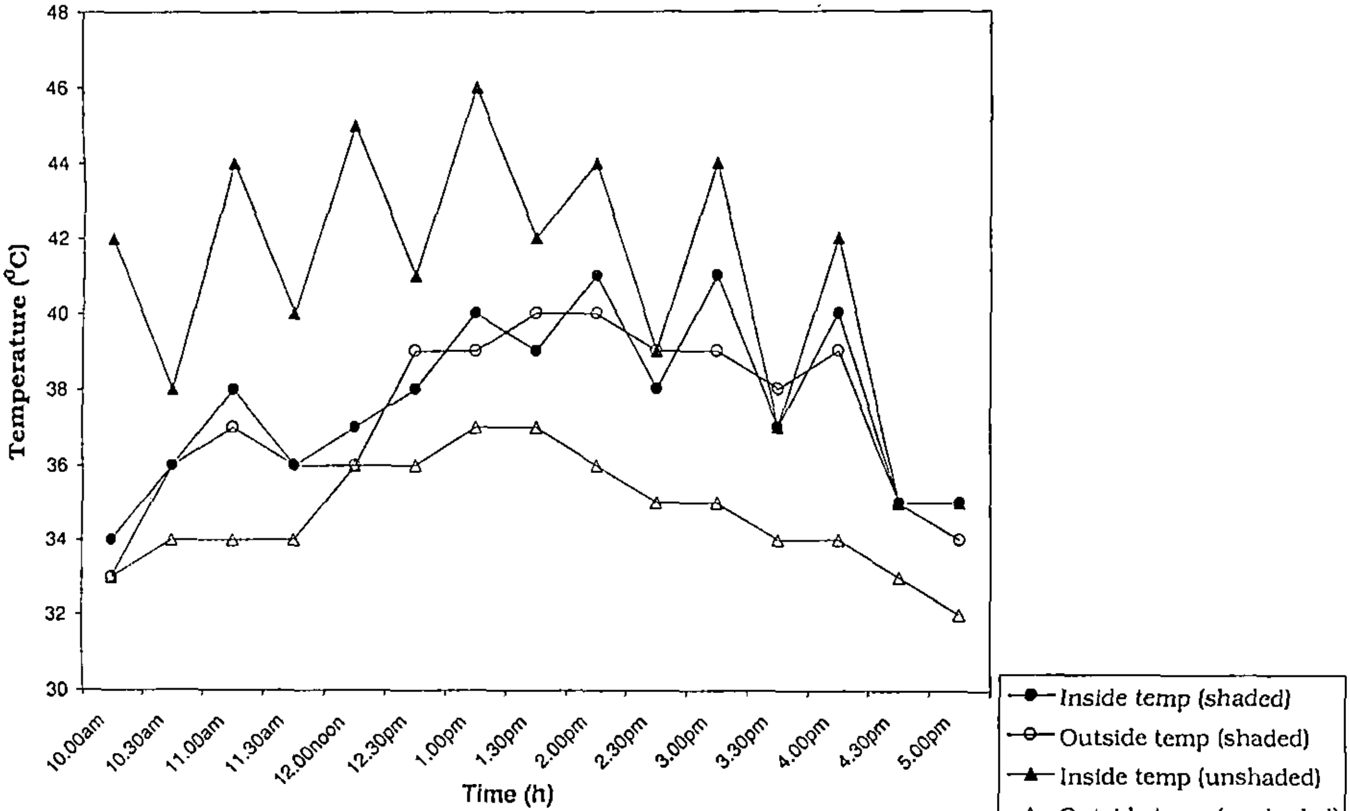

Fig. 22 Variation of temperature inside and outside the greenhouse without ventilation while operating fan and pad system with and without shade cover.

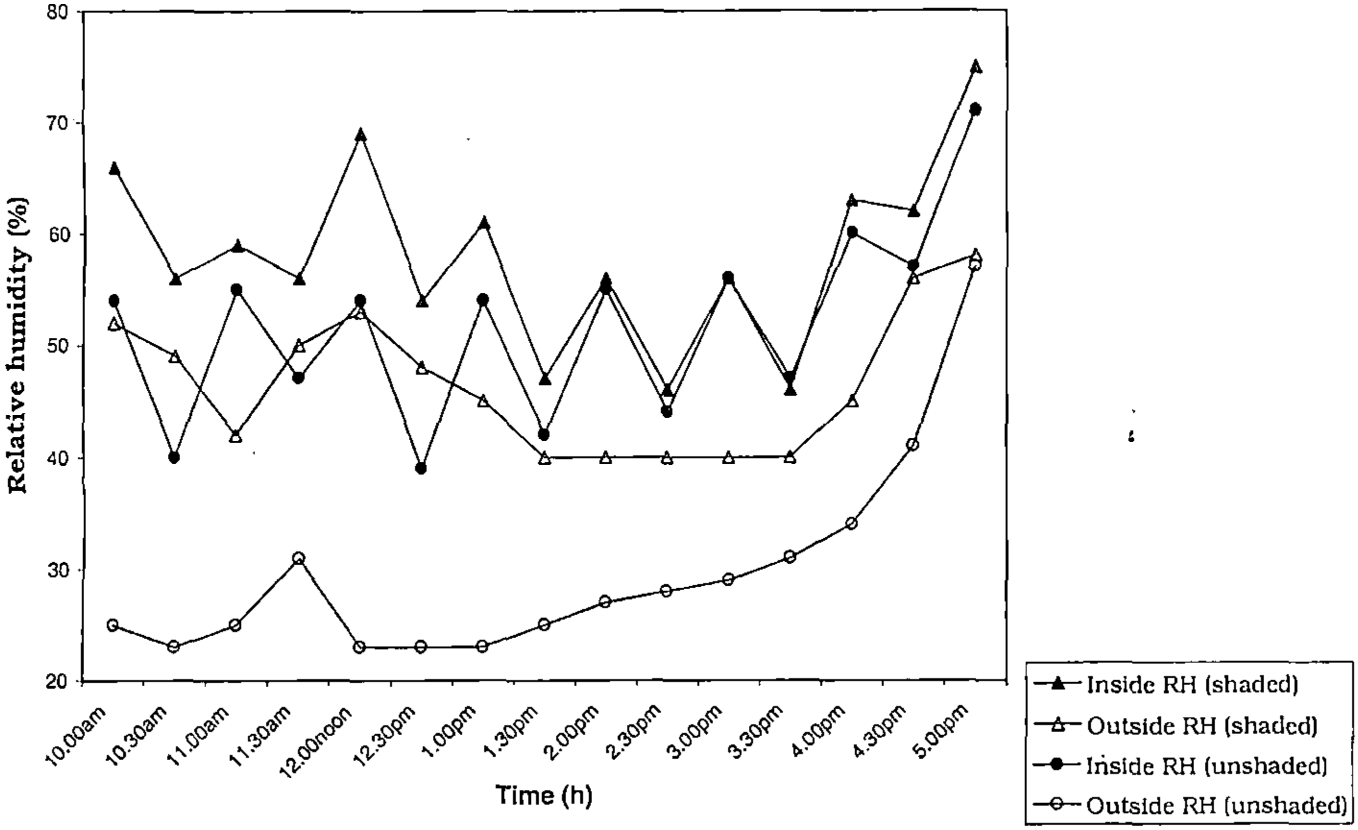

Fig. 23 Variation of relative humidity inside and outside the greenhouse without ventilation while operating fan and pad system with and without shade cover.

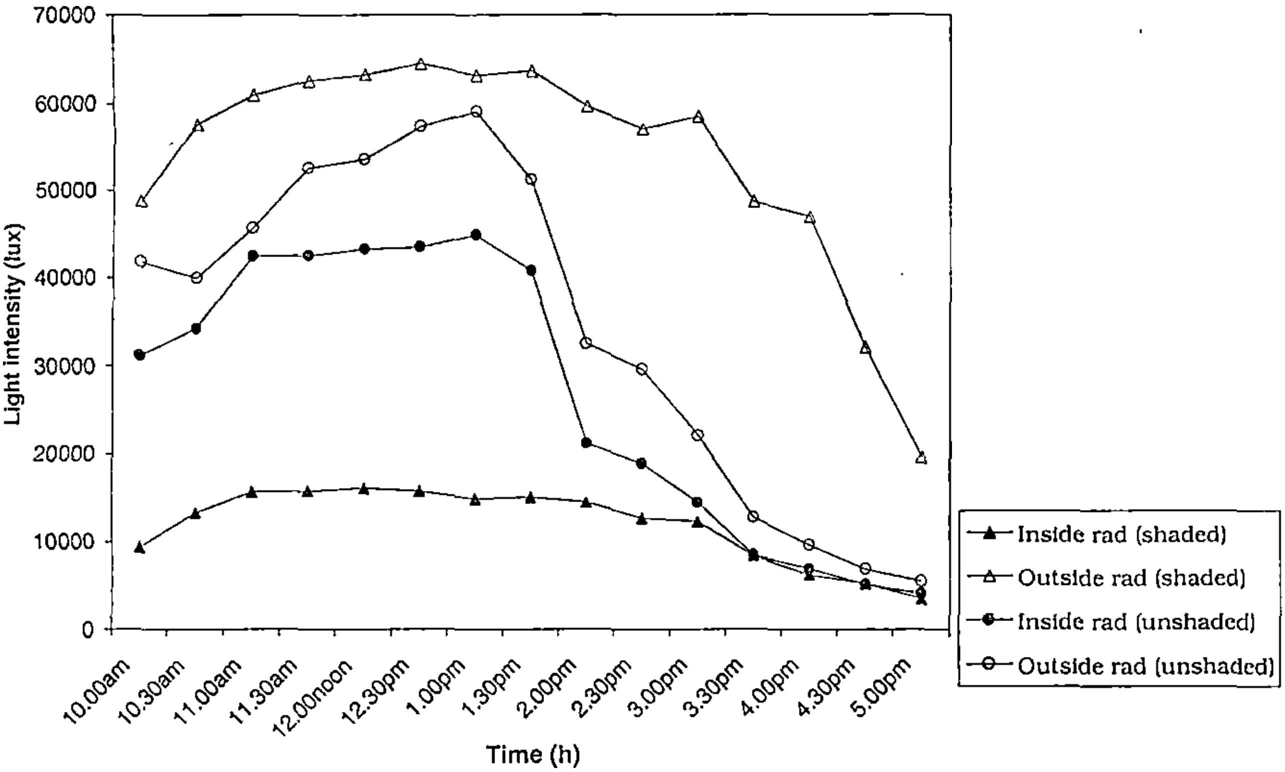

Fig. 24 Variation of light intensity inside and outside the greenhouse without ventilation while operating fan and pad system with and without shade cover.

Table 24. 95% confidence intervals for the mean values of the degree of cooling obtained while operating the mist system under shaded and unshaded conditions.

Ventilation (%)	Shaded condition	Unshaded condition
2.3	5.875 to 7.697	2.976 to 5.595
4.6	5.270 to 7.016	2.296 to 4.847
6.9	4.947 to 6.480	2.359 to 3.641
9.2	4.995 to 6.576	2.067 to 3.790
11.5	5.019 to 6.410	2.222 to 3.492
13.8	4.875 to 6.697	2.310 to 3.547

Table 25. Statistically accepted mean values of the degree of cooling at 5% level of significance for different percentages of ventilation while operating the mist system under shaded and unshaded conditions.

Ventilation (%)	Shaded condition	Unshaded condition
2.3	7	5
4.6	7	4
6.9	6	3
9.2	6	3
11.5	6	3
13.8	6	3

unshaded greenhouse. Table 24 shows the 95% confidence intervals for the mean values of the degree of cooling at different percentages of ventilation under shaded and unshaded conditions. Table 25 shows the statistically accepted mean values of the degree of cooling at 5% level of significance at different percentages of ventilation while operating the mist system under shaded and unshaded conditions. These tables show that, at all percentages of ventilation, the confidence interval is higher under shaded condition. This has resulted in better cooling within shaded greenhouses. By providing 2.3% of ventilation for a shaded greenhouse, we can reduce the greenhouse temperature to 29°C.

4.7.1 Effect of two shade net layers on greenhouse cooling

Table 26 shows the variation of climatic parameters inside and outside the greenhouse provided with two shade net layers while operating mist system at 13.8% ventilation. The system reduced greenhouse temperature to 31°C. Relative humidity was increased to 80% or more while operating the mist system. Inside light intensity was 5 to 10% of the outside light intensity. Mean value of the degree of cooling was 6, and the one sample t-test showed that mean value of 6 can be accepted. 95% confidence interval for the mean was 5.013 to 6.989. 95% confidence interval for unshaded and single shaded conditions were 2.310 to 3.547 and 4.875 to 6.697 respectively. Confidence interval under two shade net layers condition is higher than that of unshaded condition, but almost equal to that of single shaded condition. Paired sample t-test among these three conditions showed that there is significant difference between unshaded and double shaded, and unshaded and single shaded conditions. But there is no significant difference between double shaded and single shaded condition. So the use of two shade net layers will not give any additional benefit and it is merely a wastage of money. Moreover, under two shade net layers, light intensity inside the greenhouse was only 5 to 10% of the outside light intensity. So, the use of two shade net layers is not advisable.

Table 26. Different climatic parameters inside as well as outside the greenhouse at 13.8% ventilation (*two shade net layers, with fan and mist system*).

Time	Relative humidity(%)		Temeprature (^0C)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	62	60	34	33	4120	48600
10.05am	80		30			
10.30am	58	56	36	36	5200	57600
10.35am	80		31			
11.00am	53	52	36	36	6200	62500
11.05am	80		31			
11.30am	66	52	36	36	5900	62300
11.35am	80		31			
12.00noon	70	56	36	35	685	10700
12.05pm	88		31			
12.30pm	62	42	37	38	5700	61500
12.35pm	80		31			
1.00pm	58	42	37	39	4600	54600
1.05pm	80		31			
130pm	58	42	37	39	4600	51200
1.35pm	80		31			
2.00pm	65	42	37	39	4700	51800
2.05pm	80		31			
2.30pm	65	42	35	39	3800	49900
2.35pm	83		31			
3.00pm	70	42	35	37	3200	41200
3.05pm	80		31			
3.30pm	65	44	37	38	1710	36100
3.35pm	83		31			
4.00pm	70	45	35	37	4200	41300
4.05pm	80		31			
4.30pm	70	58	34	35	765	23400
4.35pm	84		31			
5.00pm	76	63	34	34	515	18300

4.8 Variation of Soil Temperature inside the Greenhouse

Soil temperatures at 5cm, 10cm and 20cm depth from the surface were taken from 9 am to 5 pm and are shown in tables 27, 28 and 29 respectively. These tables show that, in the morning the temperature was minimum at 5cm depth and maximum at 20 cm depth. As the ambient temperature increased, soil temperature increased first at 5 cm, then at 10 cm and finally at 20 cm depth. Temperature variation was more for 5 cm depth and least for 20 cm depth. Data showed that ventilation had no effect on variation of soil temperature inside the greenhouse. This may be due to the fact that soil was relatively moist with mist system and such variation in soil temperature may not be expected. However the values of soil temperature at different depths inside the greenhouse was less than that recorded outside.

4.9 Overall view of the study

The study was conducted during the summer season. Due to some technical reasons it was not possible to extend the study to all seasons. The peak cooling requirement is at summer and hence the study was conducted during that season. The study revealed that variation of temperature and relative humidity inside the greenhouse is dependent on the intensity of light. Temperature variation at different layers inside the greenhouse under different percentages of ventilation showed that there was no much variation between temperatures at different layers inside the greenhouse and the temperature at the middle of the greenhouse was almost equal to the average temperature inside the greenhouse. During night hours, temperature and relative humidity inside the greenhouse were nearly the same for all the cases of ventilation.

The overall view of the experiments conducted during the study is shown in Fig. 25. This figure is drawn with the mean value of the degree of cooling calculated as outside temperature minus inside temperature from 10.00 am to 5.00 pm against different treatments. It is evident the figure that with natural ventilation alone, greenhouse temperature cannot be lowered below atmospheric. For the present study only side ventilators are used. More cooling may be obtained if roof ventilators are provided in addition to the side ventilators. Greenhouse designs should include roof

Table 27. Variation of soil temperature (^{0}C) at 5 cm depth inside the greenhouse at different percentages of ventilation (shaded condition, with fan and mist system).

Time	Percentage ventilation						
	0	2.3	4.6	6.9	9.2	11.5	13.8
9.00am	28.5	29.5	28.5	28.5	28	28.5	28.5
10.00am	29	30.5	29	29	28.5	29	29
11.00am	29.5	30.5	29	29.5	29	29	29.5
12.00noon	30	30.5	30	30	30	29.5	30
1.00pm	30.5	30.5	30.5	30.5	30.5	30	30.5
2.00pm	31	31	31	30.5	31	30.5	31
3.00pm	31.5	31	31.5	30.5	31.5	31	31.5
4.00pm	31.5	31	31.5	31	31.5	31.5	31.5
5.00pm	31	31	31.5	31	31	31.5	31

Table 28. Variation of soil temperature (^{0}C) at 10 cm depth inside the greenhouse at different percentages of ventilation (shaded condition, with fan and mist system).

Time	Percentage ventilation						
	0	2.3	4.6	6.9	9.2	11.5	13.8
9.00am	29	30.5	29	29	28.5	29	29
10.00am	29	31	29.5	29.5	29	29	29.5
11.00am	29.5	31	29.5	30	29.5	29.5	29.5
12.00noon	30	31	30	30.5	30	29.5	30
1.00pm	30.5	31	30.5	30.5	30.5	30	30.5
2.00pm	31	31	31	30.5	31	30.5	30.5
3.00pm	31.5	31.5	31.5	30.5	31.5	31	31
4.00pm	31.5	31.5	31.5	31	31.5	31.5	31
5.00pm	31.5	31.5	31.5	31	31.5	31.5	31.5

Table 29. Variation of soil temperature (^{0}C) at 20 cm depth inside the greenhouse at different percentages of ventilation (shaded condition, with fan and mist system).

Time	Percentage ventilation						
	0	2.3	4.6	6.9	9.2	11.5	13.8
9.00am	29.5	31.5	30	30	29	29.5	29.5
10.00am	29.5	31.5	30	30	29	29.5	29.5
11.00am	29.5	31.5	30	30	29	29.5	29.5
12.00noon	30	31.5	30.5	30	30	29.5	30
1.00pm	30	31.5	30.5	30.5	30	30	30
2.00pm	30.5	31.5	31	30.5	30.5	30	30
3.00pm	30.5	31.5	31	30.5	30.5	30	30.5
4.00pm	30.5	32	31.5	30.5	31	30.5	31
5.00pm	31	32	31.5	31	31.5	30.5	31

** At 0% ventilation, fan and pad and mist systems were not used

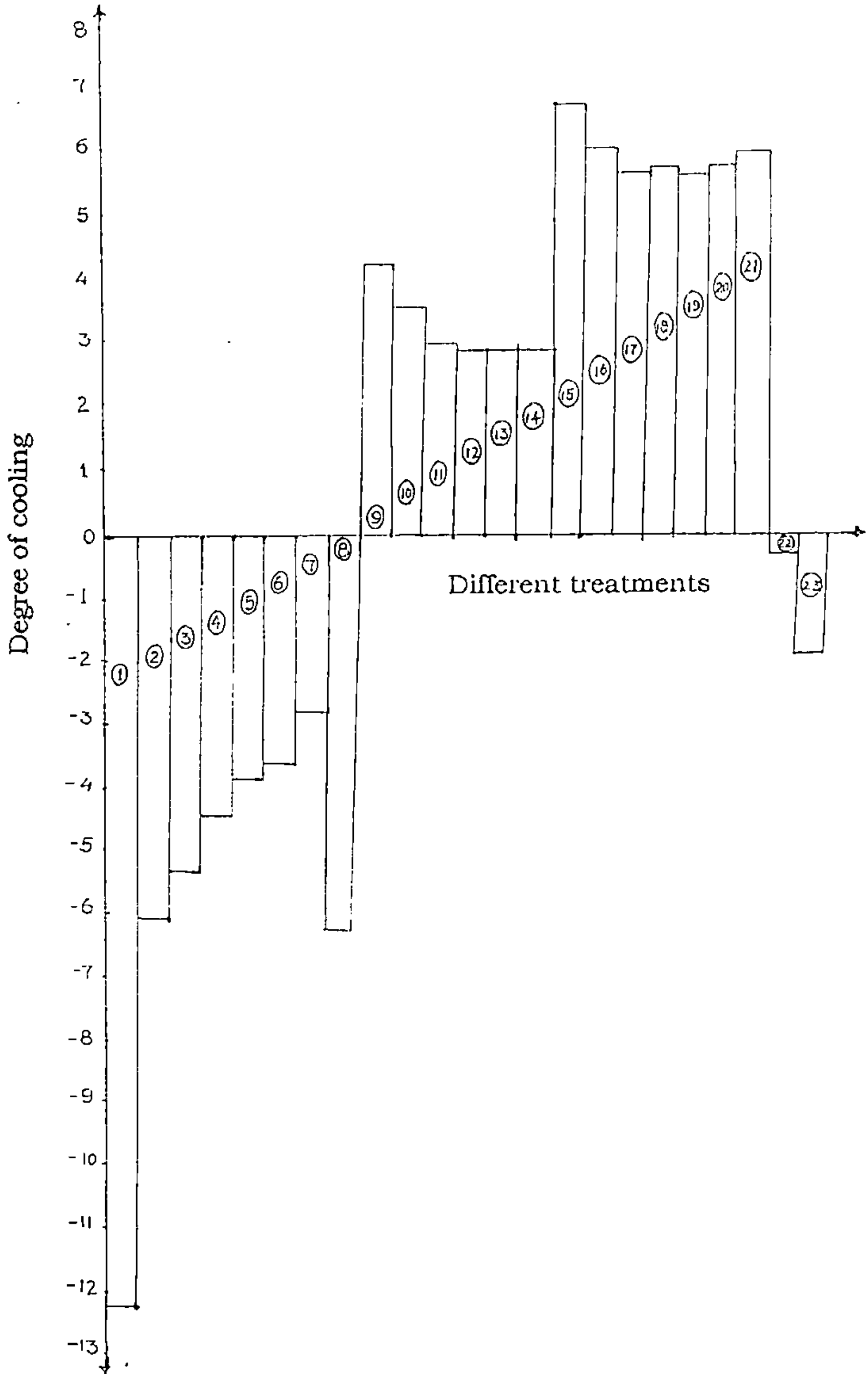

Fig. 25 Overall view of the study.

Legend for Fig. 25

(1) Unshaded condition, no ventilation, without fan and pad and mist systems (static condition]
(2) Unshaded condition, 2.3% ventilation, without fan and pad and mist systems
(3) Unshaded condition, 4.6% ventilation, without fan and pad and mist systems
(4) Unshaded condition, 6.9% ventilation, without fan and pad and mist systems
(5) Unshaded condition, 9.2% ventilation, without fan and pad and mist systems
(6) Unshaded condition, 11.5% ventilation, without fan and pad and mist systems
(7) Unshaded condition,, 13.8% ventilation, without fan and pad and mist systems
(8) Unshaded condition, no ventilation, with fan and pad system
(9) Unshaded condition, 2.3% ventilation, with fan and mist system
(10) Unshaded condition, 4.6% ventilation, with fan and mist system
(11) Unshaded condition, 6.9% ventilation, with fan and mist system
(12) Unshaded condition, 9.2% ventilation, with fan and mist system
(13) Unshaded condition, 11.5% ventilation, with fan and mist system
(14) Unshaded condition, 13.8% ventilation, with fan and mist system
(15) Shaded condition, 2.3% ventilation, with fan and mist system
(16) Shaded condition, 4.6% ventilation, with fan and mist system
(17) Shaded condition, 6.9% ventilation, with fan and mist system
(18) Shaded condition, 9.2% ventilation, with fan and mist system
(19) Shaded condition, 11.5% ventilation, with fan and mist system
(20) Shaded condition, 13.8% ventilation, with fan and mist system
(21) Two shade net layers, 13.8% ventilation, with fan and mist system
(22) Shaded condition, no ventilation with fan and pad system
(23) Shaded condition, no ventilation, without fan and pad mist systems

ventilators. For heat tolerant plants, natural ventilation can be used for cooling. The present study was undertaken during the summer season of the year. For kharif and rabi seasons, crops can be cultivated inside the greenhouse with optimum percentage of natural ventilation. Natural ventilation has no operating cost and no additional initial investment. So it is very economical.

Greenhouse cooling increases with increase in percentage of natural ventilation. At 2.3% ventilation, mean value of the degree of cooling inside the greenhouse was 50% more than that at static condition. At 4.6, 6.9, 9.2, 11.5 and 13.8% ventilation, the mean value of the degree of cooling inside the greenhouse were 56, 63, 68, 70 and 81% more than that at static condition.

Fan and pad system could reduce the greenhouse temperature to some extent. However natural ventilation is found to be better than the fan and pad system alone for this particular study. Mean value of the degree of cooling for fan and pad system is 49% greater than that at static condition. But natural ventilation could give better cooling than 30 minutes interval intermittent operation of fan and pad system alone. This may be due to the air entry into the greenhouse through the openings around the ventilators, lesser capacity of the fan or the inefficiency of the pad.

Mist system reduces the greenhouse temperature to a great extent within a short period. Mean value of degree of cooling inside the greenhouse is 135, 129, 124, 124, 124 and 124% greater than that for static condition at 2.3, 4.6, 6.9, 9.2, 11.5, and 13.8% ventilation respectively. While using the mist system inside a greenhouse, as the percentage ventilation increases greenhouse cooling decreases and afterwards it comes to equilibrium. This is because of the greater air entry through the ventilators. As large amount of hot air enters the greenhouse, greenhouse cooling decreases. Above 4.6% ventilation, degree of cooling was observed as almost same for this particular study. This shows that higher percentages of ventilation have no effect on greenhouse cooling while using the mist system. But if we use mist system inside the greenhouse at no ventilation condition, greenhouse humidity increases upto 100% and it is not favourable for crops. Hence some percentage of ventilation is essential. This study suggests 2.3% ventilation for greenhouses while operating the mist system inside the greenhouse.

Roof shading is a good method for greenhouse cooling. Misting inside the greenhouse covered with one 75% shade net gave more cooling than that under unshaded condition. While operating the mist system inside a greenhouse at 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8% ventilation, the mean values of degree of cooling inside the greenhouse were 155, 150, 146, 147, 146 and 147% greater than that at static condition. While operating the fan and pad system inside a shaded greenhouse, the mean value of the degree of cooling was 98% greater than that at static condition, while for an unshaded greenhouse, the degree of cooling was only 49% greater than that at static condition. Mean value of the degree of cooling for a shaded greenhouse without fan and pad and mist systems was 85% greater than that for an unshaded greenhouse without fan and pad and mist systems. The above results show that shading has a significant effect on greenhouse cooling. Providing two layers of shade net over the greenhouse will not give any additional cooling than single shaded condition. While mist system is operated inside the greenhouse covered with two shade net layers at 13.8% ventilation mean value of the degree of cooling is 149% greater than that under static condition. The same at single shaded conditions was 147% greater than that of static condition. The degree of cooling was almost the same for both the cases. While providing two layers of shade net, the light intensity inside the greenhouse was reduced to 10 % of that at outside. This is not suitable for the crop growth.

Operating mist system inside a shaded greenhouse at 2.3% ventilation gives greatest cooling than all other treatments. Greenhouse temperature can be reduced to 29°C with this treatment. But the selection of crops should be done carefully, because while using shade net, the light intensity is only 25% of that outside. So shade loving and shade tolerant plants can be very well cultivated in this condition. For crops which require high light intensity, operating mist system inside an unshaded greenhouse at 2.3% ventilation is more beneficial.

The greenhouse used for the study is equipped with only side ventilators and the maximum ventilation that can be provided is only 13.8%. This percentage can be increased by providing roof ventilators in addition to the side ventilators, and thus little more cooling can be achieved. So further study is to be conducted to find out the optimum ventilation while roof and side ventilators are provided together. For the present study, the discharge from each mist unit was 1 lpm. The total discharge from the mist system was 0.6 lps. This is very high and lot of water is wasted because of it. Moreover the foliage gets wetted because of the high discharge. This may cause plant diseases. So the mist discharge is to be reduced. Further study is to be conducted to find out the optimum mist discharge. If all the water coming from the emitter is evaporated, then high value crops can be cultivated inside the greenhouse very economically with this system.

Summary

SUMMARY

Greenhouse technology is being used in India as a solution to many specific situations related to the increase in production and productivity of crops. Some of these situations are cultivation in inclement agro-climatic conditions, off-season cultivation of horticultural and floricultural crops, nursery raising and plant propagation, export-oriented cultivation of horticultural crops and intensive cultivation of medicinal, aromatic and non-conventional plants. The growth and production of crops are dependent on the climatic factors like light, temperature, air composition and humidity. Controlled greenhouse microclimate provides favourable environment for optimum growth and production of crops, regardless of the climate prevailing outside the greenhouse.

Of the various forms of controlled environment agriculture, greenhouse cultivation is the most important one. Heating or cooling inside the greenhouse is to be done depending on the crops to be cultivated and the outside climate. Kerala falls under humid tropical climate and for this climate cooling is to be done during the daytime. The different cooling methods used in this study were natural ventilation, fan and pad system, mist system and roof shading and combinations of various methods.

The least expensive method used in greenhouses to control excessive temperatures is the natural ventilation. In many areas and for many crops, adequate cooling can be obtained with natural ventilation alone. The effect of different percentages of natural ventilation on greenhouse microclimate was studied for humid tropical climate and the optimum percentage of ventilation was determined.

The temperature, relative humidity and light intensity, both inside and outside the greenhouse were recorded at one hour interval for different percentage of ventilation viz. 0, 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8.

Another popular method of greenhouse cooling is evaporative cooling. Two types of evaporative cooling methods were tested. They were the fan and pad system and the mist system. The effects of these two systems were studied with and without shade net. Fan and pad system was operated without ventilation. The system was operated from 10.00 am to 5.00 pm.

Misting is another method of cooling tested inside the greenhouse. Mist system was operated with two exhaust fans. Mist system and fans were operated at 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8% of ventilation on different days from 10.00 am to 5.00 pm. Misting was also done inside the greenhouse provided with shade cover.

The major findings of the study are summarised as follows

1. The least expensive method to cool greenhouses in humid tropics is natural ventilation. Greenhouse cooling increases and relative humidity decreases with increase in percentage of natural ventilation. Inside and outside temperature values at different percentages of ventilation showed that, inside temperature was higher than the outside temperature. This implies that ventilation alone is not sufficient to bring down the greenhouse temperature below atmospheric. 95% confidence intervals for the mean of the inside to outside temperature difference values were found out and the least value was obtained at 13.8% of ventilation. So 13.8% ventilation can be taken as the optimum percentage of natural ventilation.

2. The variation of climatic parameters inside the greenhouse at different percentages of ventilation showed that, these parameters vary widely during daytime. During night hours, climatic parameters inside the greenhouse at different percentages of ventilation were almost equal to that at outside. The peak hours of the daytime, when cooling is essential is from 10.00 am to 5.00 pm. During this period inside temperature was very high. Temperatures at various layers inside the greenhouse were measured for different percentages of ventilation and it showed that there is no much variation in the temperature at various layers inside the greenhouse. The temperature at the middle of the greenhouse was almost equal to the mean of the temperatures measured at different layers inside the greenhouse.

3. It was revealed from the study that the fan and pad system alone is not effective for greenhouse cooling in this particular study. Comparison of the greenhouse cooling obtained using fan and pad system alone with that obtained at different percentages of natural ventilation, showed that even 2.3% of ventilation can give better cooling than fan and pad system. This may be due to the air entry into the greenhouse through the openings around the ventilators, lesser capacity of the fan or the inefficiency of the pad. Inside to outside temperature difference was calculated using the data obtained with fan and pad system at no ventilation. This was compared with that for 0, 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8% of ventilation without using fan and pad and mist systems from 10.00 am to 5.00 pm. 95% confidence interval for the mean of the temperature difference at each ventilation condition was found out. These mean values showed that fan and pad system couldn't give more cooling than 2.3% of natural ventilation alone. Moreover fan and pad system requires a lot of energy for its operation. So fan and pad system alone is not recommended for greenhouse cooling as the efficient performance of the system depends on many factors, which are difficult to control and maintain.

4. Mist system along with fans reduced the temperature inside the greenhouse to a considerable extent. Ventilation along with mist and fans had an adverse effect on cooling. As the percentage ventilation increased while fan and mist system was operating, the greenhouse cooling decreased. The study showed that misting is an effective method to cool the greenhouse within a short period of time. The degree of cooling calculated by subtracting the inside temperature from outside temperature during misting showed that it is maximum at 2.3% of ventilation. During misting, if ventilation is more, then the temperature will try to attain equilibrium with the outside temperature quickly. So 2.3% of ventilation is taken as optimum while misting

5. Shaded condition gives better cooling inside the greenhouse than the unshaded condition. Inside a shaded greenhouse, while using the mist system, the greenhouse temperature could be lowered to 29°C with a relative humidity of around 80%. Moreover for unshaded condition, misting is to be done for 10 minutes during every 30 minutes interval, but for shaded condition, 5 minutes misting during every 30 minutes gave more cooling than the other condition. For the unshaded condition, while misting was done, 2.3% ventilation gave maximum cooling inside the greenhouse and it can be taken as the optimum percentage of ventilation. Effect of roof shade on greenhouse cooling was studied by placing one 75% shade net over the greenhouse. Experiments were done under shaded condition at no ventilation

without fan and pad and mist systems and at 0, 2.3, 4.6, 6.9, 9.2, 11.5 and 13.8% of ventilation with fan and pad and mist systems. The results obtained were compared with the corresponding results for unshaded condition and showed that shade cover had a significant effect on the greenhouse cooling in all the cases. The inside temperature was higher than the outside temperature by more than 10°C during peak hours of the daytime at no ventilation condition without fan and pad and mist systems and shade cover. A shaded greenhouse, with all other conditions remaining the same, showed a difference of only one or two degree between the inside and outside temperature. When fan and pad system operated without shade, greenhouse temperature could not be lowered down to a value less than the ambient temperature. But under shaded condition, greenhouse temperature could be lowered down to a value less than the ambient temperature. Misting inside an unshaded greenhouse at 2.3% of ventilation could lower the greenhouse temperature to 32^0C. But misting inside a shaded greenhouse at 2.3% of ventilation lowered the greenhouse temperature to 29°C.

6. The effect of providing two layers of shade net, one above and other below the greenhouse was also studied. The results showed that it does not give any additional cooling and it causes only additional expense. So it is not recommended to use two layers of shade net in this particular climatic condition.

References

REFERENCES

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

Ajayambika Devi, S.J.(1995). Design, fabrication and testing of a low cost greenhouse. *Unpublished M.Tech thesis*, KCAET, Tavanur.

Albright, L.D.(1997). Ventilation and shading for greenhouse cooling. *Proc. of the international seminar on protected cultivation in India*, Bangalore.

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

Arbel, H., Segal, I., Yekutili, O. and Zamir, N.(1990). Natural ventilation of greenhouses in desert climates. *Acta Hort.* **281**: 167-174.

Attavar, M.(1997). Relevance of greenhouse technology in India. *Proc. of the International seminar on protected cultivation in India,* Banglore.

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

Bailey, B. J.(1995). Greenhouse climate control - new challenges. *Acta Hort.* **399**: 13-23.

Bakker, J. C.(1984). Effects of changes in ventilation on cucumber. *Acta Hort.* **148**: 519-524.

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

Baptista, F.J., Bailey, B.J., Randall, J.M. and Menesses.(1999). Greenhouse ventilation rate: Theory and measurement with tracer gas techniques. *J. Agric Engng. Res.* **72**: 363-374.

Bobby, T., Sinija, V.R. and Suresh, A.(1997). Environmental control in greenhouses for humid tropics. *Unpublished B.Tech Project Report*, KCAET, Tavanur.

Bohra, C.P.(1985). Forms of controlled environment agriculture. *Proc. of the summer institute on greenhouse design and environmental control*, CIAE, Bhopal.

Boulard, T. and Baille, A. (1995). Modelling of air exchange rate in a greenhouse equipped with continuous roof vents. *J. Agric. Engng. Res.* **61**: 37-48.

Boulard, T., Feuilloley,P. and Kittas, C. (1997). Natural ventilation performance of six greenhouse and tunnel types. *J. Agric. Engng. Res.* 67: 249-266.

Boulard, T., Lamrami, M.A., Roy,J.C., Jaffrin, A. and Bouirden, L.(1998). Natural ventilation by thermal effect in a one- half scale model mono-span greenhouse. *Trans. ASAE.* 41(3): 773-781.

Chandra, P.(1985). Applications of greenhouse technology. *Proc. of the summer institute on greenhouse design and environmental control*, CIAE, Bhopal.

Chandra, P.(1985). Greenhouse types and their general layout. *Proc. of the summer institute on greenhouse design and environmental control*, CIAE, Bhopal.

Chandra, P.(1985). Need for environmental control in crop production. *Proc. of the summer institute on greenhouse design and environmental control*, CIAE, Bhopal.

Chandra, P., Singh, J.K. and Majumder, M.(1989). Some results of evaporatively cooling a plastic greenhouse. *J. Agric. Engng. Res.* 26(3): 274-250.

Edward, R.D.(1990). *Probability and statistics for engineering , computing , and physiacl sciences.* Prentice hall, Eaglewood Cliffs, New Jersy. pp: 411- 473.

Feuerman, D., Kopel, R., Zeroni, M., Levi, S. and Gale.(1997). Theory and validation of a liquid radiation greenhouse simulation for performance prediction. *Trans. ASAE.* 40(1): 175-184.

Feuilloley, P., Mekikdjian, C. and Sevila, F.(1990). Static aeration in grenhouses. *Acta Hort.* **281**: 175-182.

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

Govindan, S., Jenet, P.V., Jissy, K.J. and Manoj Kumar, T.S.(1993). Design, fabrication and testing of a low cost greenhouse. *Unpublished B.Tech Project report*, KCAET, Tavanur.

Grange, R.I and Hand, D.W. (1987). A review of the effects of atmospheric humidity on the growth of horticultural crops. *J. Hort. Sci.* **52**: 125-134.

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

Harbaoni, V., Charles Nicolle, A. and Verlodt,H. (1990). Effect De Differents Types, D' Aeration statique Sur Le Bioclimat Des ABRI- Plastiques. *Acta Hort.* **263**: 315-324.

Holder, R. and Cockshull, K.E.(1990). Effects of humidity on the growth and yield of glasshouse tomatoes. *J. Hort. Sci.* **65**: 31-39.

Jolliet, O.(1994). HORTITRANS, a model for predicting and optimizing humidity and transpiration in greenhouses. *J. Agric. Engng. Res.* **57**: 23-37.

Kacira, M., Short, T.H. and Stowell, R.R. (1998). A CFD evaluation of naturally ventilated, multi-span, sawtooth greenhouses. *Trans. ASAE.* **41**(3): 833-836.

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

Kittas, C., Boulard, T., Mermier, M. and Papadakis, G.(1996). Wind induced air exchange rates in a greenhouse tunnel with continuous side openings. *J. Agric. Engng. Res.* **65**: 37-49.

Kozai, T. and Sase, S.(1978). A simulation of natural ventilation for a multi-span greenhouse. *Acta Hort.* **87**: 39-49.

Kozai,T., Sase, S. and Nara, M.(1980). A modelling approach to greenhouse ventilation control. *Acta Hort.* **106**: 125-136.

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

Masterlez, J.W.(1977). *The greenhouse environement.* Wiley and sons Inc., NewYork, Ed. I. pp. 1-30.

Mears, D.R. (1991). Greenhouse environmental control for Indian Conditions: new technologies and applications. *Proc. of the international seminar on new frontiers in horticulture,* Organised by Indo-American Hybrid seeds, Bangalore, India: 265-272.

Mignel, A.F. , Van De Barak, N.J., Silva, A.M. and Bot, G.P.A.(1998). Physical modelling of natural ventilation through screens and windows in greenhouses. *J. Agric. Engng. Res.* **70**: 165-176.

Mihara, Y. and Hayashi, M.(1978). Latent heat of water for cooling and de-humidifying ventilation in greenhouses. *Acta Hort.* **87**: 329-336.

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

Montero, J.I. and Anton, A.(1994). Greenhouse cooling during warm periods. *Acta Hort.* **357**: 49-60.

Nederhoff, E.M., Van De Vooren, J. and Udink ten Cate, A.J.(1984). Method to determine ventilation in greenhouses. *Acta Hort.* **148**: 345-350.

Oca, J.I., Montero, J.I., Anton, A. and Crespo, D.(1999). A method for studying natural ventilation by thermal effects in a tunnel greenhouse using laboratory scale models. *J. Agric Engng. Res.* 72: 93-104.

Okada, M. and Takakura, T.(1973). Guide and data for greenhouse air conditioning III. *J. Agric. Meteor.* 28(4): 223-230.

Okushima, L., Sase, S. and Nara, M.(1989). A support system for natural ventilation design of greenhouses based a computational aerodynamics. *Acta Hort.* 248: 129-136.

Pandey, M.M.(1985). Ventilation of greenhouses. *Proc. of the summer institute on greenhouse design and environmental control*, CIAE, Bhopal.

Papadakis, G., Manolakos, D. and Kyritsis, S.(1998). Solar radiation transmittivity of a single span greenhouse through measurements on scale models. *J. Agric. Engng. Res.* 71: 331-338.

Papadakis, G., Mernier, M., Meneses, T.F. and Boulard, T.(1996). Measurement and analysis of air exchange rates in a greenhouse with continuous root and side openings. *J. Agric. Res.* 63: 219-228.

Prasad, T. G.(1997). Environment and plant growth relations in greenhouses. *Proc. of the International seminar on protected cultivation India*, Banglore.

Rajinder, P. K.(1985). Greenhouse temperature control techniques. *Proc. of the summer institute on greenhouse design and environmental control* ,CIAE, Bhopal.

*Smith, B.(1988). The how, when and why building a new glasshouse. *The grower.* 109(19): 27-33.

Thevanard, D., Zhang,Y., Jewett, T.J. and Shipp, J.L.(1999). Monitoring and modelling of light penetration into double row greenhouse crops. *Trans. ASAE.* 42(1): 165-174.

Verheye, P. and Verlodt, H.(1990). Comparison of different system for static ventilation of hemispheric plastic greenhouses. *Acta Hort.* 281: 183-197.

Vladimirova, S.V., Bucklin, R.H. and Mc Conel, D.B.(1996). Influence of shade level, wind velocity and wind direction on interior air temperature of model shade structures. *Trans. ASAE.* 39(5): 1825-1830.

Walker, J.N.(1965). Predicting temperatures in ventilated greenhouses. *Trans. ASAE.* 8: 445-448.

Wang, S. and Deltour, J.(1999). Lee-side ventilation induced air movement in a large scale multi- span greenhouse. *J. Agric. Engng. Res.*74: 103-110.

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

Wells, C.M. and Amons, N.D. (1994). Design of air distribution system for closed greenhouses. *Acta Hort.* 361: 93-104.

Winspear, K.W., Postlethwaile, J.D. and Cotten, R.F.(1970). The restriction of cladosporium fulvum and botrytis cinera attacking glasshouse tomatoes, by automatic humidity control. *Annals of Applied Biology.* 65: 75-83.

Zamen, I. M.(1990). Synergy between plastic research and protected cultivation. *Proc. of XI International congress on plastic in agriculture*, New Delhi.

---

* Originals not seen

Appendices

APPENDIX I

Specifications of the greenhouse

Length	=	18.2m
Width	=	5.4m
Height (at the center)	=	3.5m
Height of the door	=	2.15m
Width of the door	=	1m
Width of the gutter	=	0.1m
Slope of the gutter	=	1 in 75
Depth of the gutter	=	0.1m
No. of ventilators	=	12
Height of the ventilator	=	0.57m
Length of the ventilator	=	2m
Height of the masonry wall	=	0.45m

APPENDIX II

Specifications of the cooling pad

Length	=	5.4m
Height	=	0.95m
Thickness	=	0.15m
Mesh size	=	0.025 square mesh

APPENDIX III

Discharge on the cooling pad

Discharge through one dripper	=	0.8 lpm
Total no. of drippers	=	100
Discharge on the cooling pad	=	0.8 X 100 /60
	=	1.33 lps

APPENDIX IV

Discharge from the mist system

Discharge from one mist emitter	= 1 lpm
No. of emitter lines	= 3
No. of emitters in each line	= 12
Discharge of mist system	= 1 X 12 X 3 / 60 =0.6lps

APPENDIX V

Specification of the pump

hp/KW	= 1.0/0.75
RPM	= 2880
Head	= 22m
Pump Size	= 25 X 25m
Voltage	= 240V
Current	= 7.0A
Make	= Akash monoblock pump

APPENDIX VI

Specifications of fan A (right side)

Diameter	= 0.65m
RPM	= 1400
Rated current	= 2.1A
Voltage	= 415V
Circuit	= 3phase, 50 Hz
Power	= 0.75 KW / 1.0 hp
Volume of air expelled	= 2.21 m^3/s
Make	= Crompton Greeves

Specifications of fan B (left side)

Diameter	= 0.61m
RPM	= 920
Rated current	= 0.85A
Voltage	= 415V
Circuit	= 3 phase, 50 Hz
Power	= 460 Watts
Volume of air expelled	= 1.66 m^3/s
Make	= Almonard

APPENDIX VII

Calculation of the percentage ventilation area

Floor area of the greenhouse =18.2 X 5.4 = 98.28 m^2

Area of one ventilator =0.57 X 2 = 1.14 m^2

Percentage ventilation area while 2 ventilators opened $= \frac{1.14 \times 2}{98.28} \times 100 = 2.3\%$

Percentage ventilation area while 4 ventilators opened = 2.3 X 2 = 4.6%

Percentage ventilation area while 6 ventilators opened = 2.3 X 3 = 6.9%

Percentage ventilation area while 8 ventilators opened = 2.3 X 4 = 9.2%

Percentage ventilation area while 10 ventilators opened = 2.3 X 5 = 11.5%

Percentage ventilation area while 12 ventilators opened = 2.3 X 6 = 13.8%

APPENDIX VIII

Variation of different parameters inside and outside the greenhouse without ventilation (unshaded condition, without fan and pad and mist systems).

Time	Relative humidity(%)		Temeprature (°C)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
7.30am	92	90	27	26	1815	3280
8.30am	80	75	30	28	4110	5230
9.30am	68	46	38	30	21300	31800
10.30am	55	28	44	35	32900	47000
11.30am	50	24	48	36	44700	55300
12.30pm	64	40	46	34	10520	16200
1.30pm	47	20	53	39	43200	54200
2.30pm	52	27	55	39	34000	43500
3.30pm	54	28	52	38	23200	29100
4.30pm	60	34	49	37	13900	16300
5.30pm	66	52	42	33	1893	3010
6.30pm	71	61	37	31	270	525
7.30pm	75	66	33	30	0	0
8.30pm	80	71	31	29	0	0
9.30pm	83	75	30	29	0	0
10.30pm	86	78	29	28	0	0
11.30pm	89	82	28	27	0	0
12.30am	90	83	28	27	0	0
1.30am	90	84	28	27	0	0
2.30am	92	86	28	27	0	0
3.30am	93	88	27	26	0	0
4.30am	95	90	27	26	0	0
5.30am	96	92	26	25	0	0
6.30am	96	92	26	25	157	286
7.30am	94	90	27	26	1778	2900

APPENDIX IX

Variation of climatic parameters inside and outside the greenhouse

Variation of parameters inside and outside the greenhouse at 9.30 am under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
Ventilation (%)	Inside	Outside	Inside	Outside	Inside	Outside
0	38	30	68	46	21300	31800
2.3	36	32	54	41	24000	36500
4.6	36	32	52	42	23600	34900
6.9	35	32	50	44	19800	30700
9.2	34	31	49	46	22800	34800
11.5	32	30	50	48	11500	19180
13.8	33	32	48	46	25600	37200

Variation of parameters inside and outside the greenhouse at 10.30 am under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
Ventilation (%)	Inside	Outside	Inside	Outside	Inside	Outside
0	44	35	55	28	32900	47000
2.3	39	35	52	28	30600	44700
4.6	38	34	48	27	32100	45900
6.9	39	36	46	29	31500	45100
9.2	37	34	44	29	32200	46100
11.5	36	33	44	31	29800	42600
13.8	36	34	41	30	35600	49800

Variation of parameters inside and outside the greenhouse at 11.30 am under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
Ventilation (%)	Inside	Outside	Inside	Outside	Inside	Outside
0	48	36	50	24	44700	55300
2.3	42	36	46	24	46100	57600
4.6	40	36	45	23	43300	54200
6.9	40	37	43	21	42800	53500
9.2	39	36	41	24	43700	54600
11.5	38	35	40	25	43200	54000
13.8	38	36	37	25	48500	59800

Variation of parameters inside and outside the greenhouse at 12.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
Ventilation (%)	Inside	Outside	Inside	Outside	Inside	Outside
0	46	34	64	40	10520	16200
2.3	45	38	45	24	49200	58200
4.6	44	38	42	22	46500	54700
6.9	43	38	41	22	47500	55400
9.2	43	39	40	22	49100	57800
11.5	41	37	40	22	46300	54200
13.8	41	38	38	22	51200	61000

Variation of parameters inside and outside the greenhouse at 1.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Ventilation (%)	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
0	53	39	47	20	43200	54200
2.3	46	39	41	20	45700	55100
4.6	46	39	40	21	43100	54200
6.9	44	39	39	20	36400	45400
9.2	44	39	37	21	41200	51500
11.5	42	38	36	22	39800	51100
13.8	42	39	34	21	44700	54600

Variation of parameters inside and outside the greenhouse at 2.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Ventilation (%)	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
0	55	39	52	27	34000	43500
2.3	47	39	42	27	33200	42400
4.6	46	39	41	28	37300	46700
6.9	45	39	40	26	37100	46500
9.2	43	38	38	30	29500	38800
11.5	43	38	36	30	27900	36500
13.8	43	40	30	24	40600	57000

Variation of parameters inside and outside the greenhouse at 3.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Ventilation (%)	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
0	52	38	54	28	23200	29100
2.3	46	39	44	28	25700	32000
4.6	44	38	42	27	26100	32400
6.9	43	37	42	26	27200	34500
9.2	42	37	42	32	25200	31400
11.5	42	37	38	32	8620	12500
13.8	42	39	30	24	28600	35500

Variation of parameters inside and outside the greenhouse at 4.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Ventilation (%)	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
0	49	37	60	34	13900	16300
2.3	41	36	50	35	8180	11920
4.6	41	36	49	35	12700	19800
6.9	40	36	47	36	13200	21500
9.2	40	37	46	36	8670	11570
11.5	40	37	43	37	10610	13400
13.8	39	37	39	33	10960	13630

Variation of parameters inside and outside the greenhouse at 5.30 pm under different percentages of ventilation (unshaded condition, without fan and pad and mist systems).

Ventilation (%)	Temperature (^{0}C)		Relative humidity (%)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
0	42	33	66	52	1893	3010
2.3	35	33	60	51	3000	4600
4.6	35	33	58	50	1620	2670
6.9	34	32	60	52	1343	2552
9.2	34	32	58	51	4720	6800
11.5	34	33	60	54	4910	7250
13.8	33	32	55	51	3050	4850

Appendix X

Variation of parameters inside and outside the greenhouse without ventilation (unshaded condition, with fan and pad system and without mist system).

Time	Relative humidity(%)		Temeprature (^0C)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	54	25	42	33	31200	41800
10.30am	40	23	38	34	34200	39900
11.00am	55	25	44	34	42400	45600
11.30am	47	31	40	34	42500	52600
12.00noon	54	23	45	36	43200	53500
12.30pm	39	23	41	36	43400	57300
1.00pm	54	23	46	37	44800	59000
1.30pm	42	25	42	37	40700	51200
2.00pm	55	27	44	36	21200	32500
2.30pm	44	28	39	35	18900	29600
3.00pm	56	29	44	35	14500	22100
3.30pm	47	31	37	34	8430	12800
4.00pm	60	34	42	34	6870	9610
4.30pm	57	41	35	33	5120	6840
5.00pm	71	57	35	32	4050	5450

Appendix XI

Variation of parameters inside and outside the greenhouse without ventilation (shaded condition, with fan and pad system and without mist system).

Time	Relative humidity(%)		Temeprature (^0C)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
10.00am	66	52	34	33	9400	48800
10.30am	56	49	36	36	13300	57600
11.00am	59	42	38	37	15700	60900
11.30am	56	50	36	36	15800	62500
12.00noon	69	53	37	36	16100	63200
12.30pm	54	48	38	39	15800	64400
1.00pm	61	45	40	39	14900	63100
1.30pm	47	40	39	40	15100	63600
2.00pm	56	40	41	40	14500	59600
2.30pm	46	40	38	39	12700	57000
3.00pm	56	40	41	39	12300	58400
3.30pm	46	40	37	38	8400	48600
4.00pm	63	45	40	39	6200	46900
4.30pm	62	56	35	35	5230	32100
5.00pm	75	58	35	34	3500	19600

Appendix XII

Variation of parameters inside and outside the greenhouse without ventilation (shaded condition, without fan and pad mist and systems).

Time	Relative humidity(%)		Temeprature (^0C)		Light intensity (lux)	
	Inside	Outside	Inside	Outside	Inside	Outside
7.30am	93	89	29	28	593	5460
8.30am	84	70	31	30	1360	15780
9.30am	72	50	33	32	4700	35600
10.30am	61	46	38	36	14800	56100
11.30am	55	44	39	37	11200	59600
12.30pm	68	58	36	34	2330	9550
1.30pm	65	58	37	35	1510	5940
2.30pn	70	60	36	34	2110	8330
3.30pm	57	40	42	40	10500	53400
4.30pm	65	55	35	33	1190	2830
5.30pm	71	65	33	32	535	2260
6.30pm	76	70	31	30	77	321

OPTIMIZATION OF GREENHOUSE VENTILATION FOR HUMID TROPICS

By

JINU, A.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Irrigation & Drainage Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679 573, MALAPPURAM

KERALA, INDIA

2000

ABSTRACT

In any agricultural sector, the need of the hour is to maximize the yield per unit area to cater the needs of our population, which is exploding at an alarming rate. Protected cultivation or controlled environment agriculture is one of the methods to increase the crop production from unit area. Of the various forms of protected cultivation, greenhouses are most common. Our state falls under humid tropical climatic condition. Greenhouse cooling is to be done during peak hours of daytime under this climatic condition. Ventilation plays an important role in green house cooling. A study was conducted to determine the optimum greenhouse ventilation for humid tropics and to analyze the effect of different cooling methods viz. natural ventilation, fan and pad system, mist system and roof shading on greenhouse cooling.

The study showed that natural ventilation could reduce the greenhouse temperature to a great extent. The different percentages of ventilation used for the experiment were 13.8, 11.5, 9.2, 6.9, 4.6 and 2.3. The study was also conducted without ventilation. As percentage ventilation increases, greenhouse cooling increases and inside relative humidity decreases. 13.8 percent ventilation gave maximum greenhouse cooling and this value is taken as the optimum percentage of natural ventilation. But the natural ventilation alone cannot meet the cooling requirement during peak hours. Fan and pad system is found to be not effective for greenhouse cooling in this particular study. Even 2.3 percentage of natural ventilation condition gave better cooling than fan and pad cooling system. Misting is an effective method to lower down the greenhouse temperature within a short period of time. Misting was done along with fans at different percentages of ventilation and the different climatic parameters were studied. The results showed that while misting, the maximum cooling was obtained at 2.3 percent of ventilation. Effect of roof shading on greenhouse cooling was tested with one shade net over the greenhouse. Roof shade has a significant effect on greenhouse cooling.

Th inside temperature of the greenhouse was higher than the outside temperature by more than 10°C during peak hours of the day time, when no ventilation was provided and fan and pad system, mist system and shade cover were

not used. But when the green house was covered with a shade net, an inside to outside temperature difference of one or two degree was observed. Also, while operating fan and pad system and mist system, shaded condition gave better cooling. Fan and pad system operated without shade cover, could not bring down the greenhouse temperature below ambient temperature. But for the shaded condition, greenhouse temperature could be lowered to a value less than the ambient temperature. Misting under shaded condition at 2.3 percent ventilation gave maximum cooling. Misting inside an unshaded greenhouse at 2.3 percent ventilation could bring down the greenhouse temperature to 32°C, but misting inside a shaded greenhouse at 2.3 percent ventilation lowered the greenhouse temperature to 29°C. Use of two shade net layers did not give any additional cooling, and at this condition the light intensity inside the greenhouse was only 10 percent of the outside light intensity. It only increases the cost of the greenhouse and hence it is not recommended to use two shade net layers for greenhouses.