*IOSR Journal of Computer Engineering (IOSR-JCE)*
*e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 24, Issue 3, Ser. II (May. –June. 2022), PP 35-43*
*www.iosrjournals.org*

# Controlled Environmental Agriculture Through Earth Tube Heat Exchanger and Sensors – A State of the Art-Review

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***Abstract***
*Agriculture, owing to the uncertainties of climate and vagaries of weather needs new interventions, modification in the existing practices or choosing new alternatives altogether. Controlled environmental conditions are thus the best alternative under changing climate which enables protection from the outdoor element and maintains optimal growing condition throughout the growing period of crops. Greenhouse technology allows farming in the controlled environment ensuring production of high value crops round the year in an efficient and eco-friendly way. In cold arid region like Ladakh, new innovative like the installation of Earth Tube Heat Exchanger and Sensors in greenhouses has proved to be an ideal method for maintaining the optimum temperature inside. In this paper, we present a state of the art review of the previously conducted research in this direction worldwide.*

***Keywords****: Climate, Weather, Greenhouse, Earth Tube Heat Exchanger, Sensors, IoT, Smart Agriculture*

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Date of Submission: 02-06-2022 Date of Acceptance: 15-06-2022

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## I. Introduction

Protective structures especially greenhouse has brought a big revolution in the agriculture production technology that integrates market driven quality attributes with production system profits. Several researches have reported very high yield of vegetables under greenhouse compared to open fields (Bisht *et al.* 2011 [1], Parvej *et al.* 2010 [2]. High summer temperature and low winter temperatures are major hindrances to successful production of crop in greenhouses throughout the year. Temperature and humidity adversely affect the crop production in tropical regions during summer months. Hence, it is important to lower the temperature inside green house during summer months to lower the temperature inside greenhouses during summer months to ensure optimum production of crop. During the winter months, an appropriate heating system is also necessary to ensure good early growth of plants.

As there is a significant variation in day and night temperature both during the summer and winter months also have a negative impact in terms of quality and quantity in the production of crop in greenhouse. To address this issue, it is necessary to use the nearly constant and stored thermal energy of the earth through an appropriate system that can provide a low-cost and alternative source of energy for heating and cooling greenhouses and buildings. As a result, connecting a building or greenhouse to the earth via buried pipes is the best approach for thermal heating and cooling because it is not affected by short-term climatic factors. A lot of energy is consumed during the heating and cooling of agricultural greenhouses. The energy requirements for greenhouse heating ranges from 7-8 litres of fuel per square metre in the south to 80 litres per square metre in the north of Europe.

According to studies on greenhouse heating strategies, even in the south, heating costs exceed 30% of the total operational cost of the greenhouse (Santamouris *et al* 1994) [3]. Since the cost of energy is high, only a small portion of greenhouse stakeholder can afford to use alternate heating systems. The absence of heating and cooling of a greenhouse significantly affects the yield, as well as cultivation time and product quality. As a result, an alternate heating/cooling system for greenhouse is of immense important. Earth Tube Heat Exchanger (ETHE) is one such system that makes use of the geothermal energy of the ground. Earth tube heat exchangers are known by the name earth - air heat exchangers (Scott et al 1965) [4], earth air pipe systems (Thanu et al 2001) [5], soil heat storage systems (Boulard and Baille 1986 [6] and underground heat exchangers (Diener et al 1990) [7], soil heat exchanger-storage system (Bernier et al. 1991) [8] However, the most appropriate and widely used term is Earth Tube Heat Exchanger (ETHE).

## II. Background of Controlled Environmental Agriculture

The Arab and Persian cultures have long used the earth as a source and sink of heat, which can be used in combination with buried pipes or tunnels to serve as a direct heat exchanger (Hourmanesh *et al* 1979, [9]. Based on this concept, systems for natural air conditioning and maintaining a comfortable interior environment has been widely used in architectural design. As a result of this design concept, many architectural projects have used systems for natural air conditioning and maintaining a comfortable interior environment. A modified version of the earth air tunnel was built later. Instead of constructing an underground tunnel, pipes made of materials such as plastic, concrete, clay, and corrugated metal were laid down instead. Square or circular pipes were used for the purpose. The relevant review of literature concerned with soil temperature and earth tube heat exchanger are as follows.

### 2.1 Deep Soil Temperature Regime Study

Penrod and Stewart (1967) [10] Kentucky, USA, investigated the soil temperature up to 3m. The calculated mean air temperature was $13^0$C and the average soil temperature was $14.09^0$C at 3m. At 21.3 m depth, the highest, mean and lowest soil temperatures were 14.1, 14.09 and $14.08^o$C.

Experiments on the earth's surface and subsurface were conducted in various countries by Givoni and Katz (1985) [11] till 1985. Researchers in Washington conducted a study at a maximum depth of 9 meters with a depth range of 2.2 metres and surface area range of 9 metres.

Mihalakakou et al. (1995a) [12] created a numerical model for calculating temperature of ground at different depths beneath the foundation of a building. The model was extremely complex because numerical analysis and superposition techniques were used to solve a complex three-dimensional ground thermal process. The entire programme was created within the Transient System Simulation Tool - a programme for simulating transient systems. Experimental data gathered at a depth of 0.3 m below the earth's surface and beneath the building foundation of the University of Ioannina Philosophical Faculty in Greece was used to validate the model.

Popiel *et al* (2001) [13] studied the distribution of temperature in two different ground-covered sites (lawns and car parks) in Poznand city of Poland. The short-period temperature variations reached a depth of approximately 1 m. The study revealed that during summer, the temperature of the ground beneath the base surface (car park) below 1 m was approximately $4^o$C higher than the temperature of the ground covered with short grass (lawn). However, during winter, the temperature distributions were nearly identical. Three distinct areas of the subsurface were identified: the surface, shallow zone, and deep zone. The surface zone was extended up to a depth of about 1 m, and the temperature of the ground was extremely susceptible to short-term variation in weather conditions. Shallow zone ranging from 1-8m (for dry light soils) to 20m (for moist heavy sandy soils) where the underground temperature remained nearly constant and near to the annual optimum air temperature. The deep zone, located below 20 metres, has a nearly constant ground temperature that slowly rises with depth in accordance with the geothermal gradient.

At the campus of the Indian Institute of Management in Ahmadabad, India, Sharan and Jadhav (2002) [14] observed the soil temperature regime. Temperature fluctuations at a depth of 1m, 2m, and 3m were studied diurnally and seasonally. At 1 m depth, the diurnal variations were almost ceased. The temperature of the soil at 1 m depth ranged from $21^0$C in January to $30^0$C in June. The difference is reduced to $6.4^0$C at 2 m depth and little less than $6^0$C at 3 m depth.

To study the soil temperature variation up to 1 m depth, Ogunlela (2003) [15] adopted the transient heat flow equation 2.2. The analysis assumed that the flow of heat was one-dimensional, that the soil was homogeneous, and constant thermal diffusivity. The lowest mean absolute error of $1.23^o$C between observed and anticipated values was achieved for the annual cycle at soil surface temperature and the maximum mean error of $3.52^o$C was recorded at 10cm soil depth. The lowest average error of $1.07^o$C at 9 a.m. and the largest of $3.67^o$C at 3 p.m. were recorded throughout the diurnal cycle.

Florides et al. (2011) [16] studied ground temperatures at eight different sites in Cyprus and analysed the performance of ground coupled heat pumps in respect to depth, time of year, geology, and altitude. The temperature of the ground was measured for one year i.e from October 2009 to October 2010. The surface zone is found to reach a depth of 0.5 metres at several locations in Cyprus. The shallow zone reached a depth of 7-8 m, followed by the deep zone, where the temperature remained same throughout the year, ranging between 18 and $23^o$C.

Pouloupatis et al (2011) [17] studied the distribution of ground temperature in the Athalassa region of Nicosia, Cyprus, between May 2006 and May 2007. The shallow zone in the area reaches a depth of 7 m, while the surface zone reaches a depth of 0.5 m. The temperature remains nearly constant below 7 m, at 22.6oC, which is close to the average annual ambient air temperature of 19.5oC. The minimum temperatures at 1m and 3m depths were measured with time lapse of roughly 15 days and 2.5 months, respectively, from the minimum ambient air temperature. The minimum mean ground temperature occurred at a depth of 5 metres with a 3.5-

month lag from the minimum ambient temperature. The time lag rises with depth, while the temperature of ground remains unaffected by the ambient temperature in the deep regions.

Salam (2011) [18] investigated the ground temperature trend in Baghdad's Alsadr and Alkry cities to see whether ground heat exchange cooling/heating systems may be adopted. For the months of January, April, July, and October 2010, daily thermocouple temperature records were installed on the ground level, as well as nine at locations of 0.5 m stairs down to 4.5 m underground. The subsurface temperature was subtracted from the ground level temperature records, and the results were evaluated. Summer horizontal cooling systems at 3 m depth or more were recorded at both sites, with difference in temperature of more than 20 degrees Celsius negative when compared to ground surface temperatures. During the winter months, positive differences were found to be around 7 and 10$^{o}$C at 4 m for Alkry and Alsadr, respectively, suggesting that it might be used as preheating systems.

Vaz et al. (2011) [19] conducted a numerical and experimental study on the use of Earth Tube Heat Exchangers (ETHE) to improve the thermal comfort and reduce energy consumption in buildings. The research was carried out in the Brazilian city of Viamao. The temperature of the ground and ETHE were simulated using the FLUENT model. Difference in soil temperatures were evaluated at depths of 0.05 m, 0.3 m, 0.5 m, 1.0 m, 2.0 m, and 3.0 m. The temperature profiles observed in the soil are consistent to a warm summer and a frigid winter. The temperature on the surface of the soil reached to around 298.0 K, confirming the boundary condition. The temperature of soil dropped in the lower levels, approaching to the mean value of the distribution, which was around 292.0 K.

The numerical technique to determine the ground thermal potential was reviewed by Brum et al (2012) [20], allowing it to be used in future ETHE thermal design. The soil domain was assumed to be two-dimensional, and a transient solution for the soil's thermal behaviour was found. The simulations were carried out using a numerical method based on the finite volume method, specifically FLUENT. The results showed excellent agreement with analytical solutions, demonstrating the computational model's validity and usefulness in predicting soil behaviour. When the numerical and experimental data were compared, there was a qualitative agreement with a difference of less than 14%. Up to a depth of 3 m, the behaviour of these solutions were identical to the experimental data.

At the Ataoja School of Science in Osogbo, Osun State, Nigeria, Oyewole.et.al (2018) [21] evaluated the change of soil temperature with depth using mathematical models. The annual soil temperature cycles were fairly well modelled. At annual depths of 0cm (top soil), 10cm, 30cm, and 50cm, differences in measured and expected soil temperatures were determined. The absolute errors for the annual cycle ranged from 0.5$^{o}$ C to 7.8$^{o}$ C, with an average of 2.7$^{o}$ C at the soil surface (0cm). The inaccuracies ranged from 0.1$^{o}$C to 4.5$^{o}$C at a depth of 10cm, with an average of 2.0$^{o}$ C. The absolute errors at 30cm deep ranged from 0.05$^{o}$ C to 2.9$^{o}$ C, with an average of 1.7$^{o}$C. The largest average absolute error was 2.7$^{o}$C, while the lowest was 1.7$^{o}$C.

### 2.2 Field Study on Earth Tube Heat Exchanger

A preliminary study was conducted in the United States to evaluate the performance and feasibility of an earth tube heat exchanger system in commercial livestock (Scott et al 1965) [22]. In Greece, significant research on earth tube heat exchangers was done in the late 1980s. In a greenhouse with a floor area of 150 m2, an earth tube heat exchanger of 20 aluminium pipes of 15m length, 0.2m diameter, and 0.2mm thickness were installed at a depth of 2m. Mavroyanopoulos and Kyritsis 1986 [23]. From November to May, the earth tube heat exchanger was able to keep an absolute minimum air temperature of 7$^{o}$C inside the greenhouse, while the outside absolute minimum air temperature was -3$^{o}$C. Only 20% of the energy input to the greenhouse was consumed by the fan of the earth air heat exchanger.

During the winter, Kozai (1989) [24] evaluated the heat balance and studied the thermal performance of a commercial solar greenhouse. For heat exchange between the indoor air and the soil, eight electric fans were installed with solid PVC pipes of 100 mm diameter installed at depths of 0.5 and 0.9 metres respectively. The pipes were separated by 0.5 m. The circulated air in the pipe had an average speed of 4.7 ms-1. When the mature crop was present, the air within the greenhouse had a higher dew point temperature than the surface temperature of the heat exchange pipe buried in the soil. As a result, a substantial portion of latent heat was transferred to soil at this time.

Diener et al (1990) [7] installed an earth tube heat exchanger (ETHE) in a commercial poultry house at West Virginia University's poultry farm in Morgantown. The heat exchanger was approximately 33 metres in length which ended in a sump. The incoming air was drawn in through the annulus of a 457-mm metal culvert pipe. A stand pipe situated above the sump allowed air into the annulus. A 305-mm thin-walled inner pipe was used to expel air into the sump. Both pipes' diameters were chosen so that the areas of the intake and exhaust pipes were roughly equal. When the same volume of air is used in each pipe, the air velocity is the same. When compared to a control flock, the heat exchanger saved an average of 42 percent on energy. Intake air temperatures were reduced by as much as 16° C when employed in the cooling mode.

To reduce the consumption of heating energy, Bernier et al (1991) [25] constructed and assessed a soil heat exchanger storage system in a commercial type greenhouse. It was made up of 26 non-perforated, corrugated drainage pipes of 102 mm diameter which were installed in the ground. At 450 mm and 750 mm depths, two rows of 13 pipes, each of 12 m long, were placed. The pipes were 450 mm apart and were placed parallel to the greenhouse's longitudinal axis. At a flow rate of $0.91m^3s^{-1}$, a 0.75 KW blower disseminated the hot air collected in the greenhouse trough these pipes. The heat stored was recovered via convection at the soil surface as well as forced circulation through the exchanger pipe, with a minimum temperature difference of $2^oC$ between the air and the soil required for efficient functioning of the system. During the test period, a mean coefficient of performance (COP) of 4.6 was noted, according to the results.

Baxter (1992)[26] designed and operated a single-pass heat exchanger at the University of Tennessee in Knoxville, Tennessee, to study its potential as an alternate energy source. The system comprises of 64 m of 15-inch pipe made of metal were installed at 1.8 metres deep in red clay soil, with risers at the input and outflow, as well as at 15-meter intervals. In the system, a high-pressure, direct-drive industrial blower with radial blade wheels was fitted. A hot-wire anemometer was used to determine the airflow velocities through the pipe. At the riser tube's output, anemometer readings were recorded radially in a cross-sectional plane. The average volume of airflow was 0.213 m3s-1. For two winter seasons in a row, the system was run on a 24-hour daily schedule. Even when the ambient air temperature dropped below 0 °C several times during winter operation, the output air never dropped below 0 °C. During the winter of 1984-85, the lowest ambient temperature was -28.60 °C, with a contemporaneous outlet temperature of 1 °C. For many years, the performance of earth tube was satisfactory to exceptional. The coefficient of performance (COP) ranges from 1.6 to 4.2, indicating that the ETHE's energy exchange performances are mainly depends on weather. The efficiency of the tube ranged from 82.4% to 87.2%.

Baxter (1994) [27] tested the performance earth tube heat exchanger system in cooling mode. The basic soil temperature of the 1.8 m deep soil remained low enough for effective cooling mode performance during the summer months. However, this magnitude of basic 1.8m deep soil temperature gradually rises during the course of summer months. The temperature of soil increased from 15 degrees Celsius up to 20 degrees Celsius between $2^{nd}$ June and $31^{st}$ August. An average drop in temperature from 35°C to 23.6 °C of the airflow was recorded during the seven hottest days of July, a reduction of 11.4 °C in air temperature. In the cooling mode, the COP ranged from 1.4 to 2.69 for mean values of energy exchange. The cooling mode study was done in conjunction with a heating mode study (Baxter 1992), and both modes performed well.

Santamouris et al. (1994) [28] presented the design, construction and operation of a $1000m^2$ prototype passive solar agricultural greenhouse. The features of this greenhouse is that it has a large storage wall on the north side and a sequence of earth to air heat exchangers installed under the structure. The earth to air heat exchanger consists of 5 PVC pipes, each 30 metres and 22 centimetres in diameter, installed at a depth of 1.5m. Over the course of three years, monitoring of the greenhouse revealed that the passive systems provided energy equivalent to 35% of the heating requirements of an identical conventional greenhouse.

During the summer months in the Chicken farm of PAU, Ludhiana, India, Singh and Singh (1994) [29] performed research on cooling the poultry shed without using electric power but by using an earth pipe heat exchanger. The air for the shelter was supplied by sucking via an 18.5-meter-long, 20-centimeter-diameter PVC pipe installed in the ground at a depth of 1.7 metres. A vane type anemometer was used to measure air velocity at 0.5, 1.5, 4.5, and 10.5 ms-1. At 0.5 ms-1 air velocity, the temperature in the experimental shed was 6-8 °C lower than in the control shed. The temperature difference between the experimental and control sheds dropped as air velocities increased. As the air velocity in the pipe increased, the efficiency of cooling by earth pipe heat exchanger decreased.

Thanu et al (2001) [30] investigated the thermal performance of earth air pipe system constructed at Gulmohar farm home Gurgaon, India. It consist of two rectangular tubes of 60 cm X 80 cm with a length of 76.5 m, formed of bricks, plastered inside, capped with stone slabs of 2.3 cm thickness and installed at a depth of 4 m made up the earth air pipe system. It was designed for cooling three bedrooms, a drawing room, a dining room and a kitchen in a farmhouse. At the delivery duct, the average velocity of air flow was observed to be 6.7 ms-1. The air going through the ground air pipe system was cooled by 8.3 degrees Celsius throughout the summer. During the winter, this technology heated the air by an average of 4 degrees Celsius. In the months of May and June, the monthly average relative humidity of the conditioned chamber was determined to be 52.8 percent, compared to 40.2 percent at the system's suction point and 43.5 percent in the ambient. During the winter, the monthly average relative humidity of the air at the delivery point was reported 50.7 percent, while the suction air had a value of 55.8 percent. According to the results, the performance coefficients of the system during summer, monsoon, and winter were 7.9, 1.9, and 2.1. During the summer, the efficiency of such a method was verified.

Kabashnikov et al. (2002) [31] proposed a numerical model for determining the ground and air temperature in a ground heat exchanger for ventilation systems. The model was created using Fourier integral as a representation of temperature. From the standpoint of air-to-ground heat exchange, an analytical expression for the ideal tube length was found. The air flow rate, variation in length, diameter of tubes, depth of burial, and spacing between tubes were all taken into account in a parametric analysis to analyse the performance behaviour of the EAHE. The dependence of the heat power of the system on time during its operation exclusively during the winter months for ten years was estimated, as was the degree of loss in the heat exchanger's effectiveness on decreasing the spacing between the tubes. The calculated results matched the experimental data.

Pfafferott (2003) [32] investigated the performance of three Earth Air Heat Exchangers (EAHX) installed in DB Netz, Fraunhofer ISE, and Lamparter office buildings in Germany in order to characterise their proficiency. The EAHX at DB Netz AG reduced the exit air temperature near the without disturbing soil temperature. Based on total surface area, Fraunhofer ISE's EAHX provided the highest specific energy gain. The EAHX at Lamparter has the highest COP when considering decreased heat transfer. The temperature ratio RT, which specifies the temperature damping between the intake and output temperatures, is an important feature for passive cooling applications. The lower the RT, the more cooling energy is delivered to the structure. The EAHX at DB Netz AG had the smallest RT (high convective heat transfer between pipe and air) because of its high specific surface area (high conductive heat flow between soil and pipe) and the relatively small pipe diameter.

Sharan and Jadhav (2003) [33] investigated the working of a single pass Earth Tube Heat Exchanger (ETHE) in Thor, Ahmedabad, India. The ETHE system comprises of 50 metres of mild steel pipe with a nominal diameter of 10 cm and a thickness of 3 mm, buried at a depth of 2.85 metres. Fins made up of GI strip were spirally looped across the pipe's outer surface for the whole 50-meter length. A direct-drive industrial type 0.5 hp blower with radial blades was used to circulate the air. The air velocity was measured with a digital vane type thermal anemometer at 11 ms-1. In cooling mode, the ETHE cooled 5.6 $m^3min^{-1}$ of 40.6$^oC$ air to 26.6$^oC$, while in heating mode, it heated 8.3$^oC$ to 23.0$^oC$. In cooling mode, the average COP was 3.3, and in heating mode, it was 3.8.

To reduce greenhouse energy consumption, Wang and Liang (2006) [34] tested a subsurface heat storage system in a double-film-covered greenhouse and another greenhouse that does not have heat storage system using plant physiology. In the heat storage layer, heat-exchanging pipes were installed. They were 76 mm in diameter, 18 m in length, and 15 cm in diameter from the centre of the pipes to the floor surface. The 45 pipes were evenly spaced over the greenhouse's width, with a central distance of 133 mm. The results shows that the temperature in the double filmed covered greenhouses was 5.2 °C, 4.6 °C and 2.0 °C higher than the temperature of soil in the adjacent reference greenhouse during clear, cloudy and overcast sky in winter.

Sharan and Jethva (2008) [35] studied a single span saw tooth greenhouse with an earth tube heat exchanger in a closed loop. The research was carried out in the dry region of Kothara, Gujarat, India. ETHE was made up of eight mild steel pipes organised in two levels at 3 m and 2 m depth, with pipes measuring 23 m in length, 200 cm in diameter, and 1.5 m apart. Air was drawn from the greenhouse via a single duct, cycled through underground bundle pipes, and then returned to the greenhouse via a single duct. ETHE was able to heat the greenhouse within half an hour from 9$^oC$ to 22-23$^oC$ during a cold winter night. Natural ventilation and roof shading worked well during the day until February, keeping the temperature inside at around 34 degrees. During particularly hot days, fogging was also used along with ETHE. In this way, the temperature inside was prevented from rising above 36-37 degrees.

With a 47 m horizontal, 56 cm nominal diameter U-bend buried galvanised ground heat exchanger, Ozgener and Ozgener (2011) [36] evaluated the operating parameters of an underground air tunnel (Earth to Air Heat Exchanger) for heating a greenhouse. It was designed and installed at the Solar Energy Institute at the Ege University, Izmir, Turkey. On cold winter days, the underground air tunnel could supply 60.8 % of the design heating load. Despite the challenges of integrating geothermal energy with traditional space heating and cooling systems, underground air tunnels appear to be a promising alternative.

The ground temperature gradient and the efficacy of an Earth Air Heat Exchanger (EAHX) were investigated by Woodson et al. (2012) [37]. The EAHX was built in Ouagadougou, Burkina Faso, at the International Institute for Water and Environmental Engineering. This horizontal open-loop system was 25 meters long and 1.5 meters deep (Condensation was able to drain from the pipe through a hole at the bottom of the pipe due to it being slanted). The pipe was made of PVC pipe with a diameter of 125 mm. Air inlets for the EAHX are located 15 and 25 meters apart from the building's air output. By using two air inlets, two different pipe lengths can be tested. An EAHX with 25m of pipe was examined in this investigation. A 7.6 degree Celsius reduction in air temperature from the outside was achieved.

Rosa et al. (2020) [38] designed an open-loop earth-air heat exchanger (EAHE) that provides passive contribution to minimise building energy demand for heating and cooling by providing thermal pre-conditioning of the required ventilation air. The purpose of this research is to assess the effect of three variables on the thermal performance of a large EAHE system installed in a warm-summer Mediterranean climate: pipe spacing, pipe diameter, and airflow velocity. ANSYS-CFX® simulation was used to analyse the EAHE transient behaviour in heating and cooling operation modes and the influence of each parameter on the outlet air temperature and soil-air heat transfer rate was evaluated. Numerical results were compared to prior analytical results and validated against experimental data. The greater the air velocity, for a certain pipe diameter and distance between pipes, the lower the thermal performance, primarily for cooling. For a given air velocity and pipe diameter, the distance between pipes can be lowered from 1.0 m to 0.5 m without compromising EAHE performance, resulting in a 50 percent reduction in land area required for EAHE pipes.

Nassreddine et al. (2020) [39] tested the effectiveness of an earth-to-air heat exchanger without the need of additional equipment (fans, air blowers, etc.). In this study, the climatic conditions of the Bechar region in Algeria's southwest were taken into account. The EAHE was composed of a PVC pipe of length of 66 metres and diameter of 0.11 metres. The annual undisturbed subsoil temperature at 1.5 m depth was 28 °C. The humidification regime resulted in an increase of 19% of humidity (RH) for EAHE. The dehumidification regime has resulted in a reduction of RH by 27 percent. The daily operating regime for the hygrometric regime was 62.5 percent dehumidification (from 00 h to 09 h and from 18 h to 23 h) and 37.5 percent humidification (from 00 h to 09 h and from 18 h to 23 h) (from 10 h to 17 h). In arid regions, EAHE technology offers great potential for improving building hygrometry.

**2.3 Field studies on use of sensors.**

Ahonen et al. (2008) [40] designed a wireless sensor node for tracking the disturbances in greenhouse using sensor platform provided by Sensinode Ltd. It consists of three commercial sensors that can measure four different climate variables. A modest sensor network was installed at Martens Greenhouse Research Foundation's greenhouse in Niirpio, Western Finland, to test the feasibility of the developed node. An experiment of one day was conducted to evaluate the reliability of the network and its capability to detect microclimate layers, which often occur between lower and upper flora. The researchers were able to demonstrate that the network of sensors can also detect variation in greenhouse climate caused by local disturbances such as direct sunlight near the greenhouse walls.

The design and implementation of an agriculture Greenhouse Environment Monitoring System based on ZigBee technology is presented by Liu Dan et al. (2015)[41], which uses the CC2530 chip as the core. In order to control the environment data, wireless sensors and control nodes use the CC2530F256 chip as the core. Data capture, data processing, data transmission, and data reception are all part of this system. A temperature sensor on the data terminal node measures ambient temperature in real-time. Processed data is sent to the intermediate node via a wireless network. The intermediate node collects all data and delivers it to a PC through a serial connection, where it may be seen, analysed, and stored while providing real-time data for agricultural greenhouses, fans, and other temperature control equipment, allowing for automatic temperature control.

Ravi et al. (2016) [42] developed a smart greenhouse model that enables farmers to perform field work automatically without the need for extensive manual inspection. After monitoring the present water level with an ultrasonic sensor, proper water management tanks are constructed and filled with water. Using growth lights, plants are also supplied with the required wavelength light at night. Sensors that measures humidity and temperature as well as a fogger, are used to adjust temperature and air humidity. The GSM module is used to manage a tube well (a phone call or text messages). Pollination is accomplished through the use of bee-hive boxes, and ultrasonic sensors are used to measure honey and send an email to buyers once the boxes are full. Furthermore, data from storage containers is uploaded to a cloud service (Google Drive) and delivered to an e-commerce company.

Zhaochan Li et al. (2017) [43] presented a smart greenhouse management system based on the Internet of Things and web-based technologies using sensor networks. The system is comprised of sensor networks and a software control system. The master control centre and different sensors that use Zigbee protocols make up the sensor network. Serial network interface converters connect the hardware control centre to the middleware system. The middleware uses an underlying interface to communicate with a hardware network and an upper interface to communicate with a web system. The best web system offers users with an interface for view and managing hardware facilities; administrators can use this system to remotely manage the temperature, humidity and irrigation in agricultural greenhouses by viewing the status of the greenhouses and issuing orders to the sensors.

Liu Dan et al. (2017) [44] introduced an intelligent Monitoring System based on the Android platform, which allows users to rapidly access monitored metrics on mobile devices from anywhere in the globe, as well as real-time video monitoring, maintenance, and management. The test and application demonstrate that it is a strong practicality and application prospect since it is stable, affordable, has good mobility, and is simple to run.

Unsal et al. (2018) [45] designed a low-cost, high-efficiency IoT monitoring system for agricultural applications. Using Arduino compatible NodeMCU and Wemos WiFi modules, a wireless greenhouse monitoring system based on IoT technology was explained in detailed. The system collects data of the light, temperature, humidity, carbon dioxide ($CO_2$), and soil moisture through sensors and sends it to a remote server via internet. A web service accepts data from the greenhouse system and stores it in a database. As a result, the data collected by the greenhouse system can be viewed on a web server.

D. Shende et al. (2018) [46] created a Raspberry Pi 3 circuit to continually monitor and measure the conditions of soil moisture, humidity, temperature, and lighting in the growing environment, so that adjustments are made accordingly to maximize plant growth. In the paper, a system based on wireless sensor nodes is described for monitoring soil quality. Using this system, each sensor collects data. In this application, they use three sensors: a temperature sensor, a humidity sensor, and a soil moisture sensor which determine whether the field is dry or wet, and a light detection and response (LDR) sensor which determine whether the field is properly lit. By using this system, soil quality is maintained, which is necessary for the successful growth of the crop. The farmer can predict and analyze greenhouse parameters using this project. Thus the farmer can predict & analyze the greenhouse parameters using this project. Crops selected for prediction & analysis are tomatoes & brinjal. In a greenhouse environment, two samples of crops are taken and the system is validated for these crops. The total power used by devices and the total expenditures are assessed for controlling devices. Thus, the farmers will be able to forecast the total amount of control for next year's crops. In this system, with controlling action, the product quality & quantity is increased compared to crops that grow without controlling action.

Using IoT technology, Cia et al. (2019) [47] built an intelligent greenhouse control system. IoT technology and fuzzy adaptive PID control algorithms were used to study greenhouse control strategies. Simulations were carried out using MATLAB software. Based on the simulation results, the greenhouse temperature was optimally controlled. A constant temperature of 16.5 °C was maintained in the greenhouse, and an average humidity value of 68.2% RH-89.3% RH was maintained.

In the paper Aleem Ali et.al. (2020) [48] discussed the smart technologies are not only confined to the agriculture sector but these find a wide application in other sectors too. These technologies are used to locate the location of the accident and the information of the location can be sent through the GPS to the emergency offerings for assistance. Ali Aleem (2021) [49] Proposed the Internet security architecture is another field where the use of IoT is on the rise. For IoT-based data communication, a secure system based on blockchain is proposed. In terms of processing time and writing time, a comparison was made between the proposed system and the existing IoT-based system.

## III. Research Gap

| Research Paper | Authors | Summary | Research Gap |
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| IoT based Smart Greenhouse (2016) | R.. Kodali, V. Jain and S. Karagwal | - Ultrasonic Sensors are used to check water level in a tank.<br>- Humidity and temperature sensors control how much humidity is present in the air, and a fogger is used to control these elements. | - The automatic greenhouse equipment can be powered by non-conventional energy sources such as solar panels and wind turbines.<br>- Cooling in the greenhouse can be accomplished using the Peltier effect. |
| A New Greenhouse Monitoring System Based on Internet of Things Technology (2018) | E. Unsal, A. F. Yelkuvan1, M. Taşbaşı, Ö. Sönmez | - An IoT-based wireless greenhouse monitoring device was developed using Arduino compatible NodeMCUs and Wemos Wi-Fi modules.<br>- Light, temperature, humidity, carbon dioxide ($CO_2$) and soil moisture values are collected by the sensors and transmitted to a remote server via the internet. | - Renewable Solar energy can be used to supply powers to the sensors.<br>- Data logger can be used to record the temperature and humidity in the greenhouse. |
| The future of farming through the IoT perspective (2020) | Chetan N Kulkarni, Ajay U Surwade | - Due to the use of Internet of Things (IoT) and sensors, agriculture and environmental monitoring have become easier in the present era.<br>- Sensors such as humidity, air temperature, irrigation, soil composition, soil moisture, and soil moisture sensors can be connected to provide environmental information in an unstructured way. | - Accurate forecasting of weather conditions and information about favourable conditions for agriculture will assist farmers.<br>- Data mining technique can be applied on the data structure which would be helpful to the farmers in predicting suitable conditions for farming. |
| Applications of IoT for achieving sustainability in agricultural sector: A comprehensive review (2021) | A. Maroli , V. S. Narwane, B. B. Gardas | - IoT applications in the agri-food supply chain can reduce food waste and water waste, improve soil management, reduce carbon emissions, reduce pesticide usage, and increase revenue.<br>- Technical issues received more attention than social or economic concerns as a result of the adoption of new technologies. | - Despite the fact that the study was based on a systematic review approach, a bibliometric evaluation may provide better insights that could be explored in future studies.<br>- The domains of IoT and food safety may be investigated in tandem. |
| Recent advancements and | Bal Bahadur Sinha, R. | - This paper provides a thorough discussion of the major components, new | - More research, inventions, and initiatives, primarily in the field of |

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| challenges of Internet of Things in smart agriculture: A survey (2022) | Dhanalakshmi | technologies, security issues, challenges and future trends involved in the agriculture domain.<br>- It contains an in-depth report on recent advancements in agriculture. | IoT-based smart agriculture, would improve farmers' quality of life and result in significant improvements in the agricultural sector. |

## IV. Conclusion

It has been noted that the usage of ETHE in conjunction with sensors has resulted in the optimal temperature being maintained inside greenhouses. Various studies and state of art have proved that ETHE has been able to increase the temperature inside a greenhouse from $9^0$C to 22-$23^0$C in just half an hour during cold winter night.

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