DEVELOPMENT AND TESTING OF EVAPORATIVE COOLING BOX FOR NATURALLY VENTILLATED GREENHOUSE

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PROJECT REPORT

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DECLARATION

We hereby declare that, this project entitled **“DEVELOPMENT AND TESTING OF EVAPORATIVE COOLING BOX FOR NATURALLY VEVENTILLATED GREENHOUSE”** is a bonafide record of project work done by us during the course of study, and that the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship or other similar title of any other University or Society.

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Place: Tavanur

Date: 07/02/2017

CERTIFICATE

Certified that this project entitled **“DEVELOPMENT AND TESTING OF EVAPORATIVE COOLING BOX FOR NATURALLY VENTILLATED GREENHOUSE”** is a record of project work done jointly by Adarsh S.S. and Jincy under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar title of another University or Society.

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ADARSH S.S **JINCY**

DEDICATED TO OUR

AGRICULTURE

ENGINEERING

PROFESSION

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

CEA	Controlled environment agriculture
A.D	Anno Domini
Co_2	Carbon-di-oxide
%	Per cent
°C	Degree Celsius
R.H	Relative Humidity
Eg	Example
et al	And others
µm	Micrometer
ETHE	Earth-tube– heat–exchangers
t/ha	Tonne per hectare
mm	milli meter
ppm	Parts Per Million
NIR	Near infrared radiation
FIR	Far infrared radiation
NV	Natural Ventilation
CFD	Computational fluid dynamics
PAR	Photosyntetically active radiation
RPTs	representative plant temperatures
LDPE	low-density polyethylene
Rn	Net Radiation
Nm	Nano meter
NIR	Near Infrared radiation

PWM	Pulse width modulation
VPD	Vapour pressure deficit
LEA	Leaf area ratio
Kpa	Kilo Pascal
NAR	Net assimilation rate
RGR	Relative growth rate
PG	Plastic greenhouse
FS	Fogging system
AFR	Air flow rate
EFR	Evaporation flow rate
ET	Evapotranspiration
λE_{-c}	Transpiration rate
gc	Stomatal conductance
m/s	meter per second
PFDC	Precision farming development centre
UV	Ultra violet
Cm	Centimetre
M.S	Mild steel
Db	Dry bulb
wb	Wet bulb
t	Temperature
ISSN	International standard serial number

Introduction

CHAPTER I

INTRODUCTION

The world scenario has been changing from plentiful to limited resource application, by adopting intensive farming practices rather than extensive farming practices and looking forward into the judicial application of chemicals. The exponentially growing world population has to be met from this limited available resource, which exerts a continuous pressure on land and agriculture. Due to these limited resources, the need of intensive cropping is felt to a large extend. To meet the present and future requirements, agricultural production to be sustainable, and practices adopted should be environment friendly. Emphasis on the need to improve the efficiency of agricultural inputs in farming systems has generated the need of new alternative techniques.

Increasing demand for non-seasonal fruits, vegetables and other agricultural products need a controlled environment where it is possible to grow them irrespective of the ambient seasonal conditions where as conventional agricultural practices can only control the nature of root media through tillage, manuring, fertilizer application, irrigation etc. There is no control over light, temperature, air composition and humidity in open field cultivation. Controlled environment agriculture is a combination of horticultural and engineering techniques that optimizes crop production, crop quality and production efficiency. Concept of CEA is not new rather it incorporates new edge of technological advancements. The known CEA production is recorded in history was mandated by the Roman emperor, Tiberius caeser (14-37A.D.).

Now days in many developing countries, agriculture has been a sustainable foreign exchange earner, which is necessary for national development. Enhancement of production of fresh fruits, vegetables, flowers and indoor plants for domestic as well as for export, therefore, becomes relevant. Export of horticultural produce requires high quality standards and assured availability. However traditional open field techniques are greatly constrained to meet export obligations resulting from the heavy use of chemicals and fertilizers, There is a need ,therefore to look alternative technologies to increase agricultural yield. The use of efficient inputs must be improved and the latest technologies development should be incorporated as well as in order to achieve the domestic as well as export food and nutritional targets.

So greenhouse technology provides an acceptable plant environment that contributes to a profitable enterprise. The microclimate of a plant is specified with respect to light, air composition, temperature and root media. Greenhouse technology is the basic factor which contributes to the development of agriculture production technology that integrates market driven quality parameters with production system profits. Instead of being merely a sustainable practise, greenhouse technology empowers agriculture as a profession giving more marginal returns to the input.

Green house is a structure primarily of glass or sheets of clear plastics, in which temperature and humidity can be controlled for the cultivation or protection of plants. Greenhouse can also be defined as the sophisticated structure providing ideal conditions for satisfactory plant growth and production throughout the year. The internal environment (microclimate) of the greenhouse is controlled by growth factors like light, temperature, humidity and air composition. The main objective of greenhouse cultivation is to provide a congenial inside microclimate to optimize the growth of plants. Thus, it promotes off seasonal cultivation of crops and also in areas, where the natural climate is not suitable for cultivation of a particular variety of flora.

The reliable information about world wide area distribution of greenhouses is very difficult to find, since various researchers are giving different estimates. Out of the global greenhouse area, the bulk consists of simple plastic houses and is readily on all five continents especially in the Mediterranean region, china and japan. However in Europe, such as Netherlands, Italy, Germany, France and Denmark, there is a considerable proportion of protected cultivation in glass houses. Greenhouses are constructed in such a way that, they must have adequate structural strength to withstand loads, such as its own weight, wind, snow, hanging baskets as well as high light transmission, low heat consumption, sufficient ventilation efficiency, low cost of construction and low operating cost. A combination of design standards, construction light transmission, heat consumption and climate control may optimize greenhouses construction to a desirable extends.

Now a day various types of greenhouses are present, their classification is mainly based on working principles, shape, cover material, utility season etc. The type of greenhouse by a grower depends on local technical, legal and economic conditions. In many cases local tradition, compatibility with existing greenhouses and available market play are the important roles in the decision making. A successful and efficient greenhouses design requires accurate knowledge of local climatic conditions useful for analyzing and predicting the structural functional behavior of greenhouse design suitable locations. Orientation of greenhouse is important as greenhouse frames cast shadows on the crop inside it thus effecting the light available to the plants. The magnitude shadows depends on the season of the year as the angle of the sun varies with the sea son at a given place. Therefore, latitude and altitude of the area should be considered while selecting the site for the greenhouse.

The microclimate of a plant is specified with respect to light, air composition,, temperature and root media. Greenhouses are structures, which make use of solar radiation for creating a favorable environment for plant growth depending upon their location, structure and arrangement. Plant’s responds to light, amount light, duration, and spectral requirements, type of light source and distribution of light in greenhouse are the various factors affecting the lighting system of a greenhouse. Intensity of can be reduced by providing shades over the growing area. Temperature is the relative hotness or coldness of a object, which effects the basic physiological process common to all plants. The rate of respiration and photosynthesis increases with increase in temperature and also the chemical reaction is doubled for every 10°C rise in temperature. However, increase in photosynthesis is limited after a rise in temperature, due to available energy and CO_2 concentration. Relative humidity is the ratio of amount of water vapor present in the air to the amount of water vapor required to saturate it. It affects the leaf area development and stomatal conductance. Oftentimes, high level of humidity results in yield loss of crop. Under normal conditions, about 70% of relative humidity should be maintained in the greenhouses for better plant growth.

Although greenhouse protects crops from external bad weather, high temperature and humidity during summer months cause adverse effect on crop production. During summer, the internal environment of a greenhouse becomes unfavorable for crop production since high intensity of solar radiation increases the air temperature inside the greenhouse through the greenhouse effect. A cooling system is required in reducing extra thermal load within the greenhouse, summer cooling and winter cooling are two different forms of cooling in greenhouse. The basic difference between these two system lies on the air temperature that is external to the greenhouse. During summer it is desirable to cool the air before passing it over the plants. With this, cooled air is introduced directly and uniformly over the plants. During winter prior to making contact with the plants in order to prevent cold spots, the cold external air is introduced indirectly mixed with the undesirable warm air within the greenhouse. For best results, the flow of incoming air must be smooth in the summer, but turbulent in winter so as to bring about rapid mixing.

Summer cooling is again classified into passive greenhouse cooling and active greenhouse cooling based on the working principles. In passive greenhouses, mechanical energy is not generally required to move fluids for their operation. Fluids and energy moves by mean of temperature gradient developed through absorption of radiation. They rely on natural convection and radiation for heat transfer. Design of passive system is such that they have minimum solar gain in winter to reduce cooling loads. The greenhouse walls, floors and roof are used as structures for collecting, storing and distributing solar energy within it by the natural process of convection, radiation and conduction.

Natural ventilation and shading are the two passive methods used to reduce the thermal load in greenhouse. Natural ventilation is caused by wind and temperature gradient inside and outside greenhouse. Natural ventilation is provided through ventilation openings; one at the ground level and the other on the roof, replacing the internal hot air by external cooler during hot summer. The external cool air enters the greenhouse through the lower side openings. while hot internal air exists through the roof openings due to density difference between air masses of different temperature and thereby lowering of temperature in greenhouse. Shading is one of the efficient methods of controlling entry of unwanted radiations inside the greenhouse. Shade cloth over the roof of a greenhouse or shade paints are commonly used for shading. Aluminum meshes and liquid foams can also be used to provide shading effect to control incidence of solar radiation and to reduce the temperature within the greenhouse.

In active greenhouses, mechanical or electrical energy is required to move the working fluid in the system. The greenhouse makes use of fans and pumps. Forced ventilation and evaporative cooling are the two types of active cooling method to reduce the thermal load in the greenhouses. When the rates of heating become higher than the rate of heat removal through the roof vent, then the heat removal is only possible through forced ventilation. In this system working medium is put into motion artificially by means of a fan or compressor. The rate heat removal depends on the capacity of fan and its rotational speed. The inside air is replaced by the outside air which reduces the greenhouse temperature.

Evaporative cooling is the most effective cooling method for controlling the temperature and humidity inside a greenhouse.However, its suitability is restricted to the respective region and climate as humid tropics seldom suits for its application due to high humidity levels. Evaporative cooling systems are based on conversion of sensible heat to latent heat of evaporated water, where water is supplied mechanically. The temperature of air reduced due to evaporation of water in air. Thus, the temperature decreases at the expense of increase in humidity, while the enthalpy of air remains constant in the process. Pad and fan cooling, roof evaporative cooling, mist and fog type cooling are the different types of evaporative cooling methods commonly used.

In evaporative fan and pad system, induced draught fan is installed in one side wall and a cooling pad on the opposite wall of the greenhouse. Water is circulated through the pad using a pump to keep it wet and air is forced to pass through the wet pad due to suction from induced draught fan. The humidity inside the greenhouse is raised due to the addition of water vapour in the air. The main drawback of evaporative cooling system based on cooling pad and extraction fan is the thermal gradient developed along the direction of air flow.

Roof of the greenhouse receives maximum solar radiation and evaporating water from the roof surface can decrease the heat flux from it. So roof evaporative cooling is a technique in which water is circulated on the roof surface resulting in the formation of a water film. This water film helps to lower the sensible heat gain of the greenhouse air, thereby reducing its temperature.

In misting and fogging system, evaporative cooling uses very small water droplets 2-60 µm in diameter for fogging range) which are sprayed into greenhouse air under high pressure using nozzles. A fraction of water droplets evaporate while coming in contact with air and due to high latent heat of vaporization of water, air temperature gets reduced. The misting is generally used for creating the high humidity along with cooling. The foggers are fitted so as to provide complete fog inside the greenhouse.

In tropics due to high irradiance on summer, the plant temperature in greenhouse can exceed the air temperature by 5-15°C. Even sufficient ventilation provides insufficient cooling for many plants and the air temperature inside the greenhouse cannot be decreased below outside temperature by using ventilation only. So, additional cooling arrangement must be provided.

Development of suitable cooling system that provides congenial microclimate for crop growth is a difficult task as the design is closely related to the local environmental conditions. Besides, the selection of appropriate technology for cooling depends on the crop to be grown, maintenance, ease of operation and economic viability. Hence, understanding of greenhouse, its size, shape, covering material and external weather helps in the development of suitable cooling system. Evaluating micro climate in different designs of the greenhouse and establishing physical and physiological relationship of crops is necessary for greenhouse designers to improve cooling system that is suitable for crop growth. Earlier studies on greenhouse cooling revealed that the present techniques used for cooling were not satisfactory. There is a necessity to find suitable cooling method for greenhouse cooling in peak summer. Thus, development of applicable cooling technologies is an important research endeavour.

In order to overcome these situations an evaporative cooling system can be developed for the active summer cooling in greenhouse. Recently, many cooling system has been developed but most of them find failure in controlling diseases as well as obtaining a profitable yield from greenhouses. For example, in case of mist cooling system, the development of disease is the major problem and algae may develop in the wetted areas and hence the crop yield will be reduced significantly. When a fogging system is adapted as a cooling option in greenhouse, then there will be greater chance of foliage get wetted and crop is highly susceptible to diseases. All these factors will badly effect the crop production and hence reduction in the crop yields. So a better microclimatic condition should be provided to achieve optimum performance of the greenhouse crops and to enhance the greenhouse production. For achieving this goal, an evaporative cooling box consisting of fan and pad can be developed in anon-hermetic greenhouse. So the main aim of evaporative cooling box is to attain maximum cooling efficiency with optimum control over the growth factors.

Three evaporative cooling boxes with fan and pad system have been developed, tested and its performance were evaluated and compared, in order to determine the best evaporative cooling option for greenhouses as an active summer cooling method.

With the above point of view, a project was under taken in the Kelappaji College of Agricultural Engineering and technology to develop an evaporative cooling box for the naturally ventilated greenhouse with the following objectives.

1. To investigate and develop an evaporative cooling box system for greenhouses in the climatic condition of Kerala.
2. To study its field level cooling efficiency.

Review of literature

CHAPTER II

REVIEW OF LITERATURE

The world population is estimated to be increasing day by day, but the space is being limited. So, hi-tech agricultural practices such as green house can be constructed to take an advantage over the space limitation and looking forward into the higher productivity. A green house with an efficient cooling system promises higher and uniform production rate even in the hot climatic conditions.

2.1 GREEN HOUSE

Green house is a structure primarily of glass or sheets of clear plastics, in which temperature and humidity can be controlled for the cultivation or protection of plants. Greenhouse can also be defined as the sophisticated structure providing ideal conditions for satisfactory plant growth and production throughout the year**.**

Linker and Seginer (2000) carried out a study on fault detection and isolation in greenhouses. The first part of this paper presents an analysis of the effect of different failures on greenhouse operation. A simulation study shows that failures prevent the greenhouse climate from being controlled optimally, and may result in significant financial losses to the grower. Subsequently, two methods for failure detection and isolation are presented. The first method is based on a comparison between the measured greenhouse climate and the predictions of a reference model. This comparison is performed according to the Unknown Input Observer approach, which ensures robustness of the diagnosis with respect to noise and modeling errors. The second method is aimed specifically at detecting crop water stress during noontime hours. At such times, the high heat load requires strong ventilation, which reduces the detection capability of the first method. Crop water stress detection is achieved by suspending the ventilation for short periods of time (30 minutes), and comparing the greenhouse climate response to some reference response.

Sharan(2010) conducted a research to develop greenhouse technologies which economically control water and energy in order to improve farming in water-scarce, hot, semi-arid regions of north-west India. A greenhouse under investigation was coupled to earth-tube– heat–exchangers (ETHE) and also had provisions for shading, natural ventilation and mist nozzles. Tomatoes were grown in the greenhouse. In the cooler months, a regime of natural ventilation and top shading kept the greenhouse temperature close to ambient temperature. Mist was not used. Evaporation and later transpiration may have aided cooling. This cooling effort became less effective in warmer periods as the cooling load increased and dense foliage appeared to hinder ventilation. Forced ventilation via ETHE and top shading was then implemented. Inside temperature occasionally rose 2-3 °C above the ambient temperature. Cropping could be done through the spring and early summer. Heating was affectively achieved with ETHE in cold nights of December and January keeping the inside temperatures well above 12°C. Yields were 68 t/ha - nearly twice the open field production, while the water used (266 mm) was nearly half of the open-fields usage. This appears to be a promising new way to improve livelihoods from farming**.**

2.2 GREENHOUSE COOLING

Dayan*et al.*(2006) conducted a study on cooling of roses in green house. Rose flowers produced in greenhouses during the Israeli summer are of poor quality, due presumably to the high temperatures and low air humidity obtained with natural ventilation (NV). Several variants of commercial cooling methods were tested to reduce the duration of high temperature exposure in greenhouses. The treatments included were: NV, with and without shading, and forced ventilation with and without an evaporative pad. Modified concepts issued from a steady state energy balance model set a frame for analyzing the course of action of the treatments. The cooling treatments hardly reduced average temperatures of air, plant, or flower. Due to morphology, the plant absorbed most of the radiant energy entering the greenhouse, and most of it was removed as latent heat. In comparison to NV, the treatments produced limited additional cooling because each of them reduced the transpiration rates.

Kumar *et al.*(2009) carried out a study on design and technology for greenhouse cooling in tropical and subtropical regions. High summer temperature is a major setback for successful greenhouse crop production throughout year. The main intent of the paper is to present a comprehensive review on the design and technology for cooling of greenhouse during summer months. Effect of characteristic design parameters on greenhouse microclimate and the applicable cooling technologies have been discussed. A detailed survey of literature revealed that, apart from cooling, studies on greenhouse design, evaluation of new cladding materials for greenhouse covering and natural ventilation with respect to local climate and agronomic condition is necessary to achieve desirable benefits. Analysis of the earlier studies revealed that a naturally ventilated greenhouse with larger ventilation areas (15–30%), provided at the ridge and sides covered with insect-proof nets of 20–40 mesh size with covering material properties of NIR (near infrared radiation) reflection during the day and FIR (far infrared radiation) reflection during night is suitable for greenhouse production throughout year in tropical and subtropical regions. The detailed review presented in this paper indicated that existing cooling technologies are not enough and widely accepted to cater the needs of greenhouse grower. There is a necessity to develop cheap and effective technology suitable to local climatic conditions to boost up the greenhouse industry.

Lee and wang (2010) conducted a study on cooling capacity assessment of semi closed green houses. The study was based on the study conducted by Dutch researchers and Ooteghemon significant benefits of closed greenhouse systems. Results of this study were used on Ohio conditions estimated that 90% and 92% of CO2 loss through cooling and dehumidification ventilations when an elevated CO2 level of 800 ppm must be maintained. This study also found that for Wooster, Ohio to achieve economical year-round closure, due to the larger weather variation and lack of accessibility to aquifers, a better economical return would be expected with semi-closed designs that allow the greenhouse to vent when the heat load is approaching a certain per cent of peak levels. The study also determines the amount of heat which can be recovered with thermal storage. The models used for the above analyses were evaluated using data collected in a greenhouse located at Wooster, Ohio. Convection and infiltration heat loss prediction were validated during cloudy and clear sky nights. The results gave prediction disagreements of 0.2% to 2% and 30% under cloudy and clear sky conditions, respectively. Also evaluated was the potential recoverable heat from ventilation exhaust. Result showed that ventilation time prediction disagreement were -8.2% and 0.8%, when net solar radiation transmittances were estimated at 0.54 and 0.57, respectively. Although further improvements of this model could be done, the data processing framework established for the heat recovery strategy evaluation is valuable for the assessment of potential benefits of semi closed greenhouse.

Ganguly and Ghosh(2011) presented a comprehensive review of the literature that deal with ventilation and cooling technologies applied to agricultural greenhouses. The representative application of each technology as well as its advantages and limitations are discussed. Advance systems employing heat storage in phase change materials, earth-to-air heat exchangers and aquifer-coupled cavity flow heat exchangers have also been discussed. For an agricultural greenhouse equipped with cooling and artificial ventilation system, availability of uninterrupted electric supply is important. To achieve grid independence, dedicated power generation and storage systems need to be integrated with the greenhouse. The relevant literature on such power generation system for greenhouse application has been reviewed and is discussed here. This review concludes by identifying some important areas where further research needs to be undertaken.

Li and Wang (2015) conducted a research based on the Technology and Studies for Greenhouse cooling. The main purpose of this paper is to present some technologies and studies for greenhouse cooling in summer. In this paper, some applicable and practical cooling technologies have been discussed. Test and investigation respectively conducted three cooling measures such as natural ventilation, evaporate-cooling and shading cooling. There are some respectively differences among them. All of the methods have disadvantages and advantages. The choice of efficient cooling method depends on many aspects, such as local climate, agronomic condition, design and covering materials. To achieve desirable benefits, the combination of different cooling methods is necessarily used. The study reveals that Evaporation cooling is the most effective cooling method for controlling the temperature and humidity inside a greenhouse. However, its suitability is restricted to the respective region and climate when the humidity level is high. The entry of un- wanted radiation or light can be controlled by the use of shading. Researches show that shade net application with different perforated mesh size and their evaluation with respect to local climate and region are necessary to get cooling benefits in summer.

2.3 SUMMER COOLING SYSTEM IN GREENHOUSE

2.3.1 NATURAL VENTILATION

Natural ventilation results from the pressure difference created due to wind velocity and the effect of thermal buoyancy. This helps to maintain greenhouse inside air temperature close to that of ambient and is the most economical method to maintain a desired microclimate inside a greenhouse when the ambient conditions are moderate. Considerable research work has been done on naturally ventilated greenhouses. Many researchers have developed and presented analytical models to determine the temperature and air exchange rate in naturally ventilated greenhouses and in recent years advanced tools like CFD, Neural Network and Genetic Algorithm have been used to develop models for greenhouses operating under natural ventilation.

Wang and Deltour(1997) conducted an experiment for measuring natural ventilation induced airflow patterns using an ultrasonic anemometer in Venlo type greenhouse openings. Airflow distribution in the greenhouse windows is important to understand the mechanism of natural ventilation and the optimal ventilation system can be provided. The full-scale measurements of the airflow in a large Venlo-type greenhouse were carried out by use of an ultrasonic anemometer. polar plots can be used to find the clear airflow patterns around the greenhouse under leeside ventilation. The air velocity in a greenhouse central ventilator was considered as a function of the opening angles both in leeside and windward sides. The airflow across the opening is affected by the external wind and opening angle. The measuring time period is drastically reduced from the 15 minutes to 5 minutes in order to accelerate the measurements. opening angle of leeside and windward side greatly influence the air velocity in the center of greenhouse. The results show that the non-dimensional ventilation function of leeside increases with the opening angle but decreases with the opening angle of windward side. Thus the new method to measure directly the air velocity by a sonic anemometer allows us to measure the airflow distribution in the opening under different conditions and to build a non-dimensional ventilation function.

Baptista *et al.* (1998) conducted an experiment to measure the ventilation by sing tracer gas techniques. Leakage and ventilation rates were measured in a four span glasshouse at Silsoe Research Institute. Two tracer gas techniques were used; a decay rate method with different positions of the leeward ventilator and a continuous injection method with the leeward ventilators open 10%. For each ventilator position, influences of wind speed, wind direction and temperature difference between inside and outside were analysed,. It was found that wind speed had a great influence on leakage and ventilation rates. Temperature difference affected ventilation rates under low wind speeds. The air exchange rate was linearly related to wind speed For each ventilator position,. 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 ventilator opening. With a 10% opening, the results obtained with the decay and continuous methods were compared and showed good agreement for wind speeds greater than 1 m/s. The results for 10 and 20% ventilator openings obtained by using the decay method were compared with those obtained by applying the theory of convection. It was found that the combined effect of wind and temperature difference gave satisfactory predictions of ventilation rates when pressure differences generated by wind forces and temperature differences were used. Also, the values obtained by measurement and prediction based on pressure difference were in close agreement, with a global wind effect coefficient similar to that found in the literature.

Juwaw *et al.* (2003) carried out a study on effect of different ventilation strategies on the microclimate and transpiration of a Rose Crop in a greenhouse. The study was aimed at reducing internal air temperatures of a greenhouse shelter in Zimbabwe. The ventilation rate was evaluated by using water vapour balance method and the results were employed in calibrating and validating the ventilation sub-model of the greenhouse climate model, the GDGCM model, in a naturally ventilated three span azrom type greenhouse in Zimbabwe. Two ventilation regimes such as configuration with roof vents only with closed side vents and configuration with both side vents and roof vents open, were investigated. Crop transpiration was estimated using the Penman-Monteith method. The model was fitted to experimental data for ventilation rates, and the statistical analysis was carried out for determining the parameters for the model, the discharge and wind effect coefficient. The results showed that there was a good fit between measured and predicted values for the model on the two ventilation regimes. The air renewal rate was found to be influenced by the nature of ventilation regime in place. These results showed that the configuration with roof vents only gave lower ventilation rates. So that the most effective vent configuration was the combination of roof and side vents. The simulated temperatures from the model showed that the configuration with both roof and side vents was more effective in reducing the inside air temperature on selected hot days.

Shu-zhen *et al.* (2005) developed an prediction and analysis model of temperature and its applied to a naturally ventilated multi-span plastic greenhouse equipped with insect-proof screen. The model was developed to predict the variation of air temperature in the naturally ventilated greenhouse equipped with insect-proof screen. Roof ventilation and combined roof and sidewall ventilation were considered in the model. This model was validated against the results of experiments conducted in the greenhouse when the wind was parallel to the gutters. The least squares method was used to determine the model parameters. The analysis of the effects of wind speed and window opening height on the air temperature variation were carried out in the model. Comparison between two types of ventilation showed that there existed a necessary ventilation rate which results in air temperature decrease in natural ventilation under special climatic conditions. Under the same climatic conditions, the temperature decrease is smaller for roof ventilation than for combined roof and sidewall ventilation. According to real-time outside and inside climatic conditions, the model can be used to predict air temperature reduction achievable by natural ventilation.Active ventilation and other temperature reduction measures should be implemented if the temperature decrease cannot meet the requirements.

Katsoulas *et al.* (2006) conducted a study on effect of Vent Openings and Insect Screens on Greenhouse Ventilation. The objective of this work was to experimentally investigate the influence of vent type (side, roof or both) and of an anti-aphid insect screen used to prevent insect intrusion on the ventilation rate of a round arch with vertical side walls, polyethylene covered greenhouse. The greenhouse was equipped with two side roll-up vents and a flap roof vent located at the University of Thessaly near Velestino in the continental area of Eastern Greece. Microclimate variables as well as the airflow rate were measured during summer. Two measuring methods were used for the determination of ventilation rate are the decay rate 'tracer gas' method, using nitrous oxide N_2O as tracer gas, and the greenhouse 'energy balance' method. In order to study the effect of vent type on ventilation rate, in a greenhouse with an anti-aphid insect screen in the vent openings, airflow was determined during periods with ventilation being performed by roof, side or both roof and side vents. Furthermore, in order to study the effect of insect proof screen on airflow, measurements were also carried out during periods that ventilation was performed by side vents without a screen in the openings. The values obtained by the tracer gas method being slightly lower than those obtained by the energy balance method. Furthermore, the data of ventilation rate obtained by the tracer gas method fitted better to the model used for the prediction of ventilation rate. In addition, the use of anti-aphid screen in vent openings caused a 33% reduction in greenhouse ventilation rate. From greenhouse ventilation performance point of view, it was found that the most effective vent configuration was the combination of roof and side vents, followed by side vents only (46% reduction in ventilation), while the least effective was roof vent (71% reduction ventilation).

Lopez *et al*. (2011) developed a methodology for studying natural ventilation in Mediterranean greenhouses by means of sonic anemometry. In addition, specific calculation programmes have been designed to enable processing and analysis of the data recorded during the experiments. Sonic anemometry allows us to study the direction of the airflow at all the greenhouse vents. Knowing through which vents the air enters and leaves the greenhouse enables us to establish the airflow pattern of the greenhouse under natural ventilation conditions. In the greenhouse analysed in this work for *Poniente* wind (from the southwest), a roof vent designed to open towards the North (leeward) could allow a positive interaction between the wind and stack effects, improving the ventilation capacity of the greenhouse.

Kittas *et al.* (2012) conducted a study on climatic control in Mediterranean green houses. In these areas, natural ventilation and whitewashing are the most common methods/systems used for greenhouse climate control during summer, since it require less energy, less equipment operation and maintenance and are much cheaper to install that other cooling systems. However, generally these systems are not sufficient for extracting the excess energy during sunny summer days and therefore, other cooling methods such as forced ventilation combined with evaporative cooling (mist or fog system, sprinklers, wet pads), are used. On the other hand, during winter period, heating and dehumidification are necessary for a standard quality production. The necessary ventilation rate can be obtained by natural or by forced ventilation. For effective ventilation, ventilators should, if possible, be located at the ridge, on the side walls and the gable. whitening applied onto a glass material enhanced slightly the PAR proportion of the incoming solar irradiance, thus reducing the solar infrared fraction entering the greenhouse. One of the most efficient solutions for alleviating the climatic conditions is to use evaporative cooling systems, based on the conversion of sensible heat into latent heat by means of evaporation of water supplied directly into the greenhouse atmosphere (mist or fog system, sprinklers) or through evaporative pads (wet pads). The reduction of the energy requirement of the greenhouse is related to the more strategic choices of the grower in relation to his greenhouse construction, cover and environmental equipment in terms of heating system, ventilation, cooling, screens etc.

Rojano *et al.* (2014) conducted a study on dynamic of climatic condition in green house in two locations of Mexico. For most greenhouse locations in Mexico, climate dynamics are primarily influenced by the local weather because they mainly have naturally ventilated structures. Since during the year there is weather fluctuation, greenhouse climate demands strategic use of ventilation having effects on other climate variables. This work conducts an investigation about a representative greenhouse, which is simulated by Computational Fluid Dynamics (CFD) in order to know the effects of weather conditions from two locations in Mexico on the air temperature and humidity within the greenhouse. A typical greenhouse of northeast of Mexico, with a natural ventilation system was studied. This greenhouse has three spans and an orientation North-South. The model considers tomato crop effects by adding the evapotranspiration phenomenon. Then, the goal is to compare with experimental data three representative scenarios that cover the wind speed variation and its associated climatic variables such as temperature, humidity and solar radiation. Furthermore, it is possible to combine the effects of the climatic variables with thermal properties of the cover, buoyancy effects, physical properties of the insect-proof screen and the estimation of evapotranspiration. Additionally, this investigation serves to initially provide accurate estimations of energy dynamics and the most convenient location within the greenhouse to log climatic data.

2.3.2 FORCED VENTILATON

Dayana *et al.* (2004) conducted an experiment on Simulation and control of ventilation rates in greenhouses. A simple model is presented, which enables the calculation of ventilation in a commercial rose-growing greenhouse (greenhouse). The model represents the greenhouse as three vertically stacked horizontal segments and addresses the energy and vapour transfer among these segments and between them the plant canopy and the external environment. The model equations show how ventilation can be calculated from the heat and vapor balances and how they can describe the internal microclimate. Air exchange rates obtained by the model are similar to published results obtained by tracer experiments and CFD. The model can be updated and calibrated for various conditions and structures, in accordance with online measurements of transpiration, leaf temperature, air temperatures and humidity at several heights above ground level. By making some assumptions, representative plant temperatures (RPTs) can be calculated instead of being measured. The validity of the model assumptions is established by comparing numerical results with experimental data. Good agreement is obtained between the numerical output of the model and the experimental measurements, for most times of the day. The simplified model is used to demonstrate the calculation of representative plant temperatures when forced ventilation is applied to cool the plants.

2.3.3 SHADING AND WHITENING

Baille *et al.*(1999) studied the influence of whitening a greenhouse roof on microclimate and canopy behaviour during summer in a greenhouse located in the coastal area of eastern Greece. The study revealed that whitening the greenhouse roof reduced the average greenhouse transmission coefficient for solar radiation due to which air temperature and vapour pressure deficit changed drastically, while the increase in rate of transpiration was marginal.

Kittas *et al.*(1999) conducted a study on Influence of Covering Material and Shading on the Spectral Distribution of Light in Greenhouses. The solar photon flux distribution was measured in the range from 400 to 1100 nm under a twin-span glasshouse and under the same glasshouse with blanked roof, external shading net and internal aluminized shade-screen. Measurements were also carried out under a twin-span polyethylene greenhouse, a multi-span greenhouse with fibre glass and a polyethylene tunnel. For each greenhouse configuration, the measured solar photon flux spectra were used to calculate the solar transmission for the photo synthetically active radiation waveband (PAR), from 400 to 700 nm, the near infrared waveband (NIR), from 700 to 1100 nm, and the whole waveband, from 400 to 1100 nm. Other parameters having a physiological interest were also determined: the broadband PAR to TOTAL photon flux ratio and PAR to NIR photon flux ratio; and the morphogenesis-related parameters, such as the red to far red photon flux ratio, the phytochrome equilibrium, the relative cycling rate, the blue to red photon flux ratio and the blue to far red photon flux ratio. The results provided a better insight on the quantitative and qualitative properties of the light environment under each greenhouse configuration. Some significant differences in the values of blue light quality related parameters were found between greenhouses. Minor changes were observed on the PAR:TOTAL and PAR:NIR photon flux ratios, but indicated that glass and blanking tend to enrich the PAR content of the transmitted light, while the two plastic cover materials have the opposite effect, enriching the NIR content. These results stressed the need for a more precise characterization of modifications in light quality induced by greenhouse materials or shading devices as plant photosynthetic and photo morphogenetic responses may be significantly influenced by these modifications.

Preet and Willits (2000) conducted an experiment with intermittent application of water over externally mounted shad net on greenhouse. The results revealed that rise of greenhouse air temperature were reduced by 41% under wet cloth as compared to 18% under dry cloth.

Ghoshal *et al.* (2002) carried out the modelling and experimental validation of a greenhouse with evaporative cooling by moving water film over external shade cloth. The development of mathematical model through flowing water film on shade cloth, stretched over the roofs and south wall of an even span greenhouse has done to study the effectiveness of cooling in greenhouse. The model was validated experimentally for the climate of Delhi during summer period, out of the data collected in the experiments conducted under three conditions, i.e. shaded with water flow, shaded and unshaded conditions of greenhouse. Parametric studies involving the effects of flow rate of water, length of roof, relative humidity of ambient air and absorptivity of shading material on the cooling performance of greenhouse room air temperature have been made with the help of the model. From the results it was found that the room air temperature was reduced by 6°C and 28°C in shaded with water flow and shaded conditions, respectively, as compared to unshaded conditions and also the predicted room air temperatures were in fair agreement with the experimental values.

Cemek *et al* .(2008) investigated the effects of ultraviolet stabilized polyethylene, infrared absorber polyethylene double layered polyethylene and single layered polyethylene greenhouse cover on Aborigine growth productivity and energy requirement in late autumn season. They observed that double layered polyethylene covered greenhouse resulted in higher productivity.

Mutwiwa *et al.*(2008) conducted an experiment for cooling naturally ventilated greenhouses by using infrared reflection. High temperatures and humidity inside greenhouses located in the tropics is one of the major constraints to protected cultivation in areas such as central Thailand. Studies were conducted in two naturally ventilated greenhouses, clad with insect-proof nets on the sidewalls and roof ventilation openings, to investigate the effect of near infra-red

(NIR) reflecting pigments on the greenhouse microclimate and plant growth. A polyethylene film was used to cover the roof and gable of the greenhouse while a white plastic film was used as a mulching material. A shading paint containing a NIR-reflecting pigment (ReduHeat, Mardenkro B.V., Baarle-Nassau, The Netherland) was applied on the roof of one of the greenhouses ("Trt"). This led to the lowering of the greenhouse air temperature by up to 4°C when the crop was young corresponding to 18% reduction in transmission of global radiation. However when the crop was mature at 57 days after transplanting during the rainy season, transpiration cooling minimised air temperature differences between the two greenhouses. Shading reduced plant water requirement, power consumption of the fans, the number of blossom-end rot affected and parthenocarpic fruits, in both dry and rainy season. A slight reduction in marketable yield and an increase in the number of cracked fruits were observed in Trt. The results reveal that combination of natural ventilation and NIR-reflection may provide a solution for cooling greenhouses in areas with high ambient humidity and high solar radiation levels.

Abdel-Ghany *et al.*(2012) presented the reviews about problems of using conventional cooling methods in green houses in arid regions and the advantages of greenhouse covers that incorporate NIR reflectors. This survey focuses on how the cover type affects the transmittance of photosynthetically active radiation (PAR), the reflectance or absorptance of NIR and the greenhouse air temperature. NIR-reflecting plastic films seem to be the most suitable, low cost and simple cover for greenhouses under arid conditions. Therefore, this review discusses how various additives should be incorporated in plastic film to increase its mechanical properties, durability and ability to stand up to extremely harsh weather. Presently, NIR-reflecting covers are able to reduce greenhouse air temperature by no more than 5°C. This reduction is not enough in regions where the ambient temperature may exceed 45°C in summer. There is a need to develop improved NIR-reflecting plastic film covers.

Holcman and Sentelhas (2012) carried out a study for evaluating the influence of shading screens of different colours on the different microclimate variables in a greenhouse covered with transparent low-density polyethylene (LDPE). The experiment was conducted with five treatments: thermo-reflective screen (T1); a control - without screen (T2); red screen (T3); blue screen (T4); and black screen (T5), all of them with 70% of shading. An automatic micrometeorological station was installed in each treatment, measuring air temperature (T), relative humidity (RH), incoming solar radiation (Rg), photo synthetically active radiation (PAR) and net radiation (Rn) continuously. The control (T2) and red screen (T3) treatments promoted the highest solar radiation transmissivity, respectively 56.3 and 27%. The black screen (T5) had the lowest solar radiation transmissivity (10.4%). For PAR and Rn the same tendency was observed. The highest temperature was observed under blue screen (T4) treatment, which was 1.3°C higher than external condition. Blue screen (T4) treatment also presented the highest relative humidity difference between inside and outside conditions.

Ahmed *et al*. (2016) reviews common shading methods used for greenhouses in summer; their cooling effects on greenhouse air were explored to determine the optimum shading technique for arid regions. Effects of these methods on the overall microclimate as well as the distribution of the microclimatic parameters in greenhouses were discussed. The survey revealed that combining a shading method (e.g., whitewash or shade netting) with ventilation and/or evaporative cooling showed a significant effect on improving overall microclimate as well as the distribution of microclimatic parameters. This consequently reduces the energy and water consumptions and increases the crop productivity and its quality. In sunny regions, incorporating shading with a cooling method is able to maintain greenhouse air temperature at 5–10°C lower than the outside temperature, increases the relative humidity by approximately 15–20% and decreases the transmitted solar radiation by 30–50% compared to a greenhouse without shading. In cold regions, shading materials act as insula-tors;

significantly reduce heat loss from greenhouses at night. Thus, greenhouse air temperature can be maintained at 5°C higher than outside with saving approximately 15–20% of the energy used for heating. The information in this review would be useful for farmers, researchers and greenhouse designers to select the suitable cooling or heating strategy for greenhouses.

2.3.4 LIQUID DESICCANTS

Davies and Knowles (2006) conducted a study on Seawater bitterns as a source of liquid desiccant for use in solar-cooled greenhouses. This article explores the scope for exploiting the hygroscopic salts occurring in these by-products such as magnesium, calcium and sodium chloride as desiccant solutions in a greenhouse cooling system. These solutions are compared to other liquid desiccants more conventionally used in solar-driven refrigeration: namely solutions of lithium chloride, lithium bromide and zinc chloride. hygroscopicity, as quantified by the equilibrium relative humidity (ERH) is an important property and others include cost, availability, density, viscosity, specific heat capacity, thermal conductivity, heat of dilution, water absorption capacity, human- and Eco toxicity, and corrosivity. Calculations based on five locations (Tunis, Jiddah, Abu Dhabi, Mumbai and Bangkok) show that the liquid desiccant should have ERH ≤50% to give improved cooling compared to both direct and indirect evaporative systems. Except for sodium chloride, all six salts considered meet this requirement. Magnesium chloride is best suitable for cooling of greenhouses. They envisage an integrated desalination and agricultural system, comprising a solar desalination plant supplying freshwater (for irrigation) and bitterns (for cooling) to greenhouses, enabling efficient water use and local crop production in hot climates.

Lychnos (2010) conducted a study on feasibility of solar powered liquid desiccant cooling system for greenhouses. Based on the study, a regenerator and a desiccator were designed and constructed in lab. The choice of liquid desiccant is an important factor. The hygroscopicity of the liquid desiccant affects the performance of the system. Bitterns, which are magnesium-rich brines derived from seawater, are proposed as an alternative liquid desiccant for cooling greenhouses. A thorough experimental and theoretical study as carried out in order to determine the properties of concentrated bitterns. It was concluded that their properties resemble pure magnesium chloride solutions. Therefore, magnesium chloride solution was used in laboratory experiments to assess the performance of the regenerator and the desiccator. To predict the whole system performance, the physical processes of heat and mass transfer were modelled using PROMS® advanced process modelling software. The model was validated against the experimental results. Consequently it was used to model a commercials-scale greenhouse in several hot coastal areas in the tropics and sub-tropics. These case studies show that the system, when compared to evaporative cooling, achieves 3°C−5.6°C temperature drop inside the greenhouse in hot and humid places (RH>70%) and 2°C−4°C temperature drop in hot and dry places (50%<RH< 65%).

2.3.5 EVAPORATIVE COOLING

2.3.5.1 FOGGING SYSTEM

This system is based on spraying water small droplets (droplet diameter of 2 - 60 µm) with high pressure nozzles. Cooling is achieved by evaporation of droplet. Meanwhile, fogging can also be used to increase the relative humidity apart from cooling the greenhouse.In fog cooling, there will be a greater chance of foliage getting wetted and crop is highly susceptible to diseases.

Montero *et al* .(1990)carried out experiments to determine the effect of air water fogging system on the climate of two multi-arch greenhouses provided with shading screen of 45% transmissibility. They observed that during sunny days the maximum temperature reduction inside the greenhouse was 5°C compared to the control greenhouse.

Ozturk (2002) conducted an study to the investigate the efficiency of fogging system (FS) for greenhouses. The experiments were carried out in a multi-span plastic greenhouse (PG). The FS consists of a water softener and filters to prevent nozzle clogging, a water reservoir, pumps and a pressure regulator, and fog generating nozzles (FGN). The required pressure for FGN was 4.5 atm. Three nozzle lines with 82 FGN were installed in each span of the PG at 2.5 m nozzle spacing. The determination of FGN parameters were done to characterize the efficiency of the FS based on air flow rate (AFR) and evaporation flow rate (EFR). Uniform conditions of temperature and RH in the PG were observed with the FS. The FS was able to keep the air temperature inside the PG 6.6 °C lower than that outside. Therefore, the air RH inside the PG was increased by 25% on average by means of the FS examined in this study. It was found that the average efficiency of the FS was 50.5%. The efficiency of the FS increased linearly with the EFR and absolute humidity difference (AHD) between the inside and outside air. The air RH outside the PG affected the FSE in this experiment. The efficiency of the FS increased when the outside air RH was lower. The ventilation characteristics of a greenhouse should be known in order to provide good control of the inside environmental conditions, and a good crop yield of high quality produce.

Perdigones *et al.* (2003) conducted a study on cooling strategies for greenhouses in summer by Control of fogging by pulse width modulation. Combinations of ventilation cooling techniques, shade screening and low-pressure fogging can be compared to study possibilities for improving the control of greenhouse fogging systems. The study was divided into three parts: experiments, modelling and simulations. Ten combinations of five cooling techniques were tested during the summers. An analysis was carried out to determine which combinations produced significant differences in inside temperature or relative humidity. The combination of a shade screen and above-screen fogging achieved a difference in temperature almost the same as that for under-screen fogging, but the relative humidity was significantly lower when the values for the inside to outside temperature difference were compared. Then a dynamic model was developed and the model was used to simulate the inside air temperature for a fog system working without shading, and above and under a shade screen. Water consumption was reduced using control algorithms. In the three cases a simple on/off control with a fixed fogging cycle was compared with a pulse width modulation (PWM) strategy, in which the duration of the fogging pulse was increased as a function of inside temperature. The strategies with PWM applied to the fog system helps to reduce water consumption by 8-15% with respect to the strategies with a fixed fogging cycle. Thus PWM is a method of controlling the fog system as a function of cooling needs.

Toida *et al.*(2005) conducted a experiment to enhance fog evaporation rate using an upward air stream to improve greenhouse cooling performance. In this study, the use of a non-aspirated thermocouple in a column-shaped shelter with a flat roof was examined to determine the dry-bulb temperature in a greenhouse equipped with the fog system. During operation of a fog system for greenhouse cooling, fog wafts in the air inside the greenhouse. If the fog adheres to a sensing part of a thermometer, such as a junction of a thermocouple, measurement of dry-bulb temperature decreases and sometimes reaches a wet-bulb temperature while the fog evaporates. The results indicated that a combination use of the shelter and an empirical correction for eliminating radiation effects provided the most accurate determination of the dry-bulb temperature during the operation of the fog system. Owing to the fog adherence to a junction of a thermocouple in an aspirated psychrometer or a bare thermocouple without the shelter, its measurement was significantly lower than the actual dry-bulb temperature during the operation of the fog system.

Tamimi *et al.*(2013) carried out an analysis of microclimate uniformity in a naturally ventilated greenhouse with a high pressure fogging system.The objective of this study, then, was to develop a 3D computational fluid dynamics (CFD) model capable of more efficiently analysing the movement of air in a naturally ventilated greenhouse equipped with a high-pressure fogging system.

The overall model included five subunits: (1) a porous media model to simulate the ways that a crop canopy will affect airflow, (2) a solar load model and (3) a discrete ordinates radiation model to simulate solar radiation, (4) a species transport and discrete phase model to simulate evaporation of droplets, and (5) an evapotranspiration (ET) model integrated with a user-defined function. The overall model predicted temperature and relative humidity within the greenhouse with percentage errors for temperature and relative humidity of 5.7% to 9.4% and 12.2% to 26.9%, respectively (given a 95% confidence interval). The average per cent error between the simulated and measured ET was around 8%, and the CFD-simulated stomatal and aerodynamic resistances agreed well and were within the ranges indicated by earlier research. Having validated the overall model with experimental data, we then used a 24 full-factorial design to determine the effects on climate uniformity produced by four factors: position of the side vent, position of the vertical sprayer nozzles, position of the horizontal sprayer nozzles, and angle of the nozzle. On the basis of our statistical analysis, we concluded that "horizontal nozzle position" was the most significant factor for climate uniformity, while the least significant factor among those evaluated was "side vent opening".

Zhang *et al.*(2015) carried out an experiment for regulating the vapour pressure deficit by Greenhouse Micro-Fog Systems which leads to improved growth and productivity of tomato through enhancing photosynthesis during Summer Season. Experiments were carried out in a multi-span glass greenhouse, which was divided into two identical compartments involving different environments such as without environment control and with a micro-fog system operating when the air vapour pressure deficit (VPD) of greenhouse was higher than 0.5 KPa. During summer season the micro-fog system effectively alleviated heat stress and evaporative demand in the greenhouse. The favourable environment maintained by micro-fog treatment significantly enhanced elongation of leaf and stem, which contributed to a substantial elevation of final leaf area and shoot biomass and these lead to increase of marketable tomato yield per plant. The improvement of plant growth and productivity in micro-fog treatment was determined by the significantly enhanced NAR and photosynthetic capacity. Relative growth rate (RGR) of micro-fog treatment was also significantly higher than control plants, which was mainly determined by the substantial elevation in net assimilation rate (NAR), and to a lesser extent caused by leaf area ratio (LAR). Measurement of leaf gas exchange parameters also demonstrated that micro-fog treatment significantly enhanced leaf photosynthesis capacity.

2.3.5.2 MIST TYPE COOLING SYSTEM

Katsoulas *et al.* (2001) carried out a study on Effect of misting on transpiration and conductance's of a greenhouse rose canopy. The influence of greenhouse humidity control on the transpiration rate (λE_c), sensible heat flux (H_c) and bulk stomatal conductance (g_c) of a soilless rose canopy (*Rosa hybrida*, cv. First Red) was studied in a greenhouse located in the coastal area of eastern Greece. Measurements were carried out during several days in the summer (i) without air humidity control and (ii) with a mist system operating when the relative humidity of the greenhouse air was lower than 75%. The diurnal course of g_c was determined from the relation linking λE_c to canopy-to-air vapour pressure deficit (D_c) or from inversion of the Penman–Monteith equation. The two ways of estimating g_c were in good agreement, showing a significant increase of g_c under mist conditions. Co-variation of radiation and humidity during the day caused diurnal hysteresis in λE_c and g_c. The hysteresis phenomena were less marked when the mist system was operating. Normalising g_c by radiation removed most of the hysteresis and indicated a curvilinear stomatal response to vapour pressure deficit. The analysis of the energy partition at the canopy showed high negative values of the Bowen ratio ($\beta \approx -0.7$) in both conditions, indicating that canopy transpiration played a major role in cooling the greenhouse atmosphere. The contribution of the mist system to total evaporative cooling was estimated to be about 20%, with only 40–50% of the mist water being effectively used in cooling. Calculation of the crop water stress index confirmed that the crop was less stressed under misting conditions. It was concluded that the prediction of short-term variations of λE_c and g_c in greenhouse environments must account for the magnitude and diurnal variation of air VPD.

2.3.5.3 ROOF EVAPORATIVE COOLING

Cohen *et al.*(1983) experimentally investigated the cooling efficiency of greenhouse by wetting the outer roof and inner crop soil crop soil surfaces where tomatoes were grown. They reported that wetting of roof had a smaller effect on reducing air and canopy temperature than wetting the canopy. However, combination of both wetting treatments reduced inside air temperature by about 5˚C and canopy temperature by nearly 7˚C below the ambient condition.

Sutar and Tiwari (1995) carried an experimental study in a polyethylene covered even span greenhouse where water was circulated on the roof. A temperature reduction of 4-5°C was achieved compared to the control greenhouse. When a shade cloth was put on the roof air along with water circulation, the inside air temperature, reduced by 10°C compared to the control greenhouse

2.3.5.4 FAN AND PAD EVAPORATIVE COOLING SYSTEM

Bucklin *et al.*(1993) carried out an experiment for controlling temperature in Florida greenhouses using evaporative cooling system. dry bulb temperature and wet bulb temperature has to be noted .Wet bulb temperatures can be determined by checking with your local weather station or by investing in an aspirated psychrometer, a sling psychrometer, or an electronic humidity meter. corrugated cellulose that has been impregnated with wetting agents and insoluble salts to help resist rot has been used as pad .Ventilation and cooling fans equipped with anti-back draft shutters is provided.The evaporative pad cooling system must have adequate controls for the operator to be able to adjust the house environment to provide the best growing conditions for plants and a comfortable environment for workersA humidistat can be used to control pumps and fans of the cooling pad system to help prevent excessive greenhouse but are limited to simply turning pieces of equipment on or off in response to a change in temperature or relative humidity and they cannot regulate environmental conditions. So Computers and microcontrollers can be used which are rapidly decreasing in cost, while at the same time increasing in reliability and sophistication. Finally study reveals that correctly designed and installed pad system is essential to achieve maximum cooling performance.

Misra and Gosh *(2003)* presented the thermal model of a fan-pad ventilated greenhouse with distributed evaporative cooling has to minimize the temperature gradient along the length. An uneven-span ridge type greenhouse is considered, the fans being aligned along the ridge of the greenhouse and the cooling pads being aligned along the side wall segments. The analysis is based on energy balance equations for various elements like plants, floor and inside air of the greenhouse. A computer program in C has been developed to solve the energy equations and compute the performance parameters for a given set of input climatic and geometric data. The model has been compared with an earlier model available in the literature which was based on a single-element analysis considering the whole greenhouse as a single entity. The analysis suggests that during extreme summer days, the greenhouse air temperature can be maintained about 5-7oC below the ambient temperature for a given ventilation rate of 1.2 ACM and canopy shading of 50%. Parametric studies are presented to show the effects of various operating parameters viz. ventilation rate, shading and leaf area index on the greenhouse air and plant temperature.

Kittas *et al.*(2003) presented a model to predict the gradient of temperature in a fan–pad greenhouse glazed with double inflated plastic polyethylene–ethylene vinyl acetate (PE-EVA) films and partially shaded at the second 30 m of the greenhouse length by whitewash (40% shading). The model included the effect of roof shading, ventilation, and crop transpiration rate. The results showed that cooling system can maintain the greenhouse air temperature at 10°C lower than outside temperature in all circumstances. A large temperature gradient was observed between the pad and fans; it reached to 8°C along 60 m of greenhouse length. Temperature gradient in the first un-shaded part of the greenhouse was more pronounced than the second shaded part. Light transmission reduced from 60% in the un-shaded part to 40% in the shaded parts. The results also showed that a high ventilation rate with shading reduces air temperature gradient inside the greenhouse.

Fuchs *et al.*(2006) developed a procedure to evaluate latent heat cooling by means of crop transpiration and free water evaporation from a wet pad and fan system in a naturally ventilated greenhouse consisting of rose . The procedure uses concurrent external climatic factors as input data. It treats construction characteristics (dimensions and radiometric properties of the roof cover), plant foliage (leaf area, stomatal conductance) and ventilation rate as parameters to calculate heat transport coefficients. Measurements in a greenhouse rose crop showed that the numerical solution of the energy balance equation predicts accurately crop transpiration, foliage temperature, air temperature and humidity inside the greenhouse. With ventilation rates of 30 volume changes per hour and external air humidity below 50%, transpiration of a plant well supplied with water, cools the foliage and the air in the greenhouse below external temperature even when solar radiation is at its maximum value. Cooling obtained with an evaporative wet pad at the air inlet lowers vapour pressure deficit in the greenhouse and decreases transpiration rate. Still, total latent heat dissipation added to pad evaporation and crop transpiration is higher than that obtained by crop transpiration without the wet pad. The combined solution of the energy balance of the air passing through the evaporative pad and of the crop predicts accurately transpiration of the rose crop and internal temperature and humidity. The evaporative pad cools the air considerably; but the lowering of transpiring leaf temperature is only minor. Evaporation from the pad decreases when external humidity increases. Crop transpiration rate when the wet pad operates is nearly independent of external humidity and ventilation rate.

Sabeh (2007) conducted an experiment to investigate the water use by two evaporative cooling systems: pad –and fan and high-pressure-fog with fan ventilation. All studies were performed in a double layer polyethylene film-covered greenhouse with mature tomato plants. Water use efficiency (*WUE*, kg yield per m3 water use) was calculated daily according to ventilation rate, as well as for a 6-month cropping period, which used temperature-controlled pad-and-fan cooling. Pad-and-fan water use was 3.2, 6.4, 8.5, and 10.3 L m-2 d-1 for ventilation rates of 0.016, 0.034, 0.047, 0.061 m3 m-2 s-1, respectively. High-pressure-fog water use with a single central, overhead line was 7.9, 7.4, and 9.3 L m-2 d-1 for ventilation rates of 0.01, 0.016, 0.034 m3 m-2 s-1, respectively. For pad-and-fan ventilation rates less than 0.034 m3 m-2 s-1, total greenhouse *WUE* (20 – 33 kg m-3) was similar to field drip irrigation. For the temperature-controlled high-pressure-fog system, total greenhouse *WUE* (14 – 17 kgm-3) was similar to field sprinkler irrigation. For the 6-month crop cycle, combining water use by closed irrigation and pad and- fan systems produced a total *WUE* of 15 kg m-3. Pad-and-fan *WUE* increased during monsoon conditions due to lower water use rates. Evaporative cooling water use and air temperature were well-predicted by the energy balance model. Wind tunnel and full-scale studies of natural ventilation demonstrated the value of knowing airflow patterns when designing and operating a high-pressure-fog system It is possible for greenhouse tomato production to have a higher *WUE* than field production, if ventilation rates are not excessive, if closed irrigation is used, and if control methodologies are improved. Water use can be minimized by knowing how the evaporative cooling system affects greenhouse climate and plant responses.

Sapounas *et al.*(2008) presented a methodology approach to simulate by means of computational fluid dynamics (CFD) tools in a greenhouse equipped with a fan and pad evaporative cooling system d. Using the main aspects of evaporative cooling systems, in terms of heat and mass transfer, the flow and boundary conditions of the simulation model are identified taking into account both the external and internal climatic conditions. The crop (tomato) was simulated using the equivalent porous medium approach by the addition of a momentum source term. The temperature and humidity of incoming air and the operational characteristics of fans were specified to set up the CFD model. Numerical analysis was based on the Reynolds-averaged Navier-Stokes equations in conjunction with the realizable k-∈ turbulence model. The finite-volume method (FVM) was used to solve the governing equations. The 3D full scale model was solved in several differencing schemes of various orders in order to examine its accuracy. This simulation approach was used to identify the critical parameters of microclimate of a greenhouse and the regions where these have to be measured during the experimental processes. The simulation model was validated against experimental data based on the air temperature inside the greenhouse at twenty three points for three ventilation rates. These results showed good qualitative agreement in which the influence of the different airflow rates on greenhouse microclimate indicated that the proper choice of ventilation rate is a crucial factor in order to improve the efficiency of evaporative cooling systems in greenhouses.

Shukla *et al.* (2008) carried out aexperimental study in a cascade greenhouse with inner thermal curtain to see the effect of thermal curtain. A thermal model has also been developed to predict the air temperature in a cascade greenhouse. The fan-pad system has been used for evaporative cooling and an inner thermal curtain has been used to divide the greenhouse in two zones. Experiments have been conducted in hot summer conditions at Solar Energy Park, IIT Delhi, New Delhi, India for empty greenhouse. Statistical analysis has been carried out to validate the agreement of experimental observations with predicted values. The values of the root mean square percent deviation and coefficient of correlation has been found out 9.0%, 0.90; 5.0%, 0.95 and 7.0%, 0.97 for April, May and June in case of evaporative cooling without curtain in greenhouse-2. The degree of freedom for the experimental work is 10.0. It is found that the use of evaporative cooling with a thermal curtain reduces the temperature of greenhouse by 5 °C and 8 °C in the second zone of greenhouse-1 and 2 in comparison to greenhouse without curtain in May.

Fahmy *et al.* (2012) conducted a study on modeling and Simulation of Evaporative Cooling System in Controlled Environment Greenhouse. This work proposes a control- ling technique for greenhouse indoor temperature and relative humidity. The proposed greenhouse cooling system temperature controller is designed to adjust the air volume flow rate in pad-fan cooling system to fix the greenhouse indoor temperature at 20°C and 70% relative humidity. The designed control technique is realized to ensure the required and continuous operation of the greenhouse. Moreover, this work present, a complete mathematical modeling and simulation of cooling system is introduced. In addition, a computer model based on MATLAB SIMULINK software has been used to predict the temperature and relative humidity profiles inside the greenhouse. The results are realized the requirements of the greenhouse cooling system environment.

Manuwa1 and Odey(2012) conducted a study on Evaluation of Pads and Geometrical Shapes for Constructing Evaporative Cooling System. Investigations were carried out into local materials as cooling pads, and shapes for constructing evaporative coolers. Materials investigated include jute, latex foam, charcoal and wood shavings. Shapes of cooling systems considered were of hexagonal and square cross-sections. Some physical properties of pad materials that could affect the effectiveness of the evaporative coolers were also determined. Results of "No – load" tests carried out on the coolers indicated that the effectiveness of the cooling pads was in the following decreasing order of magnitude - Jute, latex foam, charcoal and wood shavings. The hexagonal shape cooler was found to be more efficient than the square shape. The average cooling or saturation efficiency for hexagonal cooler was 93.5% (jute), 91.4% (latex foam), 91.3% (charcoal) and 91.9% (wood shavings). The maximum temperatures observed were 6.4 (jute pad), 4.9 (latex foam pad), 5.2 (charcoal pad) and 3.6 degree Celsius. The results of this study will assist researchers in their selection of pad materials in the study of evaporative cooling systems.

Franco *et al* (2014) conducted a study on energy efficiency in greenhouse by using evaporative cooling techniques, i.e. a comparison study is made between cooling boxes and cellulose pads. Evaporative cooling systems using a combination of evaporative pads and extractor fans require greenhouses to be hermetic. The greatest concentration of greenhouses in the world is located in southeast Spain, but these tend not to be hermetic structures and consequently can only rely on fogging systems as evaporative cooling techniques. Evaporative cooling boxes provide an alternative to such systems. Using a low-speed wind tunnel, the present work has compared the performance of this system with four pads of differing geometry and thickness manufactured by two different companies. The results obtained show that the plastic packing in the cooling unit produces a pressure drop of 11.05 Pa at 2 m·s−1, which is between 51.27% and 94.87% lower than that produced by the cellulose pads. This pressure drop was not influenced by increases in the water flow. The evaporative cooling boxes presented greater saturation efficiency at the same flow, namely 82.63%, as opposed to an average figure of 65% for the cellulose pads; and also had a lower specific consumption of water, at around 3.05 L·h−1·m−2·°C−1. Consequently, we conclude that evaporative cooling boxes are a good option for cooling non-hermetic greenhouses such as those most frequently used in the Mediterranean basin.

Khater (2014) conducted a study on Performance of Direct Evaporative Cooling System under Egyptian Conditions. The main objective of this research is to optimize the parameters affecting the performance of the direct evaporative cooling system, to achieve that, a mathematical model of heat and mass balance of the evaporative cooling pads was developed to predict most important factors affecting the performance of the system. The model was able to predict the temperature, humidity ratio, wet bulb effectiveness, dew point effectiveness and temperature humidity index of outlet air at different ambient air temperatures different inlet air velocities, ambient air humidities and different lengths of pad. The results showed that the outlet temperature increases with increasing ambient temperature, inlet air velocity, ambient air humidities and lengths of pad. The results also showed that the wet bulb effectiveness ranged from 0.927 to 1.086. The dew point effectiveness ranged from 0.561 to 0.747. The humidity ratio ranged from 0.027 to 0.035 kg kg-1. The temperature-humidity index ranged from 21.15 to 33.56°C on study treatments. The predicted outlet temperatures were in a reasonable agreement with those measured, where it ranged 17.027 to 29.978°C theoretically while it was from 19.605 to 30.748°C experimentally. The prediction of temperature determines the optimum condition of plant growth in greenhouse, so that the model helps this optimization.

Dayioulua and Sİlleli (2014) conducted an experimental study to determine the performance parameters of system, as well as gradients of temperature and humidity along greenhouse when opening Fan-Pad cooling system. Measurements in the study were carried out by using seven sensors for different locations, as well as portable instruments, Such as digital temperature, humidity sensors and pyranometers. According to the experiment results, the non-uniform temperature changes, but approximately uniform humidity changes due to the crop transpiration were observed along greenhouse from pad panels to exhaust fans. When the cooling system closed, hourly mean temperature and relative humidity from Pad to Fan inside greenhouse changed between 30–33 °C and 30–47%, respectively, at outside climate conditions of 32 °C and 25%. After providing stabile cooling by opening Fan-Pad system, hourly mean temperature and relative humidity along greenhouse from pad to fan ranged between 20-27 °C, and 50 – 68%, respectively. The air temperature entering to greenhouse with air velocity of 0.8–0.9 m/s through pad was approximately 12–13 ºC lower than the outside air temperature. The air temperature from Pad to Fan increased approximately by 7 ºC. The method of psychometric calculations was employed to determine the cooling efficiency of Fan-Pad system. According to the calculation result, the average of air temperatures inside greenhouse was 24.5 ºC after achieving stable cooling for outside air temperature of 31.4 ºC. The hourly mean cooling effect and cooling efficiency calculated for Fan-Pad system were determined to be 6.96 ºC and 76.8%, respectively.

Materials and methods

CHAPTER III

MATERIALS AND METHODS

3.1STUDY AREA

The experiments were conducted in a naturally ventilated researchpolyhouse from November to January of 2016-17 at typical days with dry, sunny and cloudless. The research polyhouse located at PFDC, KCAET, Tavanur, Kerala. The site is situated on the cross point of 10^{o} 51’18” N latitude and 75^{o} 59’ 11” E longitude at an altitude of 8.54 m above mean sea level.

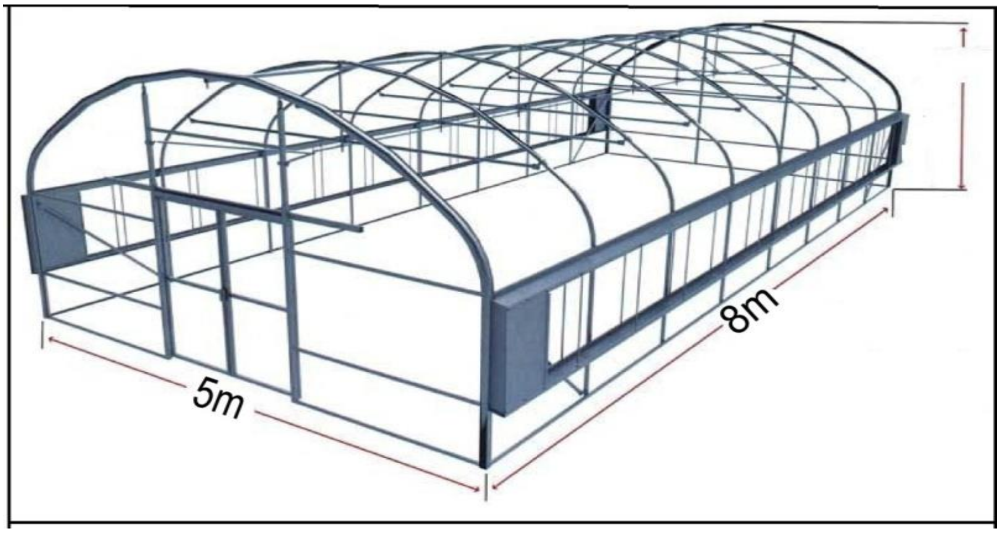


Figure 3.1 Schematic of experiment greenhouse used for cooling experiments

The floor area of the greenhouse is 40sq.m (8mx 5m). The greenhouse with galvanized steel frame is covered with polycarbonate sheets at thickness of 4 mm with double-walled and UV protection. General dimensions of the greenhouse are shown in Figure 1. The greenhouse is to be equipped with Fan-Pad cooling system.

3.2 COOLING PAD

The cooling capacity of evaporative pads depends on two factors: the flows of air and water that pass through them and the geometry of the material they are made of.

A pad material should be porous enough to allow free flow of air. It should be able to absorb water and allow evaporation. It should have maximum amount of wetted surface area for an adequate period of air water contact time to achieve near saturation. The material should be locally available and inexpensive. Moreover, it should allow easy construction into required shape and size.

It is expected that an evaporative cooling system must decrease the air temperature to the desired degree by minimum power consumption and expenses. Thus, an ideal pad media must have the highest evaporative saturation efficiency and the lowest airflow resistance. Water has to be fed through and over the evaporative pad installed by means of a water distribution pipe (PVC) having a number of pores. The water sump at the bottom of the pad should be large enough to hold all runoff (Figure 3.2).

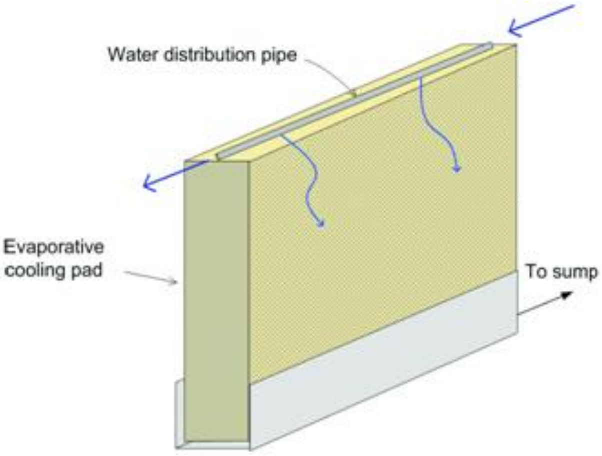


Figure 3.2 Cooling pad arrangement

3.3EVAPORATIVE COOLING BOX

3.3.1 TYPE A

Evaporative cooling box type A consists of exhaust fan and a evaporative pad material which are kept in-line inside a M.S box (40cm×25cm×40cm).

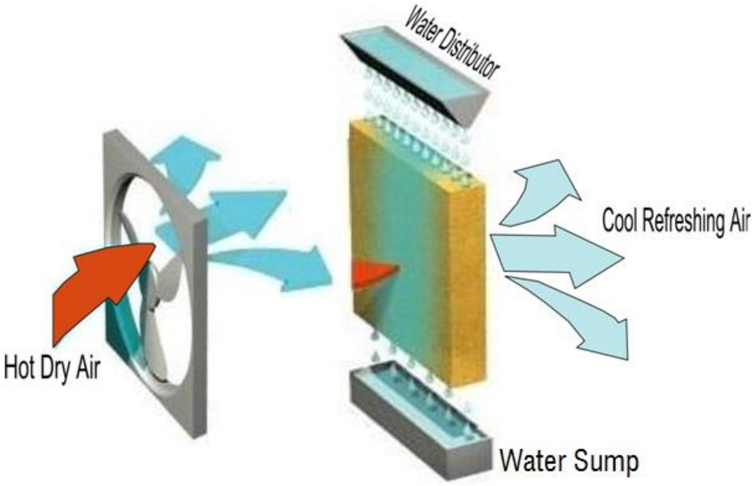


Figure 3.3Evaporative cooling pad arrangement in type A evaporative cooling box

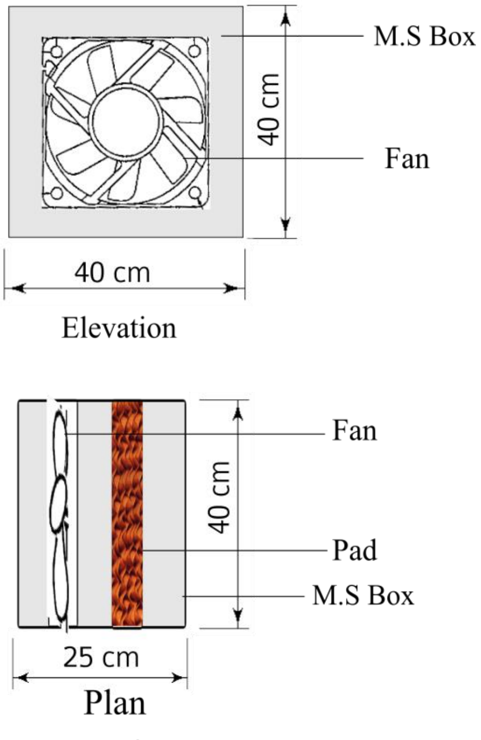


Figure 3.4Box type fan and pad cooling system(type A)

Plate 3.1 Box type fan and pad cooling system(type A)

3.3.2 TYPE B

Evaporative cooling box type B also consists of exhaust fan and an evaporative pad material and a water sump at the bottom of the pad. All having the same specifications as in type A evaporative cooling box. Only the arrangement has changed as shown in figures 3.5 and 3.6.

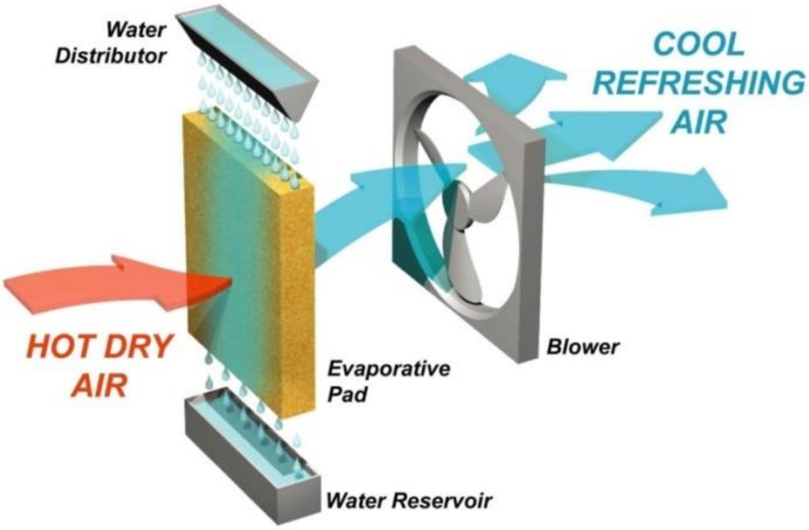
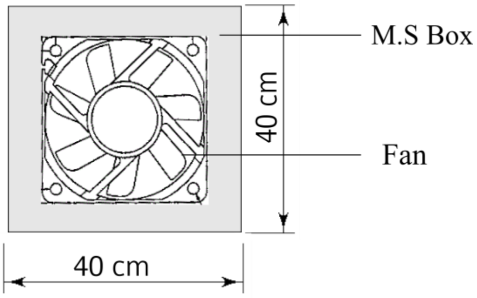
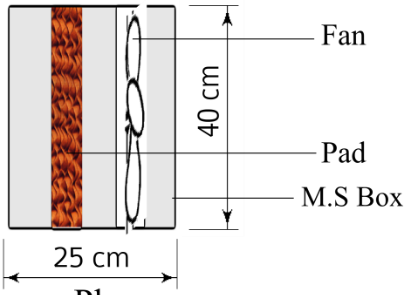


Figure 3.5Evaporative cooling pad arrangement in type B evaporative cooling box



Elevation



Plan

Figure 3.6Box type fan and pad cooling system (type B)

Plate 3.2 Box type fan and pad cooling system (type B)

Table 3.1 Specifications of particulars for type A and Type B systems

Sl No	Particulars	Specifications	Type A	Type B
1	Fan	Speed (rpm)	1350	1350
		Sweep (mm)	305	305
		Input power (W)	75	75
		No. of phases	1	1
2	Pad	Material	Jute bag	Jute bag
		Area	40cm×40cm	40cm×40cm
3	Box	Material	M.S sheet	M.S sheet
		length(cm)	40	40
		Breadth(cm)	25	25
		Height(cm)	40	40

If all vents and doors are closed when the fans operate, air is pulled through the wetted pads and water evaporates. Removing energy from the air lowers the temperature of the air being introduced into the greenhouse. The air will be at its lowest temperature immediately after passing through the pads. As the air moves across the house to the fans, the air picks up heat from solar radiation, plants, and soil, and the temperature of the air gradually increases. The resulting temperature increase as air moves down the greenhouse produces a temperature gradient across the length of the greenhouse, with the pad side being coolest and the exhaust fan side warmest (figure 3.7).

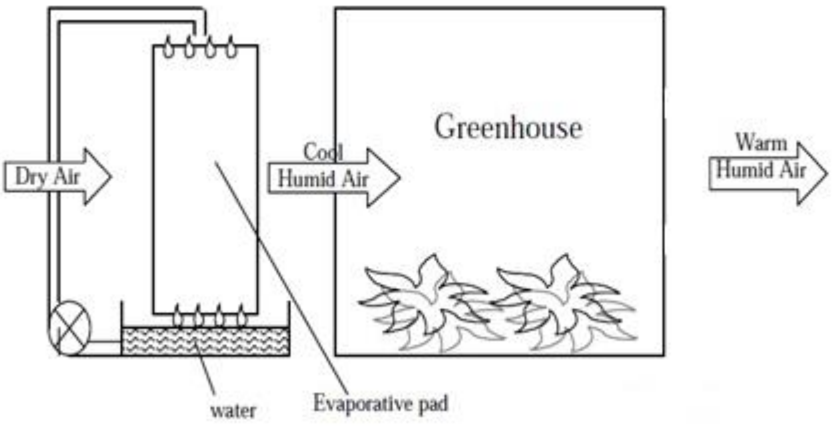


Figure 3.7 Representation of air flow through fan and pad cooling system

3.4 OBSERVATIONS

3.4.1 WEATHER PARAMETERS

Following weather parameters were recorded at different distances from the cooling boxes inside the polyhouse. The parameters are measured daily at one hour interval from 6.00 am to 6.00 pm for 10 days without cooling boxes and for a week with different type of cooling box separately.

3.4.1.1 Temperature (^oC)

Air temperatures inside and outside the polyhouse are recorded using thermo hygrometer.

Plate 3.3 Thermo hygrometer

3.4.1.2 Relative Humidity (%)

The relative humidity inside and outside the polyhouse has recorded using thermo hygrometer.

3.4.1.3 Light intensity (lux)

The solar light intensity is measured using luxmeter.

Plate 3.4Luxmeter

3.4.1.4 Air velocity (m/h)

The velocity of air flowing from the evaporative cooling box is measured using a digital anemometer.

Plate 3.5 Digital anemometer

3.4.2 PERFORMANCE PARAMETERS

The difference between the outside temperature and inside temperature can be used as an important parameter to describe the cooling performance of Fan-Pad system. For this purpose, as an easy criterion, the cooling effect of Fan-Pad system is calculated from

$$\Delta t = to - ti \qquad (1)$$

Where; Δt, temperature gradient (°C); to, outside air temperature (°C); ti, inside air temperature (°C).

The cooling efficiency (η) is determined as the ratio between the drop in air temperature after passing through the Pad and the maximum drop under conditions of air saturation.

$$\eta = \frac{t_{db}(1) - t_{db}(2)}{t_{db}(1) - t_{wb}(1)} \times 100 \qquad (2)$$

(Dayioglu, 2014)

Where; η, cooling efficiency (%); tdb(1), the outside dry-bulb temperature of entering air to Pad (°C); tdb(2), the dry-bulb temperature of leaving air form Pad (°C); twb(1), the outside wet-bulb temperature of entering air to Pad. However, two psychometric properties of entering air to the system must be known:

1. Dry bulb temperature and the wet-bulb temperatures and
2. Dry bulb temperature and relative humidity

If both dry bulb temperature (tdb) and the wet- bulb temperature (twb) is measured directly, the cooling efficiency can be calculated by substituting into equation (2). If dry-bulb temperature (tdb) of air and relative humidity (rh) are known, its wet-bulb temperature (twb) can be calculated by using psychometric chart. The method of psychometric calculations used at measurements is employed to determine the cooling efficiency of evaporative Fan-Pad system.

3.5DEVELOPMENT OF A NEW SYSTEM (TYPE C)

Based on the observations taken for both the type A and Type B systems of evaporative cooling boxes a new system of evaporative cooling box (type C) is fabricated and tested using a heavy duty fan.

Table 3.2 Specifications of fan for type C system.

Sl No	Particulars	Specification
1	Speed (rpm)	1400
2	Sweep (mm)	450
3	Input power (W)	410
4	No. of phases	1

During the observations it was found that the air that flows from the fan has got hit on the frames of the pad and pipe arrangement in type-A and type-B cooling boxes. In order to overcome that and to get uniform air flow, in type-C cooling box a duct shaped pad and pipe arrangement has developed.

Plate 3.6 M.S box for type-C cooling box.

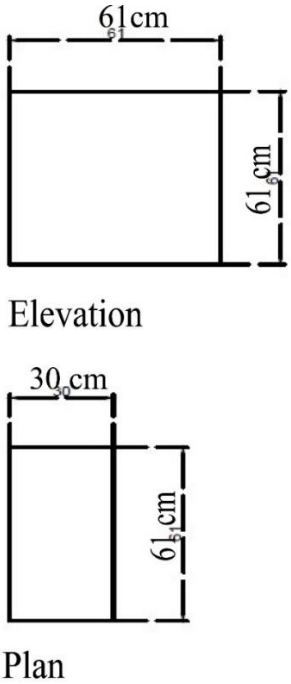


Figure 3.8 M.S box for type-C cooling box.

Plate 3.7 Pad arrangement for type-C cooling box.

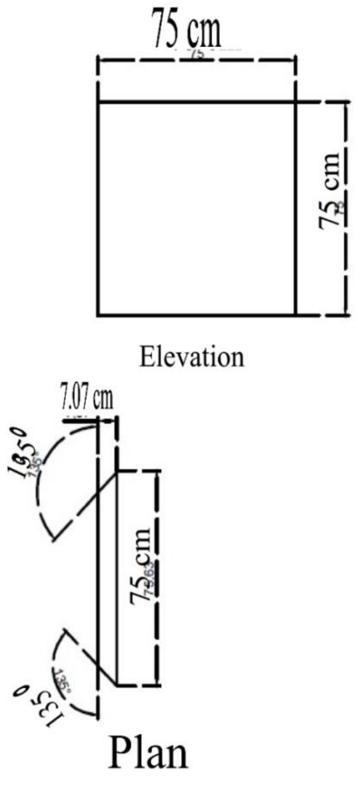


Figure 3.9 Pad arrangement for type-C cooling box.

Table 3.3 Specifications of particulars for type C cooling box

Sl No	**Particulars**	**Specifications**	**Type C**
1	Fan	Speed (rpm)	1400
		Sweep (mm)	450
		Input power (W)	410
		No. of phases	1
2	Pad	Material	Jute bag
		Area	67 cm×67 cm
3	Box	Material	M.S sheet
		length(cm)	61
		Breadth(cm)	30
		Height(cm)	61

Results and

disscussion

CHAPTER IV

RESULTS AND DISSCUSSION

The study was taken under the objective of fabrication of a evaporative cooling box for a naturally ventilated greenhouse located in KCAET college, Tavanur, near PFDC office. First of all, the cooling boxes A and cooling box B has been fabricated and installed in the naturally ventilated greenhouse and its performance has been evaluated by measuring the climatic parameters inside the naturally ventilated greenhouse for one week. Then cooling box C has been fabricated and installed in the greenhouse and then climatic parameters inside greenhouse are measured for evaluating its performance.

4.1 COMPARISON OF CLIMATIC DATA

The climatic parameters such as temperature, Relative humidity and intensity of solar radiation inside and outside of the naturally ventilated greenhouse are measured before the installation of cooling system in the greenhouse from 22-11-2016 to 1-12-2016. And the climatic parameters are again measured after the installation of cooling boxes about 1 week, here the climatological parameters before and after cooling are measured and its variation is analysed. The measurements are taken for every 1m distance throughout the entire length inside the greenhouse at an interval of 1 hour from 6.00am to 6.00pm.

4.1.1 WITHOUT A COOLING BOX

The following table shows the weather parameters for every1m distance throughout entire length from 6.00am to 6.00pm inside the naturally ventilated greenhouse before installation of cooling boxes for 10 days (22-11-2016 to 1-12-2016). The outside climatic parameters are also observed and the relative humidity of most shaded portion outside the greenhouse is considered.

4.1.1.1AIR TEMPERATURE

The daily peak air temperature inside the greenhouse are noted and tabulated in the following table and the variation in the average of the daily peak air temperature for every 1m distance are shown in table 4.2. The table showsthat there was a gradual increase in air temperature from the opening side to the rear end of greenhouse. The maximum air temperature found inside the polyhouse was about 42.5°C.

Table 4.1 Daily peak temperatures.

Date	**Distance (m)**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Out**
22/11/2016	36.9	36.8	37	37.1	37	37.2	37.2	37.1	37.2	35.7
23/11/2016	39.5	39.6	39.6	39.7	39.7	39.7	39.9	40	40.1	37.8
24/11/2016	43.5	43.4	43.4	43.5	43.6	43.7	43.8	43.8	43.9	40.5
25/11/2016	42.5	42.5	42.6	42.7	42.7	42.7	42.8	43	43.1	38.5
26/11/2016	44	44.1	44.2	44.3	44.5	44.5	44.6	44.7	44.8	41
27/11/2016	37.1	36.9	36.9	36.8	36.8	36.7	36.7	36.6	36.5	34.7
28/11/2016	40.1	40.1	40.2	40.3	40.4	40.5	40.6	40.7	40.9	37.4
29/11/2016	39.9	39.9	40	40	40.1	40.2	40.3	40.4	40.5	41
30/11/2016	41.8	41.8	41.9	50	50.1	50	50.1	50.2	50.3	36.9
1/11/2016	44	44.1	44.2	44.3	44.4	44.5	44.5	44.6	44.7	43.2
Average	40.93	40.92	41	41.87	41.9	41.97	42.05	42.11	42.2	38.67

A temperature against graph has plotted for the analysis of the above data (figure 4.1)

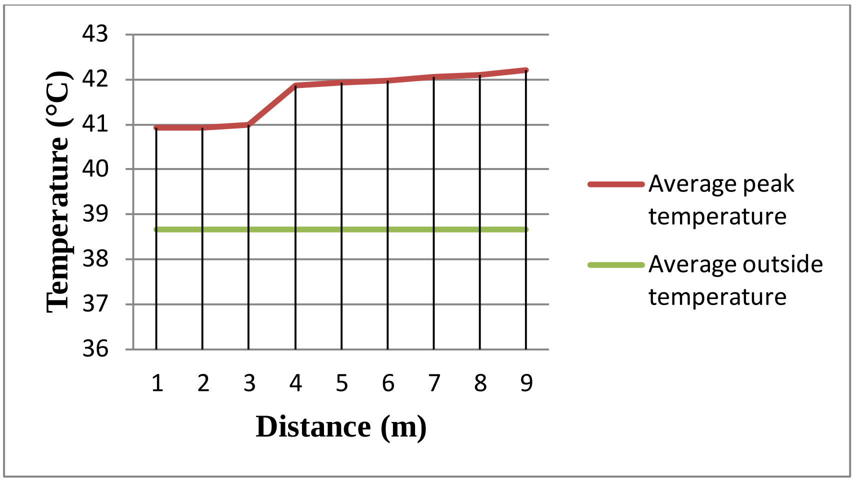


Figure 4.1 Temperature vs distance graph for the polyhouse without cooling box

4.1.1.2 RELATIVE HUMIDITY

The daily average relative humidity corresponding to the daily peak air temperatures are tabulated and a relative humidity vs distance graph has plotted.

Table 4.2 Daily R.H corresponding to daily peak temperature

Date	**R.H (%)**									
	Inside									**Outside**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
22/11/2016	29	30	31	36	36	37	38	37	38	36
23/11/2016	25	26	25	26	27	27	27	27	27	26
24/11/2106	28	29	30	28	29	29	29	29	29	29
25/11/2016	32	33	33	33	34	34	34	35	35	33
26/11/2016	27	27	28	28	28	28	28	28	29	27
27/11/2016	31	30	28	31	31	31	31	31	31	34
28/11/2016	26	26	25	25	25	26	25	25	25	24
29/11/2016	38	39	39	39	39	39	39	38	38	39
30/11/2016	28	27	28	29	30	30	30	30	31	28
1/12/2016	35	35	36	36	36	36	35	36	36	33
Average R.H (%)	29.9	30.2	30.3	31.1	31.5	31.7	31.6	31.6	31.9	30.9

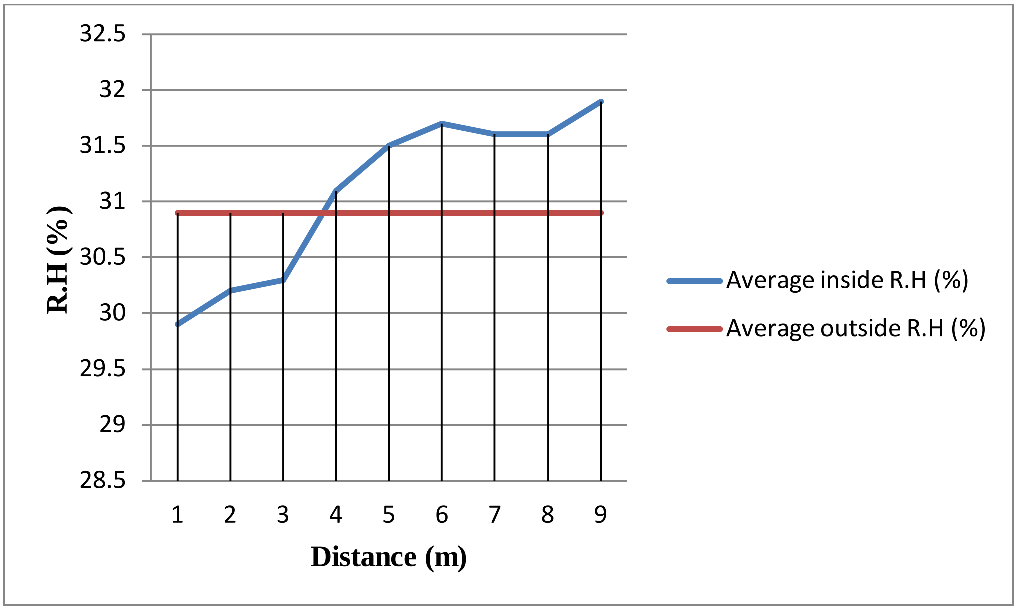


Figure 4.2 R.H vs distance graph for the polyhouse without cooling box

4.1.1.2 SOLAR LIGHT INTENSITY

The daily average solar light intensity corresponding to the daily peak air temperatures are tabulated and a solar light intensity vs distance graph has plotted.

Table 4.3 Daily intensity of solar radiation corresponding to daily peak temperature

Date	**Intensity of solar radiation (lux)**									
	Inside									**Outside**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
22/11/2016	3900	4310	4160	5600	6370	7300	9000	8210	8300	39000
23/11/2016	7540	8300	9700	10250	12400	12900	13400	14800	15100	64500
24/11/2106	13800	14500	12220	13100	1310	1320	1380	1480	1490	74000
25/11/2016	13900	13300	12400	12100	12400	13200	12800	14300	14800	38000
26/11/2016	6300	6700	7500	8700	9800	10400	12300	14200	15700	72000
27/11/2016	5700	4700	4400	4800	5100	6000	6900	7600	7800	58000
28/11/2016	9500	10800	11200	12300	14700	15600	15900	16700	16800	64000
29/11/2016	9600	9300	10800	11400	12600	13700	14800	15200	15400	51000
30/11/2016	5400	5800	6200	6400	6600	7500	7500	7800	7900	32000
1/12/2016	10400	11800	12500	12900	13600	14700	15800	16300	16700	62000
Average	8604	8951	9108	9755	9488	10262	10978	11659	11999	55450

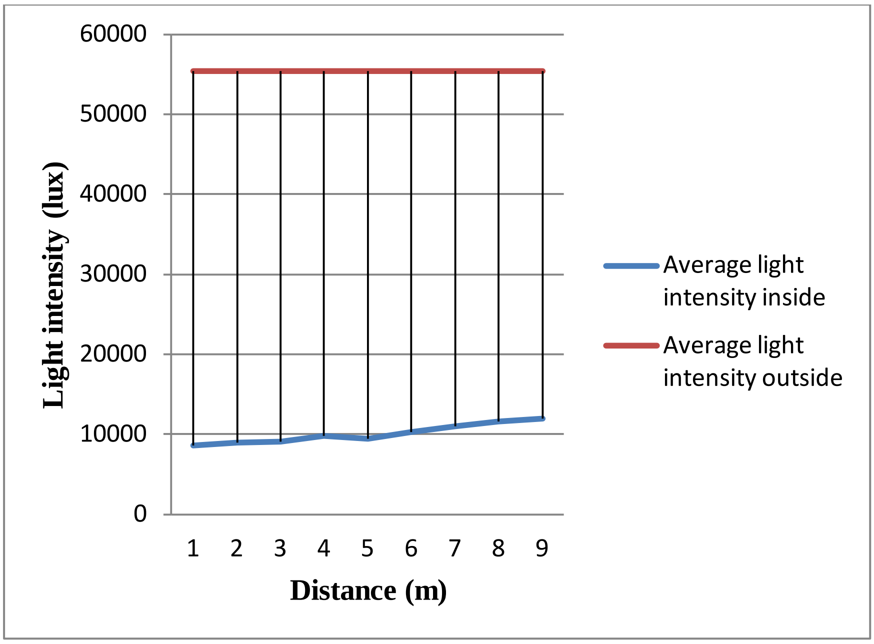


Figure 4.3 light intensity vs distance graph for the polyhouse without cooling box

From this data we could find that,

- The temperature gradually increases with distance from the opening side to rear side of greenhouse.
- There is an average increase of about 3°C in temperature inside the poly house from outside.
- As temperatures over 30°C will result in poor growth and yield, an advanced cooling system is necessary to enhance the crop performance.

4.1.2. DATA COMPARISON FOR TYPE-A AND TYPE-B COOLING BOXES

4.1.2.1 TEMPERATURE

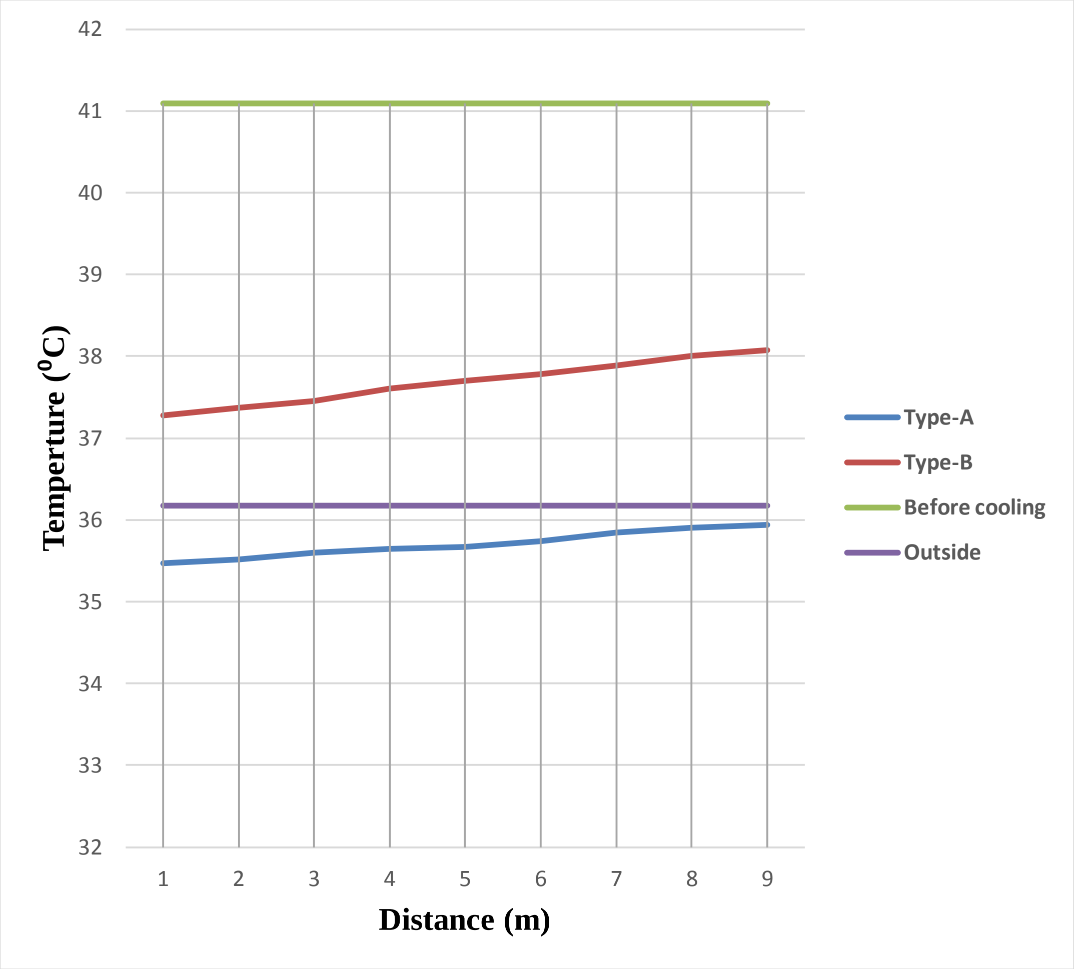


Figure 4.4 Graphical analysis of temperature variations with cooling boxes installed

As we could observe from the graph that while using type-A cooling box there is an average decrease of 5.34°C in the inside temperature and an average decrease of 3.4°C while using type-B cooling box.

4.1.2.2 RELATIVE HUMIDITY

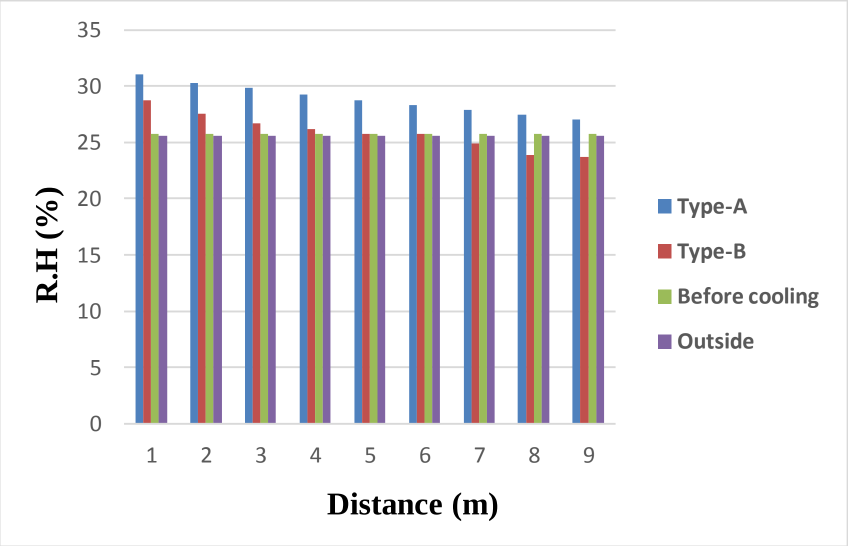


Figure 4.5 Graphical analysis of R.H variations with cooling box installed

4.1.2.3 AIR FLOW VELOCITY FROM COOLING BOX

Table 4.4 Air flow data for cooling boxes

Air flow (m/h)		
Distance (m)	**Type-A**	**Type-B**
0.5	4.4	5.5
1	2.9	2.1
1.5	1.8	0
2	0.7	0
2.5	0	0
3	0	0
3.5	0	0
4	0	0
4.5	0	0
5	0	0

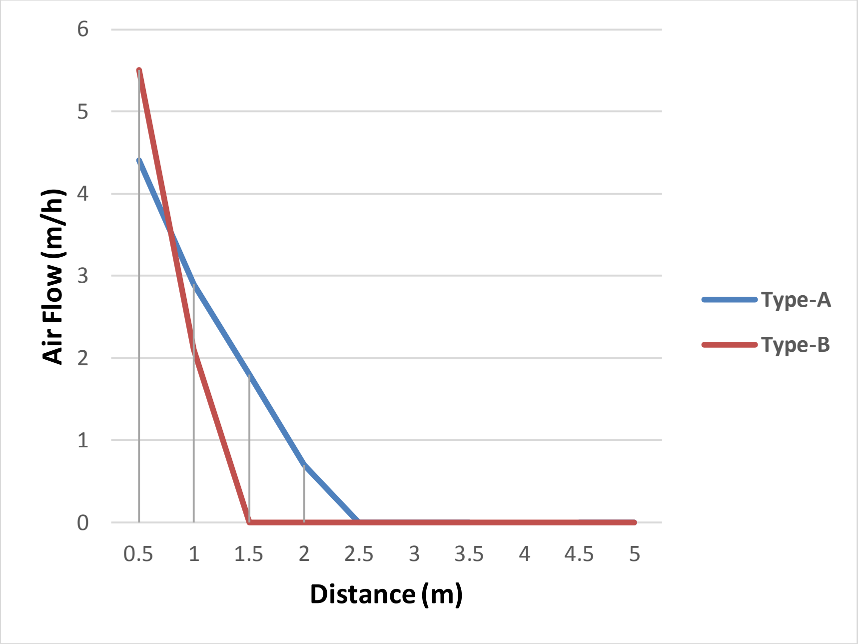


Figure 4.6 Graphical analysis of air flow for cooling boxes

From all these observations we have found that,

- While using type-A cooling box there is an average decrease of 5.34°C in the inside temperature and an average decrease of 3.4°C while using type-B cooling box.
- There is an average increase of 3.14% in relative humidity while using type-A cooling box but while using type-B there is only an increase of 0.17%.
- Even though the air flow from the type-B cooling box is 1.1 m/h greater than that from type-A, the sir flow is measurable up to a distance of 2 m. But in case of type-A cooling box, it is only up to a distance of 1 m from the box.

4.1.2.4 EFFICIENCY CALCULATION

The cooling efficiency (η) is determined as the ratio between the drop in air temperature after passing through the Pad and the maximum drop under conditions of air saturation.

$$\eta = \frac{t_{db}(1) - t_{db}(2)}{t_{db}(1) - t_{wb}(1)} \times 100$$

(Dayioglu, 2014)

Where; η, cooling efficiency (%); tdb(1), the outside dry-bulb temperature of entering air to Pad (°C); tdb(2), the dry-bulb temperature of leaving air form Pad (°C); twb(1), theoutside wet-bulb temperature of entering air to Pad.

From the above equation the efficiency of the cooling boxes has been calculated.

- Efficiency of type-A cooling box = 37.64 %
- Efficiency of type-B cooling box = 17 %

Thus the cooling box type-C is developed like that of type-A cooling box and same kind of observations are taken.

4.1.3 WITH TYPE-C COOLING BOX

4.1.3.1 TEMPERATURE

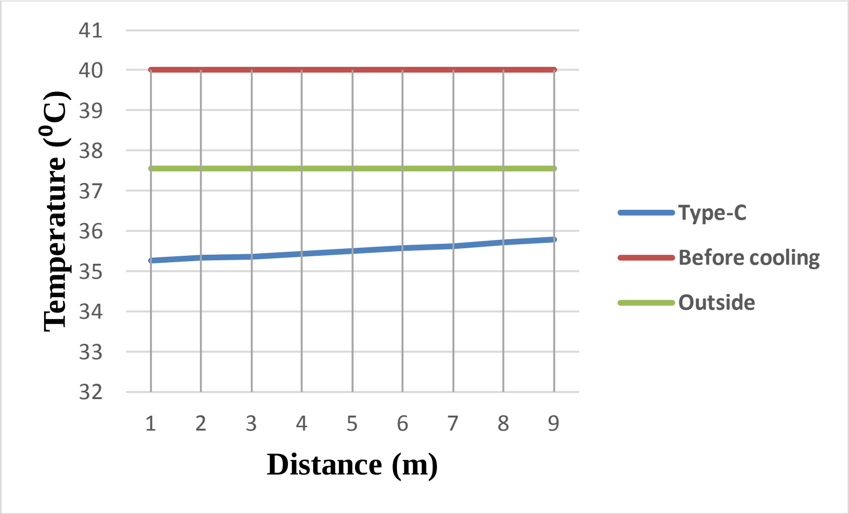


Figure 4.7 Graphical analysis of temperature for type-C cooling box.

4.1.3.2 RELATIVE HUMIDITY

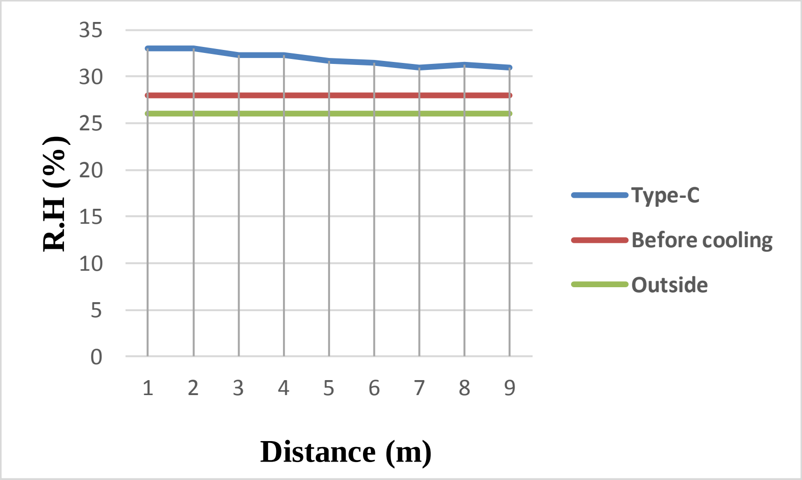


Figure 4.8 Graphical analysis of R.H for type-C cooling box.

4.1.3.3 AIR FLOW VELOCITY FROM COOLING BOX

Table 4.5 Air flow data for type-C cooling box

Distance (m)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
Air flow (m/h)	6.5	5.1	3.9	2.5	1.5	0.8	0	0	0	0

From these data we can infer that,

- While using type-C cooling box there is an average decrease of 4.5°C in the inside temperature.
- There is an average increase of 3.88 % in relative humidity while using type-C cooling box.
- The air flow from the type-C cooling box is high (6.5 m/h) comparing the same for type-A and type-B cooling boxes. It is also found that it is measurable up to a distance of 3 m.

4.1.4 DATA COMPARISON

4.1.4.1 TEMPERATURE

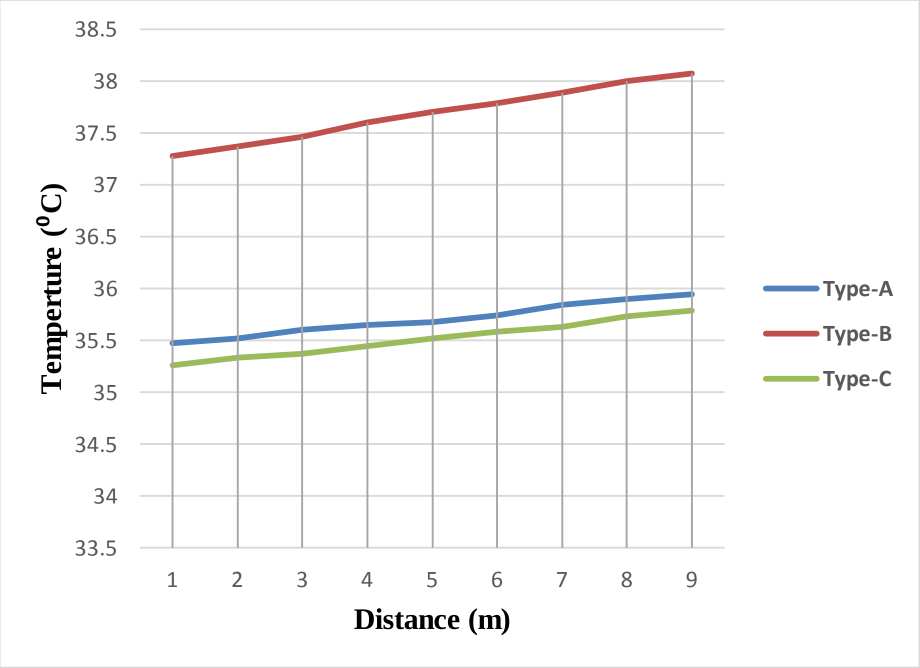


Figure 4.9 Representations of temperature data of cooling boxes

While using type-A cooling box there is an average decrease of 5.34°C in the inside temperature and an average decrease of 3.4°C while using type-B cooling box and 4.5°C in case of type-C cooling box. The difference in temperatures with the use of type-B and type-C cooling box decreases as goes from front to rear end of the polyhouse. This indicates that the temperature distribution is more uniform in case of type-C cooling box.

4.1.4.2 RELATIVE HUMIDITY

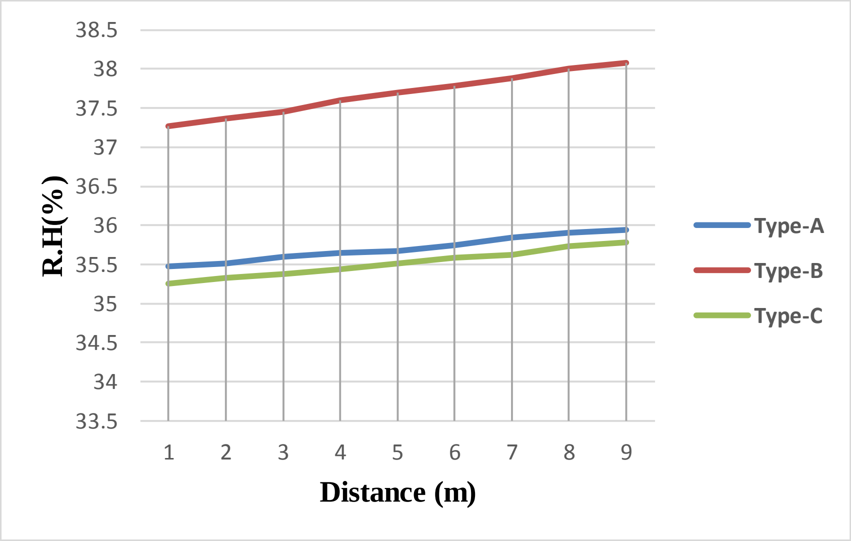


Figure 4.10 Representation of R.H data of cooling boxes

Relative humidity is more in the case of type-C cooling box than other two.

4.1.4.3 AIR FLOW VELOCITY

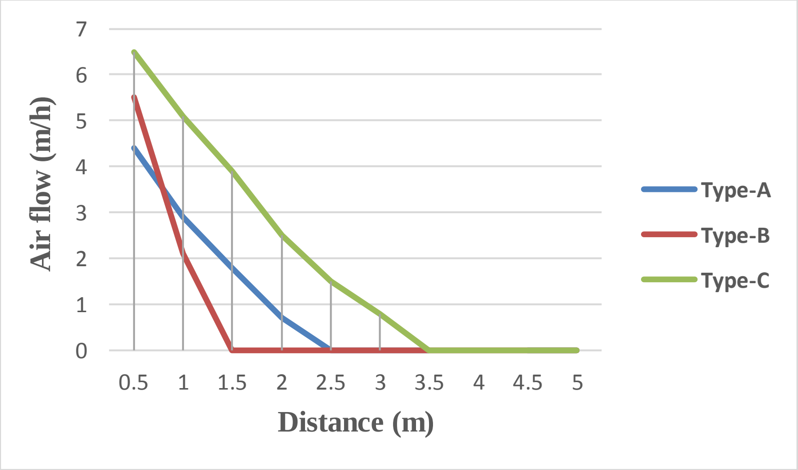


Figure 4.11 Graphical analysis of air flow for cooling boxes

Type-C cooling box delivers more velocity and uniform air flow than other two types. It delivers measurable air flow up to a distance of 3 m.

4.1.4.4 PERFORMANCE PARAMETER

- Efficiency of type-A cooling box = 37.64 %
- Efficiency of type-B cooling box = 17.00 %
- Efficiency of type-C cooling box = 30.70 %

Even though type C cooling box has got less efficiency (30.70%) than that of type A (37.64 %) type C cooling box gives more uniform weather parameters than type A and Type B cooling boxes.

Summary and conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The study entitled **“**Development and testing of evaporative cooling box for a naturally ventilated greenhouse” was taken up to fabricate a evaporative cooling box for naturally ventilated greenhouse situated in the KCAET campus and its performance is analyzed by a comparing the variation of microclimatic factors inside the green house using the cooling boxes.

The experiments were conducted in a naturally ventilated research polyhouse having a floor area of 40sq.m (8mx 5m from nov-2016 to jan-2017 at typical days with dry, sunny and cloudless. The research polyhouse located at PFDC, KCAET, Tavanur, Kerala. The site is situated on the cross point of 10^o 51’18” N latitude and 75^o 59’ 11” E longitude at an altitude of 8.54 m above mean sea level.

First of all the microclimatic parameters such as temperature, relative humidity and light intensity inside and outside greenhouse before the installation of cooling box are observed from 22-11-16 to 1-12-16.The measurements are taken for every 1m distance at an interval of 1hr from 6.00 am to 6.00 pm. Relative humidity and temperature are measured with temperature hygrometer and light intensity is measured using lux meter. Outside the greenhouse, temperature and humidity of most shaded part is noted. And its variation is studied. The graphical representation of variation of temperature reveals that the temperature gradually increases with distance from the opening side to rear side of greenhouse. There is an average increase of about 3°C in temperature inside the poly house from outside.

Evaporative cooling box type A consists of exhaust fan and an evaporative pad material which are kept in-line inside a M.S box (40cm×25cm×40cm) has been developed and fabricated. The pad material used should be economical and easily available and its cooling capacity depends on two factors: the flows of air and water that pass through them and the geometry of the material they are made of. A pad material should be porous enough to allow free flow of air. It should be able to absorb water and allow evaporation. It should have maximum amount of wetted surface area for an adequate period of air water contact time to achieve near saturation. So here a jute bag (45 cm× 45 cm) is used as pad material.

It is expected that an evaporative cooling system must decrease the air temperature to the desired degree by minimum power consumption and expenses. Water has to be fed through and over the evaporative pad installed by means of a water distribution pipe (PVC) having a number of pores. The water sump at the bottom of the pad should be large enough to hold all runoff.

Evaporative cooling box type B also consists of exhaust fan and an evaporative pad material and a water sump at the bottom of the pad. All having the same specifications as in type A evaporative cooling box, only the position of cooling pad (jute bag) varies.

The measurement of climatological parameters such as temperature, relative humidity and light intensity inside and outside greenhouse are taken from 30-12-16 to 05-01-17. The measurements are taken for every 1m distance throughout inside the greenhouse at an interval of 1 hr from 6.00 am to 6.00pm.And a comparison is between the observations obtained from the two cooling boxes(Type A and Type B). The result of the comparison reveals that the type A cooling box is more efficient than type B. Type A has reduced the temperature inside the greenhouse to some extend which enable the plants to exhibit an optimum growth conditions. But in type A cooling box cooling losses occurs due to the backward flow of air due to striking on the frame of the structure this the main disadvantage of type A cooling box

By eliminating the disadvantages of the type A cooling box, a new Type C cooling box has been developed and fabricated. Here the jute bag is again used as the pad material. The construction of Type C cooling box is in such a way that it reduces the maximum cooling losses and it exhibits an optimum performance for reducing the temperature inside the greenhouse. Then the climatic parameters such as temperature, relative humidity and light intensity inside and outside the greenhouse are measured. The measurements are taken about 1 week for every 1m distance throughout the length inside the greenhouse from 6.00 am to 6.00pm.The observations of the type C cooling system reveals that it reduces the temperature inside the greenhouse to such an extent that plants can exhibit optimum growth performance.

From the observations and analysis of the data collected, we could make a number of inferences. While using type-A cooling box there is an average decrease of 5.34°C in the inside temperature and an average decrease of 3.4°C while using type-B cooling box and 4.5°C in case of type-C cooling box. The difference in temperatures with the use of type-B and type-C cooling box decreases as goes from front to rear end of the polyhouse. This indicates that the temperature distribution is more uniform in case of type-C cooling box. Relative humidity is more in the case of type-C cooling box than other two. Type-C cooling box delivers more velocity and uniform air flow than other two types. It delivers measurable air flow up to a distance of 3 m. Even though type C cooling box has got less efficiency (30.70%) than that of type A (37.64 %), type C cooling box gives more uniform weather parameters than type A and Type B cooling boxes.

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CHAPTER VI

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Appendices

APPENDICES

APPENDIX 1

Measurement of temperature, relative humidity and light intensity inside and outside greenhouse before installation of cooling system . Daily measurements are taken for every 1m inside the greenhouse at an interval of 1 hr from 6.00am to 6.00 pm about 10 days (from 22-11-16 to1-12-16).

Date	Time	DISTANCE	INSIDE									Outside
22/11/2016	6.00 am		1	2	3	4	5	6	7	8	9	
		Temperature(°C)	24.9	24.9	24.9	24.9	25	25.1	25.2	25.3	25.4	24.5
		R.H(%)	76	76	76	76	77	79	79	79	79	71
		Light intensity(lux)	238	208	200	195	212	233	258	330	387	500
	7.00 am	Temperature(°C)	26.2	26.3	26.3	26.3	26.3	26.3	26.3	26.4	26.5	25.7
		R.H(%)	70	70	71	72	72	72	72	73	74	69
		Light intensity(lux)	430	435	442	448	456	462	472	485	492	23300
	8.00 am	Temperature(°C)	27.1	27.2	27.2	27.3	27.4	27.5	27.5	27.6	27.7	26.2
		R.H(%)	67	69	69	70	69	68	66	64	63	59

		Light intensity(lux)	580	520	502	508	525	596	655	1235	1255	30800
	9.00 am	Temperature(°C)	28.2	28.3	28.4	28.4	28.5	28.5	28.5	28.6	28.7	27.6
		R.H(%)	59	60	61	61	61	62	61	62	62	55
		Light intensity(lux)	986	1020	1120	1320	1500	1720	2010	2140	2560	31500
	10.00 am	Temperature(°C)	30	30.2	30.3	30.4	30.4	30.6	30.7	30.8	30.9	28.4
		R.H(%)	52	52	53	53	52	52	53	53	52	47
		Light intensity(lux)	1220	1542	1985	2500	2967	3115	3600	3987	4065	33200
	11.00 am	Temperature(°C)	32.1	32.2	32.3	32.3	32.3	32.4	32.4	32.5	32.5	30.5
		R.H(%)	48	49	51	51	51	51	52	53	53	44
		Light intensity(lux)	1520	1845	2400	2878	3100	3564	3852	4025	4050	35600
	12.00 pm	Temperature(°C)	34.2	34.2	34.3	34.4	34.5	34.5	34.5	34.5	34.5	32.6
		R.H(%)	41	42	43	43	44	44	43	44	45	37

		Light intensity(lux)	1995	2220	2510	2664	3115	3625	4010	4445	5625	36300
	1.00 pm	Temperature(°C)	35.5	35.5	35.4	35.5	35.6	35.7	35.7	35.7	35.8	34
		R.H(%)	35	36	36	37	37	38	37	38	39	29
		Light intensity(lux)	2560	2820	3100	3250	3865	4120	4670	5845	6995	37500
	2.00 pm	Temperature(°C)	36.9	36.8	37.1	37.1	37	37.2	37.2	37.1	37.2	35.7
		R.H(%)	29	30	31	36	36	37	38	37	38	36
		Light intensity(lux)	3900	4310	4160	5600	6370	7300	9000	8210	8300	39000
	3.00 pm	Temperature(°C)	36	36.2	36.4	36.4	36.4	36.6	36.6	36.7	36.8	35.8
		R.H(%)	35	36	36	36	37	37	38	38	38	33
		Light intensity(lux)	3540	3610	3655	3955	4255	4612	5246	6158	6580	34500
	4.00 pm	Temperature(°C)	34.5	34.5	34.5	34.6	34.7	34.7	34.8	34.8	34.8	33.6
		R.H(%)	40	41	41	42	43	43	43	45	46	36

		Light intensity(lux)	2500	2780	2995	3120	3500	4010	3775	3995	4225	33580
	5.00 pm	Temperature(°C)	32	31.9	31.9	31.9	31.8	31.9	31.9	31.9	31.9	31.5
		R.H(%)	49	53	55	63	54	52	51	50	49	48
		Light intensity(lux)	1140	1000	810	830	820	910	920	1060	1200	33220
	6.00 pm	Temperature(°C)	25.1	25.2	25.3	25.3	25.3	25.3	25.4	25.4	25.5	23.9
		R.H(%)	52	53	53	55	56	56	57	56	57	52
		Light intensity(lux)	352	354	361	367	375	382	388	394	402	738
23/11/2016	6.00 am	Temperature(°C)	25.4	25.5	25.5	25.6	25.5	25.6	25.6	25.7	25.8	21.3
		R.H(%)	75	74	74	74	75	76	76	76	77	75
		Light intensity(lux)	630	755	786	850	892	915	987	1050	1220	2700
	7.00 am	Temperature(°C)	26.8	26.8	26.8	26.9	26.9	27.1	27.1	27.1	27.1	26.5
		R.H(%)	63	72	78	78	79	78	76	74	70	64

		Light intensity(lux)	1510	1280	1210	1180	1270	1300	1530	1890	2220	3320
	8.00 am	Temperature(°C)	29.2	29.3	29.4	29.4	29.4	29.5	29.6	29.8	30	26.4
		R.H(%)	57	57	58	58	58	59	59	60	60	56
		Light intensity(lux)	2800	2900	3400	3600	3600	4200	4800	5100	5200	7500
	9.00 am	Temperature(°C)	32.9	33	33.1	33.2	33.2	33.2	33.3	33.4	33.6	27.6
		R.H(%)	43	45	45	44	45	45	47	47	47	41
		Light intensity(lux)	3600	4200	4800	4800	5300	5900	6300	6800	7100	1500
	10.00am	Temperature(°C)	34.6	34.7	34.8	34.8	34.8	34.9	35	35.1	35.3	31.2
		R.H(%)	38	37	37	37	37	37	37	38	39	37
		Light intensity(lux)	4300	4700	5500	6400	6900	7300	8200	8300	9000	20600
	11.00am	Temperature(°C)	35.3	35.4	35.4	35.4	35.5	35.5	35.6	35.7	35.8	30.6
		R.H(%)	35	36	36	37	37	37	38	38	38	36

		Light intensity(lux)	4800	5600	6800	7300	8400	9200	10600	15000	16200	35000
	12.00pm	Temperature(°C)	37.5	37.6	37.7	37.7	37.8	37.8	37.8	37.9	37.9	34.5
		R.H(%)	34	32	32	33	33	33	34	34	34	40
		Light intensity(lux)	5520	5940	6100	6300	6850	7350	7950	9250	10520	45500
	1.00 pm	Temperature(°C)	38.2	38.3	38.4	38.4	38.4	38.5	38.5	38.6	38.8	36.5
		R.H(%)	28	29	29	29	29	30	30	30	30	27
		Light intensity(lux)	6580	7250	7940	8540	9320	10520	10490	13250	16980	62200
	2.00 pm	Temperature(°C)	39.5	39.6	39.6	39.7	39.7	39.7	39.9	40	40.1	37.8
		R.H(%)	25	26	25	26	27	27	27	27	27	26
		Light intensity(lux)	7540	8300	9700	10250	12400	12900	13400	14800	15100	64500
	3.00 pm	Temperature(°C)	36	36.1	36.2	36.4	36.4	36.5	36.6	36.8	39	28.5
		R.H(%)	33	34	34	35	36	36	36	37	37	35

		Light intensity(lux)	4320	4510	5200	5690	6450	7020	8030	8420	8500	22800
	4.00 pm	Temperature(°C)	32.4	32.5	32.6	32.6	32.7	32.8	32.9	33	33.2	28.5
		R.H(%)	38	39	39	40	41	40	42	43	43	39
		Light intensity(lux)	2900	3100	3500	3600	3900	4100	4500	4600	4700	18300
	5.00 pm	Temperature(°C)	31.6	31.6	31.6	31.6	31.7	31.7	31.8	31.8	31.8	31.8
		R.H(%)	49	52	51	51	52	52	52	54	54	50
		Light intensity(lux)	1000	700	800	700	700	700	800	1000	1000	3400
	6.00 pm	Temperature(°C)	25.4	25.5	25.5	25.5	25.5	25.5	25.6	25.7	25.8	20.5
		R.H(%)	53	52	53	54	54	53	55	55	57	49
		Light intensity(lux)	110	250	190	280	330	450	520	730	760	1110
24/11/2016	6.00 am	Temperature(°C)	24.9	24.9	24.9	25	25.1	25.2	25.2	25.3	25.4	24.5
		R.H(%)	76	76	77	76	77	79	79	79	79	71

		Light intensity(lux)	238	208	202	199	217	233	256	330	388	600
	7.00 am	Temperature(°C)	26.2	26.3	26.3	26.3	26.3	26.3	26.3	26.4	26.5	25.7
		R.H(%)	70	70	71	72	72	72	72	73	74	69
		Light intensity(lux)	430	435	44	452	465	478	480	502	640	23400
	8.00 am	Temperature(°C)	27.1	27.2	27.2	27.3	27.3	27.5	27.5	27.6	27.7	26.3
		R.H(%)	67	69	69	70	70	70	68	67	66	59
		Light intensity(lux)	580	530	502	508	526	594	654	1238	1254	30700
	9.00 am	Temperature(°C)	28.2	28.2	28.3	28.4	228.4	28.5	28.6	28.6	28.9	24.4
		R.H(%)	52	53	53	53	53	53	53	54	53	51
		Light intensity(lux)	1500	1700	2100	2300	2600	3200	3800	3900	4100	45000
	10.00am	Temperature(°C)	31.8	31.9	32	32.1	32.2	32.3	32.4	32.6	32.7	32.3

		R.H(%)	46	51	54	55	56	57	61	62	61	43
		Light intensity(lux)	4500	6600	5600	7300	8000	8000	8600	11200	13000	59500
	11.00am	Temperature(°C)	34.5	34.5	34.6	34.7	34.7	34.8	34.9	35	35.1	32.2
		R.H(%)	38	38	39	38	39	40	40	40	40	38
		Light intensity(lux)	5510	6620	7330	7990	8550	8980	9010	9500	9780	62500
	12.00pm	Temperature(°C)	36.2	36.2	36.3	36.4	36.5	36.6	36.7	36.8	36.9	34.1
		R.H(%)	36	34	34	34	34	34	34	34	34	33
		Light intensity(lux)	6220	6540	7010	8210	9840	9940	10040	12200	1270	67000
	1.00 pm	Temperature(°C)	42.5	42.5	42.6	42.7	42.7	42.7	42.8	43	43.1	38.5
		R.H(%)	32	33	33	33	34	34	34	35	35	33
		Light intensity(lux)	13900	13300	12400	12100	12400	13200	12800	14300	14800	72000
	2.00 pm	Temperature(°C)	43.5	43.4	43.4	43.5	43.6	43.7	43.8	43.8	43.9	40.5

		R.H(%)	28	29	30	28	29	29	29	29	29	29
		Light intensity(lux)	13800	14500	12220	13100	1310	1320	1380	1480	1490	74000
	3.00 pm	Temperature(°C)	35.3	35.4	35.4	35.5	35.4	35.5	35.6	35.6	35.6	29.8
		R.H(%)	44	45	45	46	46	46	47	47	47	44
		Light intensity(lux)	2900	2200	2300	2400	2700	3100	3800	3900	4400	6300
	4.00 pm	Temperature(°C)	32.4	32.5	32.6	32.6	32.7	32.8	32.9	33	33.2	28.5
		R.H(%)	38	39	39	40	41	40	42	43	43	39
		Light intensity(lux)	2900	3100	3500	3600	3900	4100	4500	4600	4700	18300
	5.00 pm	Temperature(°C)	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.4	31.4	31.3
		R.H(%)	47	50	51	50	47	47	47	47	52	46
		Light intensity(lux)	720	620	670	690	690	720	780	860	930	3240
	6.00 pm	Temperature(°C)	25.4	25.5	25.5	25.6	25.5	25.6	25.6	25.7	25.8	21.3

		R.H(%)	75	74	74	74	75	76	76	76	77	75
		Light intensity(lux)	630	755	786	850	892	915	987	1050	1220	2700
25/11/2016	6.00 am	Temperature(°C)	22.5	22.6	22.6	22.8	22.9	23.1	23.2	23.2	23.2	23.5
		R.H(%)	69	69	70	68	66	66	67	66	66	64
		Light intensity(lux)	1220	1108	1034	1059	1122	1170	1340	1800	2080	2800
	7.00 am	Temperature(°C)	26.8	26.8	26.8	26.9	26.9	27.1	27.1	27.1	27.2	26.5
		R.H(%)	63	72	73	73	73	73	73	74	74	64
		Light intensity(lux)	1510	1280	1210	1180	1270	1300	1540	1880	2230	3330
	8.00 am	Temperature(°C)	27.1	27.2	27.2	27.3	27.3	27.5	27.5	27.6	27.7	26.3
		R.H(%)	67	69	69	71	71	69	69	70	71	62
		Light intensity(lux)	580	530	502	508	526	594	654	1238	1254	15000
	9.00 am	Temperature(°C)	28.2	28.2	28.3	28.4	28.5	28.6	28.8	28.9	28.9	24.4

		R.H(%)	52	52	52	53	53	53	53	54	53	51
		Light intensity(lux)	1600	1700	2100	2300	2700	3200	3700	3900	4200	17000
	10.00am	Temperature(°C)	31.8	31.9	32	32.1	32.2	32.3	32.4	32.6	32.7	32.3
		R.H(%)	46	51	54	55	56	57	61	62	61	43
		Light intensity(lux)	4500	6600	5600	7300	8000	8000	8600	11200	13000	25000
	11.00am	Temperature(°C)	37.5	37.3	37.2	37.2	37.2	37.3	37.4	37.6	37.6	35.5
		R.H(%)	32	32	32	32	30	31	31	31	31	30
		Light intensity(lux)	13200	11470	11290	11390	11450	11210	13150	1350	18550	32000
	12.00pm	Temperature(°C)	39.4	39.3	39.3	39.3	39.3	39.3	39.2	39.2	39.1	38
		R.H(%)	28	29	32	36	37	34	35	36	38	27
		Light intensity(lux)	14200	12300	12700	11900	12400	13400	13800	13500	13300	36000
	1.00 pm	Temperature(°C)	42.5	42.5	42.6	42.7	42.7	42.7	42.8	43	43.1	38.5

		R.H(%)	32	33	33	33	34	34	34	35	35	33
		Light intensity(lux)	13900	13300	12400	12100	12400	13200	12800	14300	14800	38000
	2.00 pm	Temperature(°C)	37.9	37.8	37.8	37.5	37.4	37.3	37.2	37.2	37.1	36.2
		R.H(%)	22	25	30	34	36	39	39	37	37	32
		Light intensity(lux)	3300	2700	3000	3500	4000	4900	6400	7000	6600	33000
	3.00 pm	Temperature(°C)	35.2	35.3	35.4	35.4	35.5	35.6	35.7	35.7	35.8	33.9
		R.H(%)	28	28	29	30	31	31	31	31	31	30
		Light intensity(lux)	3100	2990	3050	3220	3410	3690	4250	4870	5010	18000
	4.00 pm	Temperature(°C)	33.1	33.1	33.1	33.1	33.1	33	33	33	33	32.9
		R.H(%)	36	37	38	40	41	39	39	39	40	40
		Light intensity(lux)	1400	1300	1200	1500	1500	1600	1600	1800	2000	11000
	5.00 pm	Temperature(°C)	28.7	28.7	28.6	28.6	28.5	28.5	28.5	28.5	28.5	28.4

		R.H(%)	52	53	52	53	54	54	54	54	54	49
		Light intensity(lux)	400	300	400	400	400	400	400	500	600	1600
	6.00 pm	Temperature(°C)	24.4	24.5	24.4	24.5	24.5	24.6	24.6	24.6	24.6	20.4
		R.H(%)	62	63	63	63	63	63	63	63	63	63
		Light intensity(lux)	110	120	140	470	170	170	250	260	270	600
26/11/2016	6.00 am	Temperature(°C)	22.1	22.2	22.3	22.3	22.4	22.4	22.4	22.5	22.6	19.8
		R.H(%)	64	65	64	65	65	65	65	65	65	63
		Light intensity(lux)	220	250	280	330	440	620	650	720	740	1500
	7.00 am	Temperature(°C)	24	24.1	24.1	24.2	24.2	24.2	24.2	24.3	24.4	20.7
		R.H(%)	62	63	62	63	64	61	61	61	61	59
		Light intensity(lux)	1500	1550	1560	1800	2100	2220	2410	2540	2680	1850
	8.00 am	Temperature(°C)	24.5	24.7	24.8	24.9	25	25	25.1	25.1	25.2	22.3

		R.H(%)	59	60	60	60	60	60	60	60	59	59
		Light intensity(lux)	2830	2400	2380	2460	2440	2530	3190	3880	4360	23000
	9.00 am	Temperature(°C)	28.2	28.2	28.3	28.4	228.4	28.5	28.6	28.6	28.9	24.4
		R.H(%)	52	53	53	53	53	53	53	54	53	51
		Light intensity(lux)	1500	1700	2100	2300	2600	3200	3800	4000	4100	45000
	10.00am	Temperature(°C)	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	35.2
		R.H(%)	36	37	37	37	37	36	36	37	36	36
		Light intensity(lux)	10600	10050	9940	10270	9980	10130	10590	11600	14100	55300
	11.00am	Temperature(°C)	35.5	35.6	35.7	35.7	35.7	35.8	35.9	35.9	40.1	32.2
		R.H(%)	38	38	39	38	39	40	40	40	40	38
		Light intensity(lux)	5510	6620	7330	7990	8550	8980	9010	9500	9780	62500
	12.0	Temperat	37	37	37	37	37	37	37	37	37	34.

	0pm	ure(°C)	.5	.6	.7	.7	.8	.8	.8	.9	.9	5
		R.H(%)	34	32	32	33	33	33	34	34	34	40
		Light intensity(lux)	5520	5940	6100	7400	8460	9800	10450	1140	1250	63100
	1.00 pm	Temperature(°C)	42.5	42.5	42.6	42.7	42.7	42.7	42.8	43	43.1	38.5
		R.H(%)	32	33	33	33	34	34	34	35	35	33
		Light intensity(lux)	6200	6500	7800	9500	11500	11400	12200	11800	12000	64000
	2.00 pm	Temperature(°C)	44	44.1	44.2	44.3	44.5	44.5	44.6	44.7	44.8	41
		R.H(%)	27	27	28	28	28	28	28	28	29	27
		Light intensity(lux)	6300	6700	7500	8700	9800	10400	12300	14200	15700	72000
	3.00 pm	Temperature(°C)	35.2	35.3	35.4	35.4	35.5	35.6	35.7	35.7	35.8	33.9
		R.H(%)	28	28	29	30	31	32	32	32	32	30
		Light intensity(lux)	3100	2990	3050	3220	3410	3690	4250	4870	5010	36000
	4.00	Temperat	34	34	34	34	34	34	34	34	34	33.

	pm	ure(°C)	.5	.5	.5	.6	.7	.7	.8	.8	.8	6
		R.H(%)	40	41	41	42	42	42	43	45	46	36
		Light intensity(lux)	2500	2780	2995	3120	3500	4010	3775	3995	4225	28000
	5.00 pm	Temperature(°C)	31.5	31.5	31.6	31.7	31.8	31.8	31.9	31.9	32	31.3
		R.H(%)	47	50	51	50	47	47	48	47	51	46
		Light intensity(lux)	720	620	670	690	690	720	780	860	930	4500
	6.00 pm	Temperature(°C)	25.4	25.5	25.5	25.6	25.5	25.6	25.6	25.7	25.8	21.3
		R.H(%)	75	74	74	74	75	76	76	76	77	75
		Light intensity(lux)	630	755	786	850	892	915	987	1050	1220	2800
27/11/2016	6.00 am	Temperature(°C)	22.5	22.6	22.6	22.8	22.9	23.1	23.2	23.2	23.2	23.5
		R.H(%)	69	69	70	71	71	71	71	71	71	64
		Light intensity(lux)	1220	1108	1034	1059	1122	1170	1330	1900	2070	2800
	7.00	Temperat	26	26	26	26	26	27	27	27	27	26.

	am	ure(°C)	.8	.8	.8	.9	.9	.1	.1	.1	.2	5
		R.H(%)	63	72	73	73	73	73	73	74	74	64
		Light intensity(lux)	1510	1280	1210	1180	1270	1300	1540	1880	2230	3340
	8.00 am	Temperature(°C)	23.9	23.9	24.1	24.2	24.2	24.3	24.4	24.5	24.5	24.4
		R.H(%)	59	59	58	59	60	60	60	60	60	58
		Light intensity(lux)	1840	1800	1720	1750	1830	1870	2150	2640	3120	9400
	9.00 am	Temperature(°C)	28.4	28.5	28.6	28.7	28.9	28.9	30	30.1	30.1	27.7
		R.H(%)	43	45	45	44	45	45	47	47	47	41
		Light intensity(lux)	3600	4200	4800	4800	5300	5900	6300	6800	7100	18000
	10.00am	Temperature(°C)	30.1	30.1	30.2	30.3	30.3	30.4	30.5	30.6	30.7	28.3
		R.H(%)	37	37	37	37	36	35	35	35	35	33
		Light intensity(lux)	3200	3300	3500	4200	4500	5100	5800	6700	7800	22000
	11.0	Temperat	32	36	36	36	36	36	36	36	36	33.

	0am	ure(°C)	.2	.2	.3	.4	.4	.5	.6	.7	.8	4
		R.H(%)	34	35	34	36	36	36	36	36	36	37
		Light intensity(lux)	3500	6620	7330	7990	8550	8980	9010	9500	9780	25000
	12.00pm	Temperature(°C)	34.5	34.5	34.6	34.7	34.8	34.8	34.9	35	35.1	33.2
		R.H(%)	33	32	33	34	33	33	33	33	33	28
		Light intensity(lux)	4010	4220	4310	4460	4580	5010	5200	5500	6800	32000
	1.00 pm	Temperature(°C)	36.1	36.2	36.2	36.3	36.4	36.5	36.6	36.7	36.9	34.5
		R.H(%)	32	31	30	31	31	31	31	31	31	30
		Light intensity(lux)	5040	5100	5220	6540	6650	6810	7010	7420	7650	45000
	2.00 pm	Temperature(°C)	37.1	36.9	36.9	36.8	36.8	36.7	36.7	36.6	36.5	34.7
		R.H(%)	31	30	28	31	31	31	31	31	31	34
		Light intensity(lux)	5700	4700	4400	4800	5100	6000	6900	7600	7800	58000
	3.00	Temperat	35	35	35	35	35	35	35	35	35	34.

	pm	ure(°C)	.2	.3	.4	.5	.6	.6	.7	.8	.9	9
		R.H(%)	42	43	42	44	44	44	44	44	44	43
		Light intensity(lux)	2500	2800	3100	3300	3600	3900	4100	4200	4300	19000
	4.00 pm	Temperature(°C)	30.2	30.3	30.4	30.5	30.6	30.6	30.7	30.7	30.8	28.5
		R.H(%)	45	46	47	47	47	47	47	47	48	47
		Light intensity(lux)	1140	1240	1650	1870	2040	2180	2640	2730	3220	12000
	5.00 pm	Temperature(°C)	28.4	31.5	31.5	31.5	31.5	31.5	31.5	31.4	31.4	31.3
		R.H(%)	47	50	51	50	47	47	47	47	52	46
		Light intensity(lux)	23.8	620	670	690	690	720	780	860	930	3240
	6.00 pm	Temperature(°C)	28.4	28.4	28.5	28.6	28.7	28.7	28.8	28.9	28.9	23.8
		R.H(%)	54	55	56	57	57	57	57	57	57	54
		Light intensity(lux)	110	250	620	840	860	910	950	960	1080	1500
28/11	6.00	Temperat	19	19	19	19	19	19	19	19	19	15.

/2016	am	ure(°C)		.1	.1	.2	.3	.4	.5	.6	.7	4
		R.H(%)	88	87	88	86	88	88	88	88	88	86
		Light intensity(lux)	150	170	250	240	260	280	320	360	480	1500
	7.00 am	Temperature(°C)	20	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.1
		R.H(%)	79	78	78	78	78	78	78	78	78	78
		Light intensity(lux)	1050	1400	1500	2100	2220	2110	2450	2870	3010	6400
	8.00 am	Temperature(°C)	24	24.1	24.1	24.2	24.3	24.4	24.5	24.6	24.6	24.3
		R.H(%)	75	75	75	75	75	75	74	74	74	73
		Light intensity(lux)	1840	1800	1720	1830	1870	2150	2640	3120	3150	9500
	9.00 am	Temperature(°C)	32	32.1	32.3	32.4	32.5	32.6	32.7	32.8	32.9	28.7
		R.H(%)	64	65	64	64	65	65	65	65	65	63
		Light intensity(lux)	3500	3460	3890	4770	5810	8990	6010	6050	6080	23000
	10.0	Temperat	35	35	35	35	35	35	35	35	35	35

	0am	ure(°C)	.7	.6	.6	.8	.8	.8	.8	.8	.8	
		R.H(%)	37	37	37	37	36	35	34	33	34	33
		Light intensity(lux)	8050	9500	9400	10900	10000	10300	11100	12900	14600	50800
	11.00am	Temperature(°C)	36.2	36.2	36.3	36.3	36.4	36.5	36.6	36.8	36.9	32.4
		R.H(%)	32	31	32	31	33	31	32	32	32	31
		Light intensity(lux)	8600	9200	9900	10800	10900	11400	12500	13800	15300	60700
	12.00pm	Temperature(°C)	40.1	40.1	40.2	40.3	40.4	40.5	40.6	40.7	40.9	37.4
		R.H(%)	26	26	25	25	25	26	25	25	25	24
		Light intensity(lux)	9500	10800	11200	12300	14700	15600	15900	16700	16800	64000
	1.00 pm	Temperature(°C)	38.4	38.4	38.5	38.6	38.7	38.8	38.9	40	40.1	36.7
		R.H(%)	28	28	27	28	28	28	28	29	29	28
		Light intensity(lux)	8700	9100	9300	10400	11300	12700	12800	13400	13500	58000
	2.00	Temperat	37	36	36	36	36	36	36	36	36	34.

	pm	ure(°C)	.1	.9	.9	.8	.8	.7	.7	.6	.5	7
		R.H(%)	31	32	32	32	32	32	32	32	32	34
		Light intensity(lux)	5700	4700	4400	4800	5100	6000	6900	7600	7800	29300
	3.00 pm	Temperature(°C)	34.3	34.4	34.4	34.5	34.6	34.7	34.8	34.9	35	32.4
		R.H(%)	43	43	42	43	43	43	43	44	44	43
		Light intensity(lux)	3400	3500	3600	4100	4300	4700	5800	6700	6800	17400
	4.00 pm	Temperature(°C)	32.2	32.3	32.3	32.4	32.4	32.5	32.6	32.6	32.7	28.9
		R.H(%)	45	45	46	45	46	46	46	46	46	45
		Light intensity(lux)	2100	2300	2800	3400	3600	3900	4300	4500	4700	15300
	5.00 pm	Temperature(°C)	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.4	31.4	31.3
		R.H(%)	47	50	51	50	47	47	47	47	52	46
		Light intensity(lux)	720	620	670	690	690	720	780	860	930	3240
	6.00	Temperat	24	24	24	24	24	24	24	24	24	20.

	pm	ure(°C)	.6	.7	.7	.8	.8	.8	.8	.9	.9	3
		R.H(%)	54	54	54	54	54	54	54	54	54	53
		Light intensity(lux)	250	260	280	310	350	390	420	450	610	950
29/11/2016	6.00 am	Temperature(°C)	20.5	20.5	20.6	20.7	20.8	20.9	20.9	30	30.1	19.9
		R.H(%)	86	85	86	86	86	86	86	86	86	85
		Light intensity(lux)	470	490	510	530	550	620	740	780	910	1100
	7.00 am	Temperature(°C)	23.4	23.5	23.5	23.5	23.6	23.7	23.8	23.8	23.8	23.6
		R.H(%)	77	78	78	78	78	77	79	79	79	78
		Light intensity(lux)	900	700	700	828	862	913	1029	1200	1330	3500
	8.00 am	Temperature(°C)	26.8	26.8	26.9	26.9	27	27.1	27.2	27.2	28	25.6
		R.H(%)	68	68	69	70	69	70	69	69	69	69
		Light intensity(lux)	1100	1200	1500	1800	2300	2800	2900	3100	3300	6400
	9.00	Temperat	32	32	32	32	32	32	32	32	33	32

	am	ure(°C)	.3	.3	.4	.5	.6	.7	.8	.9		
		R.H(%)	56	56	56	56	56	55	56	56	56	55
		Light intensity(lux)	2400	2900	3700	4100	4500	5700	6800	6900	7100	18000
	10.00am	Temperature(°C)	34.1	34.2	34.2	34.3	34.3	34.4	34.4	34.5	34.7	32.5
		R.H(%)	45	46	46	46	45	45	45	46	46	45
		Light intensity(lux)	40100	5600	6300	6900	7300	8400	7200	8000	8900	35000
	11.00am	Temperature(°C)	36	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.1
		R.H(%)	42	42	41	41	41	41	42	42	41	40
		Light intensity(lux)	8700	9000	7700	7600	7600	7500	7600	9200	11600	47000
	12.00pm	Temperature(°C)	39.9	39.9	40	40	40.1	40.2	40.3	40.4	40.5	41
		R.H(%)	38	39	39	39	39	39	39	38	38	39
		Light intensity(lux)	9600	9300	10800	11400	12600	13700	14800	15200	15400	51000
	1.00	Temperat	38	38	38	38	40	40	40	40	40	38.

	pm	ure(°C)	.7	.8	.9	.9		.1	.1	.3	.5	6
		R.H(%)	45	45	46	45	45	45	45	46	46	45
		Light intensity(lux)	7800	8400	8900	9100	9600	10400	11700	11900	12400	48000
	2.00 pm	Temperature(°C)	33.3	33.3	33.3	33.4	33.4	33.5	33.5	33.6	33.7	32.8
		R.H(%)	47	49	50	52	51	51	52	49	49	47
		Light intensity(lux)	3900	2700	3300	3000	2800	3000	2900	3000	3500	14100
	3.00 pm	Temperature(°C)	33.1	33.2	33.2	33.3	33.4	33.5	33.5	33.6	33.7	31.8
		R.H(%)	53	53	54	54	54	54	54	55	55	53
		Light intensity(lux)	2800	2200	2400	2600	3200	3000	3100	2900	3200	12500
	4.00 pm	Temperature(°C)	30.1	30.2	30.3	30.3	30.4	30.5	30.5	30.6	30.7	28.4
		R.H(%)	55	56	57	56	57	57	57	57	57	55
		Light intensity(lux)	2300	2400	2600	2800	2900	3600	3400	3500	3800	8200
	5.00	Temperat	28	28	28	28	28	28	28	28	28	28.

	pm	ure(°C)	.7	.7	.6	.6	.5	.5	.5	.5	.5	4
		R.H(%)	57	57	59	59	60	60	60	61	61	60
		Light intensity(lux)	400	300	400	400	400	400	400	500	600	1600
	6.00 pm	Temperature(°C)	24.7	24.8	24.8	24.9	25	25.1	25.2	25.3	25.4	22.8
		R.H(%)	77	77	78	77	79	79	79	79	79	77
		Light intensity(lux)	110	150	240	460	550	610	610	590	670	1050
30/11/2016	6.00 am	Temperature(°C)	21.4	21.5	21.6	21.6	21.7	21.7	21.8	21.9	21.9	30
		R.H(%)	86	87	86	87	87	87	87	87	87	85
		Light intensity(lux)	140	250	260	240	270	280	310	450	680	1150
	7.00 am	Temperature(°C)	23.2	23.2	23.3	23.4	23.4	23.4	23.5	23.5	23.5	23.2
		R.H(%)	80	80	81	81	81	81	81	81	81	81
		Light intensity(lux)	710	630	610	620	650	660	720	820	910	3100
	8.00	Temperat	24	24	25	25	25	25	25	25	25	23.

	am	ure(°C)	.8	.39		.1	.2	.3	.4	.5	.6	8
		R.H(%)	78	77	77	77	77	77	77	77	77	76
		Light intensity(lux)	980	1150	1170	1260	1330	1540	1890	2560	3870	5400
	9.00 am	Temperature(°C)	25.9	26	26	26.1	26.1	26.2	26.2	26.2	26.2	26
		R.H(%)	70	70	70	70	70	70	70	69	69	65
		Light intensity(lux)	2400	1800	1600	1600	1600	1700	1800	2000	2200	8100
	10.00am	Temperature(°C)	27.4	27.5	27.6	27.7	27.8	27.9	30	30.1	30.2	27.5
		R.H(%)	65	66	67	66	68	69	70	70	71	68
		Light intensity(lux)	2650	2890	3220	3470	4510	4510	4600	5010	5220	16650
	11.00am	Temperature(°C)	29.7	29.7	29.7	29.7	29.7	29.8	29.8	29.8	29.8	29.3
		R.H(%)	50	51	50	51	51	51	50	51	51	51
		Light intensity(lux)	3600	4100	3900	4000	4000	4000	4800	5200	5800	19400

	12.00pm	Temperature(°C)	35.2	35.2	35.3	35.3	35.4	35.5	35.6	35.7	35.8	33.4
		R.H(%)	46	47	47	47	47	47	47	47	47	45
		Light intensity(lux)	4100	4300	5200	6900	7200	7300	7500	7800	8000	26610
	1.00 pm	Temperature(°C)	39.1	38.5	38.4	38.4	38.2	38.1	38	37.9	37.8	37.2
		R.H(%)	31	31	31	30	31	31	30	31	31	32
		Light intensity(lux)	4900	5600	6900	6300	6200	6200	6000	6000	6700	26600
	2.00 pm	Temperature(°C)	41.8	41.8	41.9	50	50.1	50	50.1	50.2	50.3	36.9
		R.H(%)	28	27	28	29	30	30	30	30	31	28
		Light intensity(lux)	5400	5800	6200	6400	6600	7500	7500	7800	7900	32000
	3.00 pm	Temperature(°C)	36.5	36.6	36.7	36.8	36.9	36.9	40	40.1	40.2	40.3
		R.H(%)	36	35	36	35	36	36	36	36	37	35
		Light intensity(lux)	4100	4150	4290	4970	5010	5020	5030	5070	5100	28000

	4.00 pm	Temperature(°C)	32.7	32.7	32.6	32.6	32.5	32.5	32.5	32.4	32.4	32.2
		R.H(%)	37	39	38	39	41	41	42	42	42	41
		Light intensity(lux)	3600	2500	2700	2800	2700	2800	2800	3200	3400	8200
	5.00 pm	Temperature(°C)	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.4	31.4	31.3
		R.H(%)	47	50	51	50	47	47	47	47	52	46
		Light intensity(lux)	720	620	670	690	690	720	780	860	930	3240
	6.00 pm	Temperature(°C)	26.4	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5	20.1
		R.H(%)	54	54	54	54	54	54	54	54	54	53
		Light intensity(lux)	140	150	180	190	190	200	250	250	250	960
01/12/2016	6.00 am	Temperature(°C)	21.6	21.6	21.7	21.7	21.8	21.8	21.9	21.9	30	26.8
		R.H(%)	88	88	87	88	87	87	87	87	87	87
		Light intensity(lux)	540	560	490	590	650	710	780	790	820	1050

	7.00 am	Temperature(°C)	23.8	23.8	23.9	23.9	24	24.1	24.1	24.2	24.3	22.6
		R.H(%)	85	85	86	86	85	86	86	86	86	85
		Light intensity(lux)	1050	1120	1460	1780	1850	1940	2010	2440	2430	7800
	8.00 am	Temperature(°C)	24.4	24.5	24.5	24.6	24.6	24.7	24.8	24.8	24.9	23.8
		R.H(%)	80	80	81	81	81	81	81	81	81	80
		Light intensity(lux)	1100	1200	1300	1300	1400	1500	1500	1600	1700	8600
	9.00 am	Temperature(°C)	26.1	26.2	26.2	26.2	26.2	26.2	26.3	26.4	26.5	21.8
		R.H(%)	78	76	76	77	78	77	77	77	77	76
		Light intensity(lux)	1800	1500	1500	1500	1500	1400	1600	1800	1900	9300
	10.00am	Temperature(°C)	28.9	28.9	30	30.1	30.2	30.2	30.3	30.4	30.5	28.9
		R.H(%)	65	66	65	66	67	65	66	66	66	65
		Light intensity(lux)	2100	3200	4800	5400	5900	6300	6700	7100	7300	28900

	11.00am	Temperature(°C)	31.6	31.7	31.8	31.9	32	32.5	32.4	32.6	32.7	32.8
		R.H(%)	50	50	50	50	50	50	49	47	47	43
		Light intensity(lux)	8400	8000	8200	7900	7800	9000	900	9900	10500	35300
	12.00pm	Temperature(°C)	38.7	38.8	38.8	38.9	38.9	40	40.1	40.2	40.3	29.7
		R.H(%)	47	47	46	47	46	47	47	47	47	46
		Light intensity(lux)	8600	8500	8900	9100	9300	9600	9800	10700	12300	42200
	1.00 pm	Temperature(°C)	42.1	42.1	42.2	42.3	42.5	42.6	42.6	42.7	42.7	41.5
		R.H(%)	38	38	38	38	38	38	39	39	39	37
		Light intensity(lux)	9800	10400	11500	12400	13800	14700	14900	15200	16700	58000
	2.00 pm	Temperature(°C)	44	44.1	44.2	44.3	44.4	44.5	44.5	44.6	44.7	43.2
		R.H(%)	35	35	36	36	36	36	35	36	36	33
		Light intensity(lux)	10400	11800	12500	12900	13600	14700	15800	16300	16700	62000

	3.00 pm	Temperature(°C)	36.5	36.6	36.6	36.7	36.8	36.9	7	37.1	37.2	34.3
		R.H(%)	47	47	47	47	47	48	48	48	48	46
		Light intensity(lux)	4100	4300	4300	4700	5100	5400	5300	6400	6800	18000
	4.00 pm	Temperature(°C)	34.8	34.9	35	35.1	35.2	35.3	35.3	35.4	35.5	33.6
		R.H(%)	52	52	53	53	53	53	53	54	54	52
		Light intensity(lux)	3500	3200	3400	3900	4100	3900	4500	4700	4900	7500
	5.00 pm	Temperature(°C)	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.4	31.4	31.3
		R.H(%)	64	64	64	64	64	65	65	65	66	63
		Light intensity(lux)	720	620	670	690	690	720	780	860	930	3240
	6.00 pm	Temperature(°C)	25.4	25.5	25.5	25.5	25.5	25.5	25.6	25.7	25.8	20.5
		R.H(%)	77	77	77	77	77	77	77	77	77	76
		Light intensity, lux)	110	250	190	280	330	450	520	730	760	1110

APPENDIX II

The variation of daily peak air temperature inside the greenhouse about 10 days are noted and tabulated in the following table.

DATE	DISTANCE									
	1	2	3	4	5	6	7	8	9	Outside
22-11-2016	36.9	36.8	37	37.1	37	37.2	37.2	37.1	37.2	35.7
23-11-2016	39.5	39.6	39.6	39.7	39.7	39.7	39.9	40	40.1	37.8
24-11-2016	43.5	43.4	43.4	43.5	43.6	43.7	43.8	43.8	43.9	40.5
25-11-2016	42.5	42.5	42.6	42.7	42.7	42.7	42.8	43	43.1	38.5
26-11-2016	44	44.1	44.2	44.3	44.5	44.5	44.6	44.7	44.8	41
27-11-2016	37.1	36.9	36.9	36.8	36.8	36.7	36.7	36.6	36.5	34.7
28-11-2016	40.1	40.1	40.2	40.3	40.4	40.5	40.6	40.7	40.9	37.4
29-11-2016	39.9	39.9	40	40	40.1	40.2	40.3	40.4	40.5	41
30-11-2016	41.8	41.8	41.9	50	50.1	50	50.1	50.2	50.3	36.9
01-12-2016	44	44.1	44.2	44.3	44.4	44.5	44.5	44.6	44.7	43.2
Average	40.93	40.92	41	41.87	41.93	41.97	42.05	42.11	42.2	38.67

APPENDIX III

The variation of relative humidity corresponding to the daily peak air temperature inside and outside the greenhouse

DATE	DISTANCE									OUTSIDE
	1m	2m	3m	4m	5m	6m	7m	8m	9m	
22-11-2016	29	30	31	36	36	37	38	37	38	36
23-11-2016	25	26	25	26	27	27	27	27	27	26
24-11-2016	28	29	30	28	29	29	29	29	29	29
25-11-2016	32	33	33	33	34	34	34	35	35	33
26-11-2016	27	27	28	28	28	28	28	28	29	27
27-11-2019	31	30	28	31	31	31	31	31	31	34
28-11-2016	26	26	25	25	25	26	25	25	25	24

29-11-2016	38	39	39	39	39	39	39	38	38	39
30-11-2016	28	27	28	29	30	30	30	30	31	28
01-12-2016	35	35	36	36	36	36	35	36	36	33
Average	29.9	30.2	30.3	31.1	31.5	31.7	31.6	31.6	31.9	30.9

APPENDIX IV

The daily maximum intensity of solar radiation (from 22-11-2016 to 1-12-2016) inside and outside the greenhouse.

DATE	DISTANCE									OUTSIDE
	1m	2m	3m	4m	5m	6m	7m	8m	9m	
22-11-2016	3900	4310	4160	5600	6370	7300	9000	8210	8300	39000
23-11-2016	7540	8300	9700	10250	12400	12900	13400	14800	15100	64500
24-11-2016	13800	14500	12220	13100	1310	1320	1380	1480	1490	74000
25-11-2016	13900	13300	12400	12100	12400	13200	12800	14300	14800	38000
26-11-	6300	6700	7500	8700	9800	1040	1230	1420	1570	72000

2016						0	0	0	0	
27-11-2016	5700	4700	4400	4800	5100	6000	6900	7600	7800	58000
28-11-2016	9500	10800	11200	12300	14700	15600	15900	16700	16800	64000
29-11-2016	9600	9300	10800	11400	12600	13700	14800	15200	15400	51000
30-11-2017	5400	5800	6200	6400	6600	7500	7500	7800	7900	32000
01-Dec	10400	11800	12500	12900	13600	14700	15800	16300	16700	62000
AVERAGE	8604	8951	9108	9755	9488	10262	10978	11659	11999	55450

DEVELOPMENT AND TESTING OF EVAPORATIVE COOLING BOX FOR NATURALLY VENTILLATED GREENHOUSE

By

ADARSH S.S
JINCY

ABSTRACT

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In

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Department of Land & Water Resources and Conservation Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND

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KERALA, INDIA
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ABSTRACT

The study entitled “Development and testing of evaporative cooling box for a naturally ventilated greenhouse” was taken up to fabricate an evaporative cooling box for naturally ventilated greenhouse situated in the KCAET campus and which is suitable for the climatic conditions of Kerala. For analyzing the performance of the cooling system, first of all the climatological parameters inside and outside greenhouse before the installation of cooling box are observed from 22-11-16 to 1-12-16 at an interval of 1hr for every 1m distance inside greenhouse from 6.00 am to 6.00 pm. The daily peak temperature is observed to analyze the cooling requirement by the crop inside the greenhouse. Then Type A and Type B cooling boxes are fabricated and installed in the greenhouse. The measurements of climatological parameters both inside and outside the greenhouse were taken before and after cooling. Then the observations from the two cooling boxes were compared and concluded that type A cooling box is more effective in cooling action than the type B cooling box. But in type A, cooling losses occurs due to the backward movement of air by striking on its frame. Then eliminating the disadvantages of the type A cooling box, a new type C cooling box has been fabricated and installed in the greenhouse .Then the observations are taken about 1 week and it shows that type C cooling box exhibits uniform cooling in the greenhouse and provide the optimum condition for the plant growth while type A cooling box exhibits maximum efficiency.