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Design and Development of an Efficient Model of a Hybrid Poly Greenhouse for Controlled Farming Using a Sensor Network

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ABSTRACT

This paper introduces an innovative approach to the design and development of a hybrid poly greenhouse with integrated sensor networks for controlled farming. As the global population is projected to reach 10 billion by 2050, the demand for food, clean water and energy has become a pressing issue. Climate change and its consequences, particularly in countries like India, make sustainable and efficient agriculture imperative. This study presents a solution in the form of a controlled greenhouse that utilizes regenerative low temperature evaporative cooling and sensor networks to optimize environmental conditions and irrigation. The design prioritizes resource efficiency, including water reuse and renewable energy sources, while enhancing crop cultivation and addressing food security challenges.

Key words: Wireless sensor network, irrigation system, greenhouse cultivation, sensors

INTRODUCTION

Addressing the needs of a global population projected to reach 10 billion by 2050, while ensuring access to energy, clean water and food, is indeed a significant challenge. This challenge is further compounded by the changing climate and global warming, which place increasing strain on vital resources (Gitz *et. al.,* 2016). Although climate change has a global effect, however, India is among the top five countries that will be at high risk and may face intense drought, storms, unpredictable weather and heat waves. Such a situation will hurt the economy agriculture and food production which will lead to food insecurity and loss of lives. Therefore, it is of extreme importance to develop technology solutions and optimize the use of sensors which help in keeping agriculture and food production constant by saving the crops from extreme weather events (Shivanna, 2022).

An obvious solution is to grow the crop in a controlled environment such as a greenhouse chamber with technological solutions. In the last few decades, viable technological and innovative solutions such as large-scale greenhouse farming have been introduced, improving both the yield and quality of crops. However, the cultivation of crops under the greenhouse chamber needs additional input of energy and water to regulate the microclimatic conditions inside the chamber. The selection of climate control technologies should suit the cultivated crop and be aligned with local climatic conditions. Evaporative cooling technologies such as fan pads and fog cooling are effective means of controlling climatic conditions in hot and arid locations. As compared to fog cooling, the fan pad system has a higher air saturation efficiency, and lower cost, water and energy consumption (Baudoin *et al.*, 2017). Evaporative cooling (wet pad-fan system or fogging system) is alternatively used to provide cool and moist air for plant growth.

Moreover, the growing of crops itself requires a huge amount of water. Additional water used in evaporative cooling increases the water footprint of crops. Besides increasing, the water footprint of crops evaporative cooling discharges the water/moisture, to the immediate surroundings of the structure/ system, in the form of vapour which further increases the greenhouse gas accumulation in the local environment and reduces the cooling effect by increasing the wet bulb temperature which is the lower limit of the achievable temperature in evaporative cooling (EC).

To make EC a sustainable technology, several innovative works have been done. Several authors have proposed that solar-powered EC providing cooling by utilizing renewable energy, such as solar energy, is one solution to address the energy issues. There is tremendous progress in this direction such as the utilization of solar power to operate the system hence lowering the energy cost and dependency on fossil fuel. In hot and humid areas where airflow requires to be dehumidified to the required growing conditions, solar regenerators can be combined with desiccant-assisted cooling systems to provide the heat required for regenerating the dehumidifying ability of the desiccant. Some work has also been done to improve the greenhouse cladding to achieve low heat loss.

There is less focus on the water consumption of EC but more focus on temperature control and the use of renewable energy. Therefore, based on existing state-of-the-art evaporative cooling (EC) for greenhouse use it was hypothesized that there was need to design a system that reuses the water that goes inside the system. It may help in the reduction of water consumption and aid in a further temperature reduction of the cooling chamber. Reducing the total water consumption will further improve the total water footprint of crops grown in greenhouses. A provision has been aided for reducing the input air temperature which will further reduce the wet-bulb temperature of evaporative hence, better cooling efficiency by using a sensor network. And optimization of resources using sensors to control the various parameters related to crop cultivation and irrigation systems.

Landsberg's model for computing the greenhouse air temperature reported that the temperature stayed between 4-5°C below the outside air (Misra and Ghosh, 2017a). Misra and Ghosh carried out a performance study of a greenhouse system surrounded by shallow water ponds and floating wetted surfaces under dual ventilation mode. They predicted the greenhouse temperatures using thermal models with or without evaporative cooling under natural ventilation as well as fan-induced ventilation. They reported that greenhouse temperature could be reduced by 3-6°C lower than that of the ambient temperature under dual ventilation mode when saturation efficiency and shading were 70 and 75%, respectively (Misra and Ghosh, 2017b). In another experiment, Misra and Ghosh developed a simplified thermal model for a fog-cooled greenhouse operating under natural ventilation and validated the model with an experimental arched-shaped plastic greenhouse situated in eastern India. They observed that the greenhouse inside temperature solely depended on fogging configurations. They concluded that with the low-pressure fogging system with suitable ventilation greenhouse inside temperature could be maintained at 2-4°C lower than the ambient temperature (Misra and Ghosh, 2017c).

Another research used a low-cost automation system for greenhouse cooling. The automation system was developed using logical circuits (Jinu and Abdul Hakkim, 2018). With such a system mean temperature achievable was 33°C. However, they did not present any estimates of water consumption and technical improvement in the air quality used for cooling. Some experimentation was performed with three different RH conditions (low, medium and high) to assess the porous material's ability as a cooling medium for evaporative cooling. They have concluded that excellent performance characteristics were observed when the system was operated under low RH conditions (Abaranji *et al.*, 2020).

Another study analyzed the water and energy use efficiency of greenhouse and net house under desert conditions of UAE: agronomic and economic analysis (Hirich and Choukr-Allah, 2017). Their research aim was for the water and energy use efficiency between a high-technology greenhouse equipped with a pad-fan and sunscreen system and a low-technology net house equipped with a mist system. Three crops cultivated were: cherry tomato and sweet pepper under the greenhouse and cucumber under the net house. Greenhouses used the highest water consumption for the cooling process. It was shown that a protected agriculture system consumed a considerable amount of water and energy in the cooling process. Therefore, there was a need to improve energy and water use efficiency in the protected agriculture in the GCC region.

Liu and Jeong (2020) have investigated the annual energy saving potential and system performance of two different evaporative cooling based liquid desiccant and evaporative cooling assisted air conditioning systems. In this study, it was found that the liquid desiccant and the indirect and direct evaporative cooler system (LDIDECOAS) might provide a reduction of approximately 25% in the annual primary energy consumption as compared to the liquid desiccant evaporative cooler system (LDEOAS), in Seoul.

Chen *et al.* (2021) studied on desiccant evaporative combined chilled air/chilled water air conditioning systems. In this study, a desiccant evaporative combined chilled air/ chilled water air-conditioning system was proposed. The proposed system integrated a desiccant wheel air conditioning system and a direct evaporative cooler, which was used for temperature and humidity independent control systems in humid climates. An experimental setup was built and used to test the system performance and important system parameter effects under moderate temperature and humidity (32°C, 60% RH), moderate temperature and high humidity (32°C, 80% RH), and high temperature and humidity (36 ^{0}C, 80% RH). The results indicated that for the system at a regeneration temperature of 70°C, the chilled air temperature was lower than 20°C, the chilled air humidity ratio was lower than 13 g/kg, and the chilled water temperature was lower than 18°C, which met the temperature and humidity independent control requirements.

In the field of greenhouse cultivation, sensors play a crucial role and can be categorized into two main groups: those focusing on soil conditions and those geared towards monitoring weather parameters. Table 1 shows the list of sensors utilized for tracking weather conditions and Table 2 presents a list of sensors used to assess soil properties for better understanding the nature of type and requirements of soil as per the need of crops.

PROPOSED MODEL

To design and develop a greenhouse/poly house that is based on energy and natural resource conservation and economically approachable for the cultivation of many crops that require moderate to low temperatures. And to provide another option of sustainable technology in protected cultivation to off-secession vegetable cultivation and help to uplift the socio-economic condition of farmers and also to help small and marginal farmers to approach commercial farming. Another important utility is to produce more fresh and safe vegetables in all secession and maintain the objective of food security. Evaporative cooling systems and the use of sensor networks deployed in this paper will be useful in any part of the country for most optimal cultivation in poly greenhouses.

This research work may put forward a new era of research and development in the area of farming and greenhouse agriculture using technological solutions. The specification of poly house and greenhouse used in the proposed system is shown in Table 3.

The theory behind the system and its components have been used to design and

Table 1. Types of sensors for various parameters in greenhouse

Sensor	Humidity	Temperature	Wind speed	Wind direction	Solar radiation	Air pressure	References
SHT85	Available	Available	N/A	N/A	N/A	N/A	*www.sensirion.com*
DS18B20	N/A	Available	N/A	N/A	N/A	N/A	(Datasheet of DS18B20,2020)
EE181	Available	Available	N/A	N/A	N/A	N/A	*www.campbell sci.com*
Wind monitor model 05103	N/A	N/A	Available	Available	N/A	N/A	Datasheet of 05103. 2020
CM-100 Compact weather sensor	Available	Available	Available	Available	N/A	Available	*http//wwwstevens* water website com
Pyranometer LI-200X	N/A	N/A	N/A	N/A	Available	N/A	Campbell sci.com
HMP35C	Available	Available	N/A	N/A	N/A	N/A	Campbell sci.com
Temperature sensor STS3x	N/A	Available	N/A	N/A	N/A	N/A	*www.sensirion.com*
WS500-UMB Smart weather sensor	Available	Available	Available	Available	N/A	Available	*www.lufft.com*
Pyranometer CS320	N/A	N/A	N/A	N/A	Available	N/A	Campbell sci.com
LM35	N/A	Available	N/A	N/A	N/A	N/A	*www ti.com*
SHT75	Available	Available	N/A	N/A	N/A	N/A	*www.sensirion.com*

Table 2. Types of other sensors for various parameters in greenhouse

Sensor	Moisture	Temperature	Water level	pH	Salinity	References
EC-5	Available	N/A	N/A	N/A	N/A	*http://www.decagon.com*
VH 400	Available	N/A	Available	N/A	N/A	*http://wwwvegetronix.com*
EC 250	Available	Available	N/A	N/A	Available	*http://www.stevenswater.com*
TDR-3A	Available	Available	N/A	N/A	N/A	*www.ictinternational.com*
HydraProbe II Soil sensor	Available	Available	Available	N/A	Available	*www.stevenswater.com*
DS1822	N/A	Available	N/A	N/A	N/A	*www.maxim integrated.com*
Sensor S8000 pH	N/A	N/A	N/A	Available	N/A	*www.sensorex.com*
MP406 Moisture sensor	Available	Available	N/A	N/A	N/A	*www.ictinternational.com*
WATERMARK Soil moisture sensor	Available	N/A	N/A	N/A	N/A	*www.irrometer.com*
107-L Temperature	N/A	Available	N/A	N/A	N/A	*www.campbell sci.com*
AquaTrak 5000	N/A	N/A	Available	N/A	N/A	*http://www.stevens water.com*
Pogo portable soil sensor	Available	Available	N/A	N/A	N/A	(Datasheet of Pogo 2020)
pH 3000	N/A	N/A	N/A	Available	N/A	(Techincal Data of pH 3000, 2020)
CS625	Available	N/A	N/A	N/A	N/A	*www.campbellsci.com*
109-L Temperature	N/A	Available	N/A	N/A	N/A	*www.campbellsci.com*
SEN10972 pH Sensor kit	N/A	N/A	N/A	Available	N/A	*www.generation robots.com*

Table 3. Specifications of poly house and greenhouse used in the proposed system

Item	Specification
Type of poly house	Fan pad evaporative cooling type poly house
Average inside temperature (°C)	35-37
Average outside temperature (°C)	42-44
Outdoor relative humidity (%)	25-40
Average water loss from fan pad l/h/m^2	0.17
Length (L meter)	12 South-North
Width (W meter)	8 east-west
Height (H)	10 feet and in the center 12 feet
Poly house area in m2	96
Polymer covering	Poly-ethylene
Fan radius (meter)	0.31
Fan size (LxW meter)	0.76 x 0.76
Fan rpm	900
Fan velocity (m/s)	29.21
Fan flow rate (m3/sec)	16.87
Air exchange rate	0.17
Cellulose pad size (L x W meter)	11 x 1.1
Overall power	4 hp

develop highly efficient regenerative low-temperature evaporative cooling chambers and sensor-based efficient models for better cultivation in poly hose systems. This will give a better idea of the model and feasibility of this technology.

The concept of the cooled greenhouse system is shown schematically in Fig 1. The essential parts of the system are the condenser, air mixing chamber, evaporative pad, atomizer, NIR reflector roof, fan and filter. Sensor based system for controlling irrigation and better cultivation.

Atmospheric air enters the system through the desiccators where it is dehumidified as it passes through the desiccant. Desiccated air enters into the air mixing chamber where high-temperature dry atmospheric air will be mixed with the cooler dry air which is recuperated from the condenser and passed through the desiccant filter. This mixed air stream with low RH and that low temperature will be passed through the evaporative pad and finally, the air will be cooled down to the wet-bulb temperature. Cooled air with high RH will pass through the greenhouse chamber. The air is drawn through an exhaust fan. Exhausted air will not be released into the atmosphere but will be collected through the duct and passed through to a condenser to extract the moisture from it. The extracted moisture will be collected in a tank. Collected cold water will be used to create mist using atomizers in the greenhouse chamber. The liquid temperature will be equal to or below the dew point temperature which is cooler than the wet-bulb

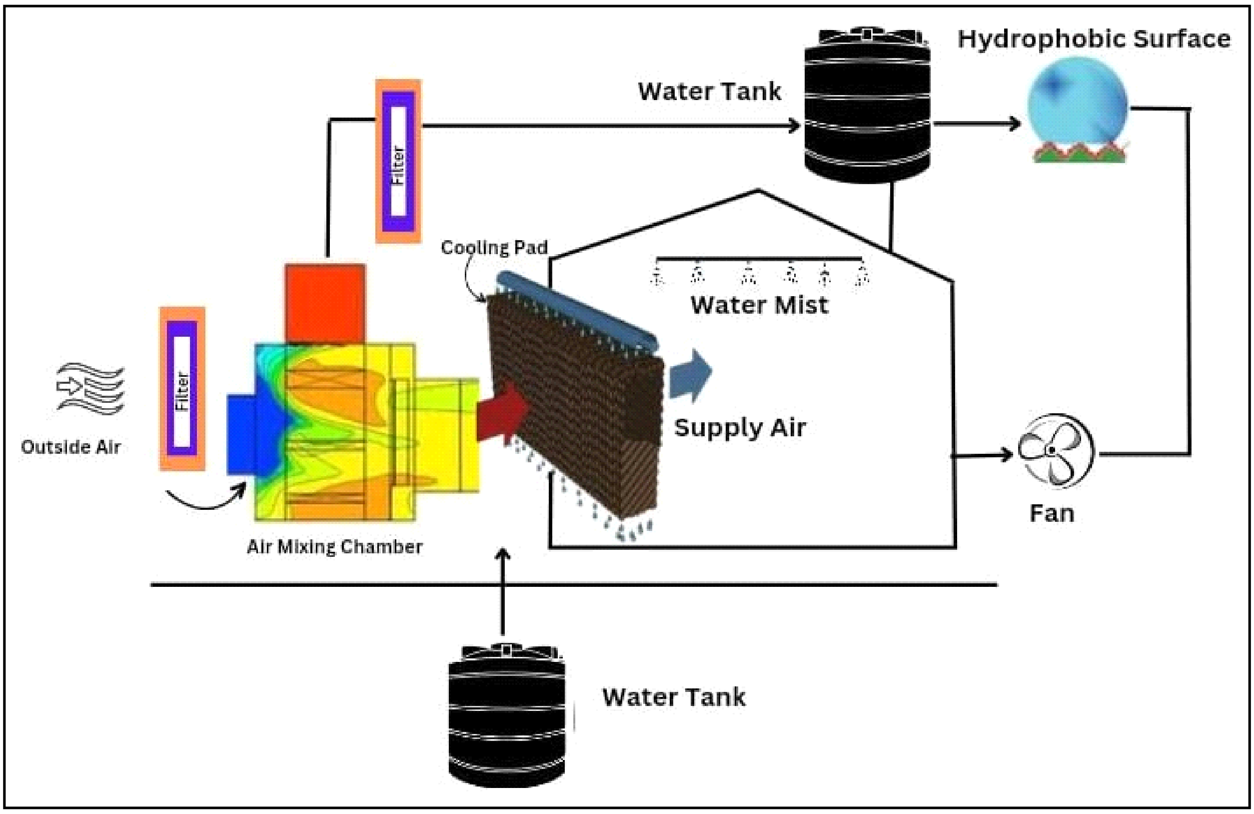

Fig. 1. Schematic diagram of proposed regenerative low temperature evaporative cooling chamber.

temperature. Hence, misting this water in the chamber will aid in further reduction of temperature.

The automated system for smartly managing greenhouse cultivation through wireless sensor networks follows a workflow algorithm as follows: sensor nodes, including both weather and plant-related sensors, continuously collect data on various environmental parameters crucial for greenhouse conditions, such as temperature, humidity, light levels and soil conditions (Fig. 2). These data are wirelessly transmitted to a base station, serving as the central data hub for collection and processing. The base station subsequently communicates with a coordinator node, responsible for in-depth data analysis, and it stores the data in a database. The coordinator node can also issue commands to other nodes to manage greenhouse conditions effectively. Terminal surveillance and data analysis are conducted, assessing the processed data against predefined threshold values for each parameter. Based on this analysis, decisions are made regarding greenhouse climate control. If the processed data indicate a need for adjustments, the system can activate devices like heaters, coolers, or shade mechanisms to maintain the ideal greenhouse conditions, or vice versa. The real-time status of the greenhouse and all relevant data are made accessible to farmers through an online application, accessible through devices such as smartphones. The ZigBee wireless communication protocol is highly recommended for its low power consumption and suitability for real-time monitoring in WSN applications, making it an ideal choice for greenhouse cultivation management.

CONCLUSION

The proposed model for a hybrid poly-greenhouse with a sensor network addresses several critical issues related to contemporary agriculture. The integration of regenerative low temperature evaporative cooling is a significant step toward reducing energy consumption and water usage, particularly in water-stressed regions. By efficiently managing air humidity and temperature, this system can create an ideal environment for crops while reducing the carbon footprint of greenhouse agriculture.

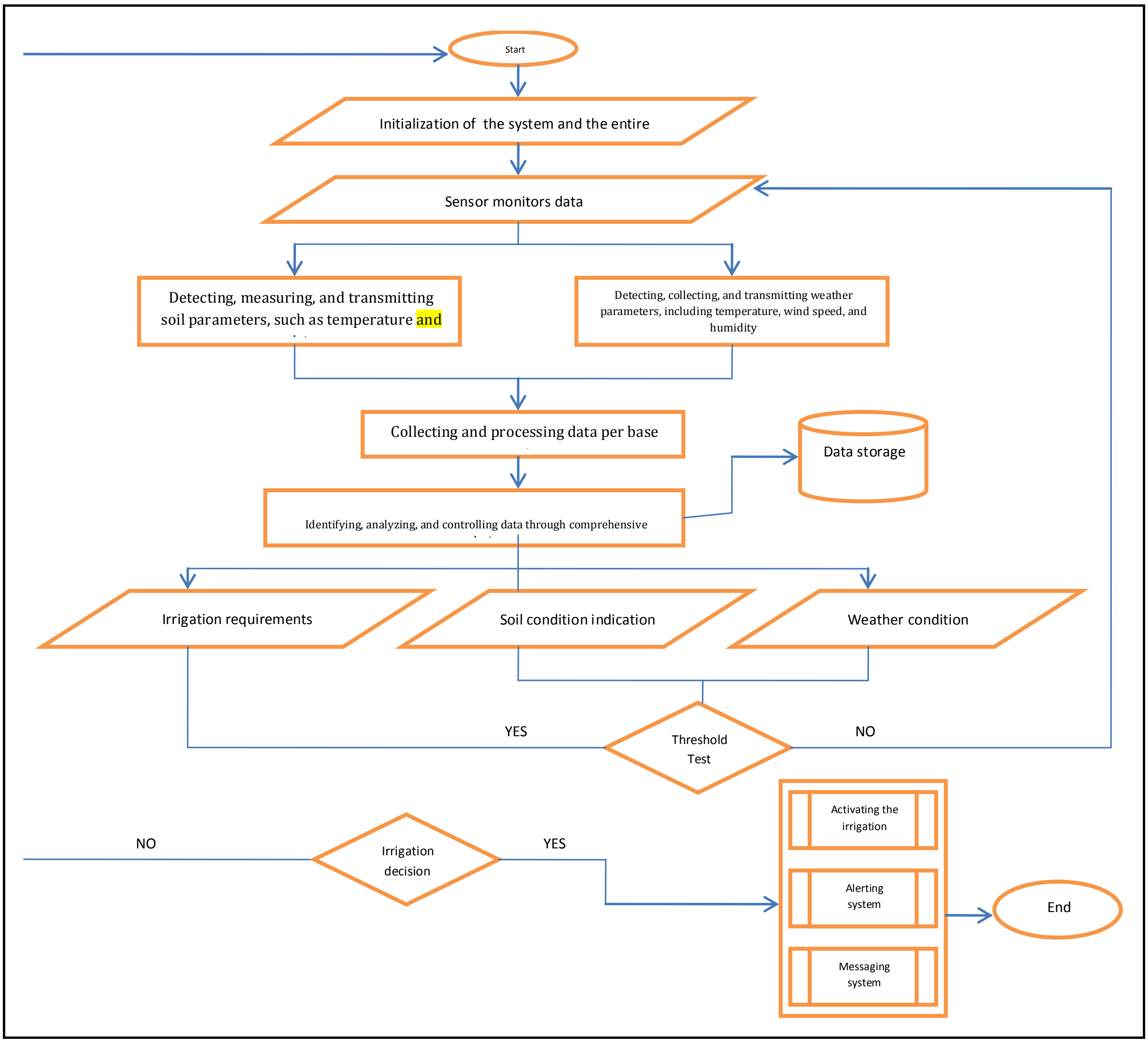

Fig. 2. Workflow diagram : Humidity, light levels, and soil conditions.

The use of sensor networks for real-time data collection and control is a vital component of the model. This technology enables precise monitoring and adjustment of environmental parameters, leading to enhanced crop growth and resource conservation. It also provides opportunities for data-driven decision-making, allowing farmers to optimize their cultivation practices.

The emphasis on resource efficiency, including water reuse and renewable energy sources, is a crucial aspect of the proposed model. By reducing water consumption and reliance on fossil fuels, the system not only minimizes operational costs but also contributes to environmental sustainability.

In conclusion, the hybrid Poly-greenhouse with a sensor network presents a compelling solution to the challenges of modern agriculture. It offers a path to more sustainable and efficient farming practices, with the potential to improve food security and economic development, especially in regions vulnerable to climate change. Further research and development in this field can lead to practical implementations that benefit both farmers and the environment.

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