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Control system for cooling for naturally ventilated greenhouse: Review

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Abstract

This review discusses the control systems for cooling in naturally ventilated greenhouses, highlighting the importance of maintaining optimal climatic conditions for crop growth in India. With the increasing need for protected cultivation due to diverse climatic challenges, The manuscript underscores the significance of natural ventilation and thermal regulation systems, including fogging and evaporative cooling mechanisms, in enhancing crop yield and quality. The review summarizes various studies that demonstrate the effectiveness of these cooling methods in regulating temperature, humidity, and vapor pressure deficit (VPD), which are critical for plant health. Additionally, it explores the impact of improper climate conditions on crop production, particularly focusing impact of temperature and humidity on growth and yield. The paper concludes by discussing automated control systems developed for greenhouse management, showing advancements in technology that facilitate precise environmental control, ultimately leading to improved agricultural productivity.

Keywords: Naturally ventilated greenhouse, VPD, evaporative cooling, heat stress

Introduction

Considering its diverse climate, India will need a significant increase in protected cultivation if its agricultural sector is to grow. However, the success rate of protected farming in this nation varies greatly based on different meteorological conditions. The harsh climate in the northern region of the country is posing major challenges for this type of technology. Conversely, areas with warm climates, such as Bengaluru and Pune, are easily adapted to this controlled farming technology. Thus, greenhouse farming is too difficult to be successful throughout India. India currently has about 30, 000 hectares of land under protected cultivation (Somasundaram *et al.*, 2020) ^[37]. Open-field farming has restrictions when it comes to vegetable production. Growing crops in a controlled setting during the off-season is known as "protected farming," and it produces superior crop yields in terms of both quantity and quality than open-field conditions. Growing crops in an enclosed or partially enclosed space, like a greenhouse, shade house, or high tunnel, is known as protected cultivation (Lamichhane *et al.*, 2023) ^[19]. Temperature, relative humidity, sunshine, and other elements are controlled in protected buildings like polyhouses or greenhouses based on the requirements of the crops. Crop health and yield are greatly enhanced by this kind of cultivation (Pattnaik & Mohanty, 2021) ^[33]. Crops grown under open field at all times affected by several diseases and pests which may lead to low productivity and low-value produce. The principal objective of protected cultivation is to create ideal and a controlled microclimate that safeguards the crops from harmful weather conditions, pests, and diseases, while enhancing environmental factors (Jewett T and Jarvis W, 2001) ^[13]. It represents a key approach in this endeavor. This kind of agrotechnology includes coverings to regulate macro and microenvironments, which promotes optimal plant growth, lengthen the growing season, stimulates early maturation, and increases yield and quality. [Junqueira and Augusto, 2016] ^[15].

Plants need ideal climatic conditions for their growth. Plants require a favorable climate with adequate moisture, warmth, and light for healthy growth and development. Humidity and warmth stimulate the growth of plants. therefore, plants can be cultivated in controlled environments where temperature, humidity, light, and other factors are adjusted to suit the needs of the plants or crops.

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In various protected cultivation methods, environmental conditions are fully, partially, or selectively modified to shield crops from adverse weather. Protected cultivation is a complex set of practices and technologies that need careful planning, production, management, and maintenance for quality production of horticultural crops and take advantage seasonality, demand, and market supply. The high demand for high-quality horticultural products forces us to switch to modern cultivation techniques such as protected cultivation. Crops can be protected from abiotic (temperature, rain, wind, humidity, etc.) and biotic (diseases and pests) stresses using greenhouse.

A greenhouse is a covered structure meant to offer plants the best possible circumstances, adjusting the climate to promote growth, reduce expenses for production, and maximize productivity in agriculture. (Badgery-Parker, 1999). The temperature inside a greenhouse increases when it receives sunshine, offering plants an adequate environment that allows growth even in bitterly cold climates. Compared with traditional methods of farming, the controlled conditions in a greenhouse gives higher yields per square foot. Additionally, this setup allows for the cultivation of crops that require longer growth periods (Wikipedia). In order to meet consumer needs, it not only enhances crop yields but also significantly enhances food quality. (Ozer and Saribaş, 2017) [30].

Natural ventilation also allows for more uniform crop cooling. Natural ventilation systems depend on the basis that heat is released by a pressure differential created by temperature changes and wind. This process is primarily influenced by the wind. Air movement is higher when the temperature gradient between indoor and outside air is larger.

Importance of cooling

Overheating in greenhouses may seriously affect the development of plants and results for a significant part of the year (Guerrero *et al.* 2012) [8]. Since an effective water spray system increases the surface area of the water exposed to the air, which optimizes heat transfer from the air to the water, thus might improve the cooling effect and efficiency of an ECS (evaporative cooling system). (Zohu *et al.* 2017) [44].

Natural ventilation systems do not work well all the time so, the cooling system is required. Fog systems create fine droplets of water to cool the greenhouse. Sprayed into the air, tiny droplets of fog remain suspended until they evaporate. A fog system can be installed in any greenhouse, such as with a natural or mechanical ventilation system. Fog cooling systems are more desirable for cooling the greenhouse and provide an ideal microclimate for plant growth and development. A fog cooling system not only cools the greenhouse through the use of air circulation but also creates a fine mist. Fog just floats into the air and randomly lands on objects without pattern or reason because it has tiny droplets. A low-pressure fog cooling system (3-5 bar pressure) promotes the ideal growing conditions for agricultural crops or plants by controlling temperature, relative humidity, and vapour pressure deficit (VPD).

Montero and Anton (1989) [27] determined the effect of an air-water fogging system on the climate of the greenhouse. Researchers compared the two greenhouses first one was consist of 26 fogging nozzles as operated when inside air temperature reached 28 °C. A humidistat stopped when

relative humidity surpassed 90%. The second greenhouse was without fogging. It was observed that the fogging nozzle significantly lowered the greenhouse temperature by 3 °C than the greenhouse without fogging. Also, by comparing both the greenhouse maximum air temperature reduction was 5 °C.

Kittas *et al.* (2001) [16] studied the temperature and humidity fluctuations during summertimes for rose production equipped with a ventilated cooling-pad system and a half-shaded plastic roof greenhouse. 61 m² of 10 cm thick cooling pads installed on the 50 m wide south wall were forced ambient air pass through them. A data logger system was implemented to record the temperature and relative humidity of the outside air. The result showed that the air temperature was always superior (up to twice as high) in first portion (unshaded) than second portion (shaded) of the greenhouse. The greenhouse temperature was able to keep below 28 °C because of the cooling system in all in all circumstances. Additionally, even in the afternoon when it was hot (up to 35 °C), the interior temperature remained 10 °C below the outside temperature.

Ozturk (2003) [18] went through the effectiveness of the fogging system (FS) for rose crops in greenhouses. A multi-span plastic greenhouse (PG) was used for the studies. Fog generating nozzles (FGN) essential a pressure of 4.5 atm. In every span of the PG (plastic greenhouse), three nozzle lines with 82 FGN (fog generating nozzles) were placed. The efficient functioning of the plastic greenhouse's FS (fogging system) was specifically examined on the hottest sunny days on record. One key indicator of the FS (fogging system) was the temperature difference between the air inside the PG (plastic greenhouse) and the air outside. Based to the evaluation findings, the temperature of the air within the plastic greenhouse (PG) varied between 23.1 °C and 34.3 °C, whereas the temperature outside ranged between 23.7 °C and 40.4 °C. In the morning and afternoon, the temperature of the air both inside and outside the PG remained quite constant. The ATD reached 6.6 °C at 16:00 PM, although the ATD within and outside the PG was just 0.63 °C at 7:00 AM. The relative humidity (RH) of the air outside the PG ranged from 28.1 to 55.7%, whereas the RH of the air inside the PG ranged from 56.3% to 76.3%. For example, researchers found that the PG with the fogging system had consistent temperature and relative humidity levels.

Li *et al.* (2006) [21] conducted experimental research in naturally ventilated greenhouses how spray rate, canopy density, vent arrangement, and external weather variables affect air temperature, humidity, leaf temperature, and transpiration rate in a high-pressure (68 atm) fog system. There were two vent configuration treatments, referred to as vent configurations "S+T" and "S+T+N" separately: south + top and south + top + north. According to the researchers, high pressure fog dropped air temperatures by around 4 °C and leaf temperatures by 0.80 °C. It also raised relative humidity by 26% and, on average, decreased transpiration rate by 22 mg m⁻² [floor] s⁻¹.

Montero (2006) [26] studied the the relationships between external and greenhouse climates, paying special attention to the relationship between ventilation rate, evaporative cooling and greenhouse temperature. Three greenhouses are compared:-1) Control greenhouse. No cooling through evaporation. 2 2) A white screen in a shaded greenhouse with 40% transmission. No cooling by evaporation. 3)

Evaporative cooling by a fog system. The relative humidity in the greenhouse is set at 85%. When ventilation was inadequate, the results indicate that shadowing resulted in a higher drop in greenhouse air temperature. It was demonstrated that the fogging technique reduced the greenhouse's dependency on ventilation for temperature. Depending on the leaf area index (LAI), fogging lowered transpiration by 12-51%. It was also shown that water use efficiency (WUE) was higher in greenhouses with shade and those with evaporative cooling for the low salinity treatment.

Impact of improper climate on crop production Temperature

Heat stress is usually referred to as a significant increase in temperature that may damage plants irreversibly. This usually occurs when the temperature elevates by 10-15 °C above the threshold

(Peet and Willits, 1998) ^[34]. Every aspect of plant processes, including germination, growth, development, reproduction, and yield, are affected by heat stress (Hasanuzzaman, 2013)

^[10] Heat causes detrimental effects on plant leaves, such as decreased leaf water potential, decreased leaf area, and early leaf senescence (Greer *et al.* 2012) ^[7]. When the temperature drops below 12 °C, cucumber leaves also suffer damage (Hamedalla *et al.*, 2022) ^[9]. Plant growth is restricted by inadequate light, and morphological indicators like plant height, stem thickness, leaf area, number of leaves, and width all decline with decreasing light intensity (Yan *et al.* 2021) ^[42]. Cucumbers' dry weight decreased due to low temperatures and inadequate light stress (Zhao *et al.* 2018) ^[43]. The ideal temperature ranges for winter crops and summer crops are from 25-31 °C and 31-37 °C respectively (Al-Rajab, 2021) ^[2]. Higher air temperatures have a negative impact on plant growth, pollination, and the reproductive process after a certain point (Klein *et al.* 2007) ^[17]. One of the primary factors impacting the growth and development of cucumbers is temperature (Farazmand, 2020) ^[6]. Cucumber is plant native to subtropical and temperature regions, and the optimum temperature for growth and photosynthesis is 15-32 °C and 25-30 °C. During the growing season, temperatures between 18 °C and 35 °C are ideal for producing cucumbers; temperatures below 10 °C or beyond 35 °C decrease crop growth and maturity.

Marcelis and Baan (1993) ^[24] studied how temperature affects the development of cucumber fruits individually. Fruit was either moved from 17.5 °C to 27.5 °C or vice versa, or crops were continuously grown at 17.5, 20.25, and 30 °C. Plants were grown at the same temperature as the fruits in tests with continuous temperature (17.5, 20, 25, or 30 °C). After being topped, the plants in the studies with varying temperatures were cultivated at 17.5 °C, and the fruits (one fruit per plant) were produced at 17.5 °C or 27.5 °C. The effect of temperature on fruit growth was investigated by growing plants with one or five fruits. The findings demonstrated that an increase in temperature enhanced the fruits' final fresh weight when one fruit was left on the plants at a consistent temperature. As the temperature increased, the maximum growth rate increased more quickly. As the number of fruits per plant increased from one to five, the growth rate per fruit fell. When five fruits were still on the plant, the final fresh weight per fruit dropped as the temperature rose.

Aloni *et al.* (2001) ^[1] conducted experiment on bell pepper because of its relatively low sensitivity to flower abortion at HT (high temperature). The plants were grown in 4 growth chambers, of which two were maintained at NT (normal temperature) and two were maintained at HT (high temperature). The researcher examined how high temperature affects carbohydrate alterations in bell pepper pollen to explore potential connections between these changes and pollen germination during heat stress. When pepper plants were kept at an average HT (32/26 °C, day/night) for 8 days prior to flowering, the pollen count at anthesis was comparable to that of plants grown in normal temperatures (NT 28/22 °C), but the *in vitro* germination of pollen from HT (high temperature) plants at 25 °C was significantly diminished.

This outcome was linked to the significant reduction in the number of seeds per fruit in the HT (high temperature) plants. The sucrose levels in the pollen of HT (high temperature) plants were less than those of NT (normal temperature) plants in high CO₂ concentration.

Hatfield *et al.* (2015) analysed The impact of temperature fluctuations on the growth and development of plants for maize crop. The experiment was conducted in a controlled chamber. In the initial test, two rows of five plants each were used to plant the maize. Every week, water was applied to each block to simulate the average amount of precipitation for that week. One block was exposed to normal precipitation levels, another to 1.25 of normal precipitation, and a third to 0.75 of normal precipitation in order to simulate excess and water shortage scenarios. Plant growth was visually observed throughout the season, and for one week at the V6, V12, and pollination stages, the air temperature in one chamber was raised by 5 °C. The minimum temperatures in the chamber with the high temperature exposures were subsequently raised by 3 °C from the end of pollen shed through crop maturity. In the second experiment, one of the compartments was kept at the typical weekly temperature throughout the growth season, while the second chamber was kept 4 °C above average. Weekly normal precipitation was applied to the monoliths in the first chamber. Results showed in first experiment that the overall vegetative dry weights between extreme temperature events varied significantly. Under conditions of surplus water, the temperature extremes had the worst impact, with biomass and yield decreasing by about two-thirds. The phenological development varied in the second experiment, when one chamber was kept at 4 °C above normal for the whole of the growth season. Only the plants' rate of development up until the start of the reproductive stage showed the effects of warm temperatures. Senescence during grain-fill was accelerated by warm temperatures, which decreased grain yield. In all cases, warmer temperatures significantly reduced grain yield in maize by as much as 80-90% when compared to a normal temperature regime, with the majority of the effects occurring during the reproductive stage of development.

Humidity

In an agricultural greenhouse, the majority of fruit and vegetable plants need a relative humidity of 50 to 90% for optimum growth (Sultan *et al.* 2021) ^[41]. Based on the range of humidity, the majority of documented vegetative growth responses (measured by length, leaf area, fresh and dry weight) of different crops show that high humidity promotes

better development (Hoffman, 1979) ^[11]. Under normal conditions, about 70% of relative humidity should be maintained in the greenhouse for better plant growth (Joliet and Hortitrans, 1994) ^[14]. Even though the dry weights of Cucumis and Lactuca were not affected by RH, the fresh weights increased (Mortensen, 1986) ^[28]. The effect of humidity on the growth of greenhouse crops is primarily determined by changes in leaf size and light interception rather than by an increase in stomatal conductance through increased leaf size and stomatal conductance at low VPD (vapour pressure deficit) (Korner and Challa, 2003) ^[18].

Amin *et al.* (2021) ^[3] examined how immature cucumber plants at the 2, 4, or 6 leaf stages were affected by LT (low temperature) (day/night: 9/5 °C, 25/18 °C as control) and HH (high humidity) (95%, 80% as control). The experiment was divided into four groups: low temperature (9/5 °C + 80% humidity), high humidity (25/18 °C + 95% humidity), low temperature plus HH (high humidity) (9/5 °C + 95% humidity), and control (25/18 °C + 80% humidity). Plants in different leaf stages received LT and HH treatments for seven days. The second, fourth, or sixth completely developed leaves were sampled by the researcher. In comparison to the control, data analysis revealed that young cucumber plants under stress conditions (LT+HH) at all leaf stages experienced substantial losses in shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, and total fresh weight.

Holder and Cockshull (1990) ^[12] examined the effects of four varied humidity treatments (0.1, 0.2, 0.4, and 0.8 kPa vapour pressure deficit) on the growth and cultivation of a long-season tomato crop over the course of 28 days. Temperature differences between the treatments were less than 0.2 °C. Following the treatment period, all compartments' humidity levels were kept at a VPD (vapour pressure deficit) of 0.3 kPa or higher. Researchers were limited to the 0.1 and 0.2 kPa VPD treatments and saw signs of calcium insufficiency 14 days after the humidity treatments began. High humidity dramatically inhibited leaf development. Fruit size was most likely the primary impact of the humidity treatments. In comparison to the lowest humidity treatment, the maximum humidity treatment resulted in a 50% reduction in leaf area.

VPD (vapor pressure deficit)

The problem with elevated atmospheric vapor pressure deficit (VPD) in plant greenhouses during the spring-summer development season, which has a major impact on high-quality production and the efficient use of agricultural resources. When exposed to High VPD (HVPD), plants often reduce their rate of photosynthesis and close their stomata (Song, 2020) ^[39]. Low vapor pressure deficit (LVPD) conditions lowered transpiration rate while increasing stomatal conductance and net photosynthetic rate for both plant species. A micro-fog device successfully maintained low VPD below 1.5 kPa (Qingjie, 2018) ^[35]. The trends in stomatal conductance and net photosynthetic rate were similar. The stomatal conductance increased by 15.6 and 14.6% in muskmelon and cucumber under LVPD (Low vapor pressure deficit) conditions, whereas the net photosynthetic rate increased by 18.2 and 19.6% accordingly. Song and associates, 2020. Low vapor pressure deficit (LVPD) conditions can increase fruit yield by 17% while also improving fruit quality. The VPD control using fogging method promotes plant growth and productivity by

improving photosynthesis (Lu *et al.* 2015) ^[23].

Leonardi *et al.* (2000) ^[20] conducted research on tomato crop and Examine how a high vapor pressure deficit affects tomato fruit quality and growth transpiration. Two adjacent, identical sections were used to cultivate plants. A fogging system was used to maintain low VPD (vapor pressure deficit) (set point: 60% relative humidity during the hottest parts of the day i.e from 09:00 a.m. till 15:00 solar time). Research showed Fruit's relative growth rate rose from 0.7 to 4 mg g⁻¹ h⁻¹ in the morning while the vapor pressure deficit (VPD) was low, and then progressively decreased from 12:00 until the evening. Under high VPD, a distinct trend was seen where a larger amplitude of variance was reported during daily hours. The relative fruit growth rate declined until 1 PM, peaked at (6 mg g⁻¹ h⁻¹) at 17 PM, then again declined to levels comparable to those seen under low VPD. Soluble solids content increased with increasing VPD, However, the water content and fresh weight per fruit dropped.

Song *et al.* (2021) ^[38] studied effect of Vapor Pressure Deficit on growth and water status in muskmelon and cucumber. Two different climate-controlled greenhouses were used to cultivate muskmelons and cucumbers. The greenhouses were installed with a humidification system (spray pressure: 2-6 MPa, droplet size: 25.8-46.2 µm) and created two different climatic conditions: LVPD (low vapor pressure deficit (high humidity) and HVPD (high vapor pressure deficit) (low humidity). The VPD was maintained below 1.5 kPa under LVPD circumstances. Each greenhouse was equipped with datalogger. The sensor of the datalogger was placed 1.6 meter above ground in the middle of the greenhouse. The vapor pressure deficit (VPD) was calculated from T (Temperature) and RH (Relative humidity) data. The results clearly showed that for both the muskmelon and cucumber plants, LVPD (low vapor pressure deficit) conditions increased net photosynthetic rate and stomatal conductance but decreased transpiration rate. Compared with HVPD (high vapor pressure deficit) conditions, the net photosynthetic rate was 18.2 and 19.6% higher and the stomatal conductance was 15.6 and 14.6% higher under LVPD conditions for muskmelon and cucumber. Plants grown in the LVPD (low vapor pressure deficit) environment use less water (12.90% less in muskmelon, 13.35% less in cucumber) than HVPD (high vapor pressure deficit) environment, and LVPD (low vapor pressure deficit) produced significantly higher yields of cucumber and muskmelon per plant.

Logics or strategies used to reduce heat load

Montero and Anton (1989) ^[27] determined the effect of an air-water fogging system on the climate of the greenhouse. Researchers compared the two greenhouses first one was consist of 26 fogging nozzles as operated when inside air temperature reached 28 °C. A humidistat stopped when relative humidity surpassed 90%. The second greenhouse was without fogging. It was observed that the fogging nozzle significantly lowered the greenhouse temperature by 3 °C than the greenhouse without fogging. Also, by comparing both the greenhouse maximum air temperature reduction was 5 °C.

Ozturk (2003) ^[18] investigated the effectiveness of fogging system (FS) in greenhouses for rose crop. A multispan plastic greenhouse (PG) was used for the studies. Fog generating nozzles (FGN) needed a pressure of 4.5 atm.

Each span of the PG (plastic greenhouse) had three nozzle lines with 82 FGN (fog generating nozzles) fitted. For the hottest recorded sunny days, the effectiveness of the FS (fogging system) in the PG (plastic greenhouse) was specifically examined. One crucial indicator of the FS (fogging system) was the temperature difference between the air inside the PG (plastic greenhouse) and the air outside. According to the experimental findings, the temperature within the plastic greenhouse (PG) fluctuated between 23.1 °C to 34.3 °C, whereas the temperature outside varied from 23.7 °C to 40.4 °C. Throughout the morning and afternoon, the temperature of the air inside as well as outside the PG remained quite constant. At 7:00 AM, the air temperature difference (ATD) between the PG's interior and exterior was only 0.63 °C; however, by 16:00 PM, the ATD had risen to 6.6 °C. The relative humidity (RH) of the air outside the PG ranged from 28.1 to 55.7%, whereas the RH of the air interior the PG varied from 56.3% to 76.3%. For example, researchers found that the PG with the fogging system had consistent temperature and relative humidity levels.

Li *et al.* (2005) ^[22] studied the effect of low pressure fogging system in a naturally ventilated greenhouse. Two naturally ventilated greenhouses were used for this experiment. One was cooled by fogging and another was not cooled. The spray rate was controlled by imposing two maximum spraying frequencies for different days: 100-second out of a 600-second period and 150 seconds running out of 600 second period. Fogging system was controlled by control computer at 15s interval. The experiment concluded that the fogging system reduces the leaf temp by 1.1 °C and air temperature by 1 °C. Relative humidity increases by 9% also transpiration rate was reduced by 6.5 mg/m²

Montero (2006) ^[26] studied the interaction between external and greenhouse climates, paying special attention to the relationship between ventilation rate, evaporative cooling and greenhouse temperature. Three greenhouses are compared: 1) Control greenhouse. No evaporative cooling. 2) Shaded greenhouse with a white screen, with 40% transmission. No evaporative cooling. 3) Evaporative cooling by a fog system. Greenhouse relative humidity set at 85%. The findings indicate that when ventilation was inadequate, shadowing resulted in a larger drop in greenhouse air temperature. It was demonstrated that the fogging technique reduced the greenhouse temperature's reliance on ventilation. Fogging decreased transpiration by 12 percent, and Montero (2006) ^[26] examined how the greenhouse and outdoor climates interacted, focusing on the connection between greenhouse temperature, ventilation rate, and evaporative cooling. A comparison is made between three greenhouses: 1) Control greenhouse. Evaporative cooling is absent. 2) 40% transmission in a shaded greenhouse with a white screen. Evaporative cooling is absent. 3) Fog system evaporative cooling. The relative humidity in the greenhouse is set at 85%. The findings indicate that when ventilation was inadequate, shadowing resulted in a larger drop in greenhouse air temperature. It was demonstrated that the fogging technique reduced the greenhouse temperature's reliance on ventilation. Depending on the leaf area index (LAI), fogging decreased transpiration by 12-51%. It was also shown that water use efficiency (WUE) was higher in greenhouses with shade and those with evaporative cooling for the low salinity treatment.

Controller based system developed and evaluated for temperature control

Banerjee and Singhal (2010) ^[5] developed microcontroller based polyhouse automation controller. LCD panel, switches and relay circuit was built outside the polyhouse and microcontroller, temperature and relative humidity sensors were located inside the polyhouse. Analog signals from the sensors converted to digital by microcontroller. The desired temperature range for a polyhouse is defined by TMAX and TMIN. The system software assists the microcontroller (PIC16F877A) in the analysis of the digital data and produces the actuation signal for the relay circuits to turn on the sprinklers, exhausts and heating pipes, in order to regulate the polyhouse's environmental conditions. Researchers concluded that developed system operates at high speed (Max 20 MHz clock input) which ensures faster execution of the codes, essential for the real time interaction with the environment.

Park *et al.* (2011) ^[32] studied on greenhouse automatic control system based on a wireless sensor network that gathers environmental data about the greenhouse, including temperature, humidity, etc. The system is made up of sensor nodes for temperature, humidity, and leaf temperature and humidity as well as relay nodes that control devices like windows, heaters, ventilators, and other equipment. The environment data that is gathered in real-time is automatically stored on a database server. The base node can accept data from the sensor nodes and store it in a database. They can then be sent over the internet from the base node to the remote control system. The suggested solution can make up for the discrepancy between the sensors' recorded temperature and humidity and the specified values. The ideal temperature for the crops to be monitored in this system can be set at the specified air temperature (20-25 °C). Researchers come to the conclusion that the suggested method can serve as the foundation for an accurate and effective greenhouse management system.

SU KO and YI MON (2014) ^[40] implemented the automatic control system for greenhouses. A microcontroller is the main processing element of the system. The temperature, light, and humidity sensors provide inputs, and an LCD display module shows the results. The humidity monitoring and control system turns on the spray pump when the relative humidity drops below the program's predetermined level. The technology reduces plant watering and enhances ventilation when the relative humidity rises above the set threshold. The light monitoring and control system turns off the bulbs if the light intensity is too high. The user can adjust the greenhouse's temperature to their preferred level using the temperature monitoring and control system. The device will activate fans when the temperature in the greenhouse surpasses the predetermined threshold. By lowering complexity and power consumption, the system has effectively addressed its drawbacks and offered a precise and adaptable method of greenhouse environment maintenance.

Othoigbe and Enokela (2015) ^[29] developed an automated greenhouse control system using Arduino prototyping platform. To monitor and control the greenhouse environment, the automated greenhouse control system makes use of sensors and actuators that are controlled by a microcontroller that is running a computer program. The Arduino integrated development environment IDE software was used to write the controller's code in the Arduino

programming language, debug it, compile it, and burn it to the microcontroller. In this research, the system's control strategy is created so that each of the various parameters can be managed as follows: 1) The definition of higher and lower threshold limits is necessary for the temperature control. When the top limit is exceeded, a fan begins to cool the greenhouse atmosphere, and when the lower limit is reached, the opposite occurs. 2) A fogging system is activated when the greenhouse enclosure's humidity falls below this threshold and is deactivated when the circumstances are optimal. When the system was set up and tested, the researchers discovered that anytime any of the microclimatic parameters departed from the preset thresholds, the sensors and actuator station reacted promptly to return the system to optimal circumstances.

Saha *et al.* (2017) ^[36] Constructed and developed an automated greenhouse system using Arduino uno. Sensors for temperature, humidity, light, and soil moisture make up the system. The microcontroller (Atmega328 MCU) receives data from these sensors after they have sensed a variety of characteristics. When specified levels are surpassed or lowered, the microcontroller signals the interface devices to restore the temperature and humidity in the greenhouse. The air conditioner is then turned on by these devices. It uses analog input from temperature and humidity sensors to generate digital output. The authors came to the conclusion that the method is more accurate and efficient than a manual system.

Conclusion

The review underscores the critical role of advanced cooling systems, such as fogging and evaporative cooling, in maintaining optimal climatic conditions within naturally ventilated greenhouses, which is essential for enhancing crop yields and quality in India's diverse climates. By integrating automated control systems, farmers can effectively manage environmental factors that significantly impact plant health, thereby ensuring improved agricultural productivity amidst increasing climate challenges.

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